Early cognitive abilities as predictors of later skills and competencies in the context of children's socioeconomic background

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Maximilian Seitz

of Ellwangen/Jagst

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University Professor Dr. Claus-Christian Carbon (chair)

University Professor Dr. Sabine Weinert (first reviewer)

University Professor Dr. Ilka Wolter (second reviewer)

University Professor Dr. Hans-Günther Roßbach (associate member)

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Summary

When investigating the cognitive abilities of young children in the first two years of life, habituation-dishabituation tasks are a standard method. Such tasks draw on the phenomena of habituation and dishabituation that are typical orientating responses toward environmental stimuli. Habituation refers to a decreasing orienting response toward sequentially presented stimuli (attention decrement), whereas dishabituation refers to a renewed increasing orienting response toward subsequent novel stimuli (attention recovery). Decades-long research on these response phenomena in both animals and humans has solidified the notion that they are forms of non-associative learning.

Thus, measures drawn from such tasks in infancy are typically interpreted as indicators of early cognitive functioning. It is argued that infants' behavioral response – for example, their looking toward visual stimuli – is a function of the match between the external stimulus and the children's internal mental representation of that stimulus. It is assumed that latent processes of visual attention as well as stimulus processing, storing, and encoding contribute to infants' behavioral responses. Therefore, their observed behavior indicates early cognitive abilities that draw on underlying cognitive mechanisms and influence situational performance in different areas of cognition. Because habituation-dishabituation tasks are adaptive in the sense that the stimulus material can be manipulated, the tasks tap into a broad range of early cognitive abilities that can be considered domain-general or domain-specific precursors of later skills and competencies, for example in language and mathematics. Although measures drawn from habituation-dishabituation tasks do not meet the psychometric requirements for individual diagnostics, interindividual differences in habituation (e.g., total fixation time) and dishabituation (e.g., attention recovery) were empirically shown to be stable and predictive of later cognitive skills and competencies.

However, previous research has several shortcomings, which is why the present empirical studies highlight two selected research gaps. First, theoretical models and empirical findings point to a considerable impact of structural components of children's socioeconomic background on their development. Consequently, research found evidence for the effects of social disparity on children's cognitive development, namely structural inequality that influences interindividual skills and competencies early on. However, while numerous studies report such effects of social disparity when assessing early cognitive abilities with standardized developmental tests, this issue is seldom addressed with habituation-dishabituation tasks because such research is typically conducted in small and homogeneous samples. Thus, the present empirical studies aimed at answering two research questions: (I) Are there effects of social disparity in measures drawn from habituation-dishabituation tasks during the first two years of life and, if so, when do they emerge? (II) Are predictive effects of measures drawn from habituation-dishabituation tasks on later skills and competencies impeded by children's socioeconomic background?

Another research gap is the relation between domain-general and domain-specific precursor abilities in the domains of language and mathematics. While many researchers argue that knowledge acquisition and skill development in these two cognitive domains require both domain-general and domain-specific abilities, the relation between such precursors is seldom explored. More specifically, the present empirical analyses aimed at answering an additional research question: (III) What is the relation of predictive effects of domain-general and domain-specific precursor abilities on later skills and competencies in the domains of language and mathematics? In this context, domain-general precursor abilities were categorical information processing, whereas domain-specific precursor abilities were word learning and early numeracy, respectively.

Four empirical studies were conducted based on data from the Newborn Cohort of the German National Educational Panel Study (NEPS SC1). The large-scale panel study administered a range of domain-general and domain-specific visual habituation-dishabituation tasks with categorical stimulus material in the household when the children were on average 7 months old (survey wave 1) and 17 months old (survey wave 2). In addition to various information on children's socioeconomic background gathered in parental interviews or questionnaires (including productive vocabulary at 26 months; survey wave 3), several observational measures and competencies were assessed at later survey waves, among others, mathematical competence at 4 years (survey wave 5).

Study 1 focused on the first research question, namely whether effects of social disparity are found in measures drawn from habituation-dishabituation tasks. While no effects were found in 7-month-old infants, all components of children's socioeconomic background (i.e., parental occupation, parental education, and household income) were positively correlated with total fixation time during habituation but not with attention recovery during dishabituation. Overall, the results point toward the emergence of effects of social disparity in early cognitive abilities measured by habituation-dishabituation tasks in the second year of life, which is in line with previous findings from neuroscientific research and studies using other behavioral paradigms.

Study 2 focused on the third research question, namely the relation between domain-general and domain-specific precursor abilities of later language skills (i.e., productive vocabulary at 26 months). Total fixation time during habituation but not attention recovery during dishabituation had a positive effect on productive vocabulary. Although measures from both the domain-general and the domain-specific task showed similar correlations with productive vocabulary, the effect of the domain-specific task was higher than that of the domain-general task. In addition, regarding the second research question, Study 2 also reported certain positive correlations between total fixation time during habituation and children's socioeconomic background, although the predictive effect of total fixation time during habituation on productive vocabulary was not impeded.

Study 3 addressed the relation between domain-general and domain-specific skills as predictors of later competency in the domain of mathematics (third research question). Here, both total fixation time during habituation and attention recovery during dishabituation had a positive effect on later mathematical competence. However, only measures of the domain-specific task had a significant predictive effect on later mathematical competence. In contrast to the findings from Study 1 and Study 2, total fixation time during habituation (and attention recovery during dishabituation) were not significantly correlated with children's socioeconomic background, and consequently, the predictive effects of the measures did not change when the socioeconomic background was controlled for.

Finally, Study 4 provides a thorough methodological overview of the habituation-dishabituation tasks that were conducted in the context of NEPS SC1. The study reports detailed descriptions of the stimulus material and testing procedure, as well as approaches to interpreting the looking time data. Because the findings of Study 1, Study 2, and Study 3 were counterintuitive regarding the direction of the effect when compared to the previous research, Study 4 documents that prolonged looking at the target in the context of NEPS SC1 was the rule rather than the exception. The study makes a strong argument about total fixation time during habituation reflecting aspects of sustained attention and self-regulation skills, which is why the measure may be used to investigate interindividual differences in early cognitive abilities.

Overall, the empirical analyses suggest that (I) effects of social disparity in total fixation time during habituation emerge during the second year of life; (II) effects of social disparity do not impede the predictive effects of the precursor abilities; (III) domain-general and domain-specific precursor abilities are relevant for knowledge acquisition and skill development, at least in the domain of language. While the reported effects of social disparity highlight the practical implication that habituation-dishabituation tasks, as well as other fixation paradigms, might produce biased and non-generalizable findings in the second year of life, effects were small, which is probably why the predictive effects on later productive vocabulary and mathematical competence were not impeded. Still, regarding the relation between domain-general and domain-specific, the studies highlight a need for further research as several shortcomings of the empirical analyses are discussed (e.g., limited standardization due to the household setting and sequence effects of the task administration). A central strength of the studies is the large and heterogeneous data set that allowed for analyzing the influence of children's socioeconomic background. The consistent effects of total fixation time show that prolonged looking at the target in habituation-dishabituation tasks should be reconsidered, especially as many researchers claim that the underlying processes of habituation and dishabituation are conceptually not well understood and should be investigated further before exploiting the method to generate indicators of early cognitive functioning.

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1. Introduction

Historically, it can be reasoned that humankind has always been interested in how people think, how they perceive their environment, and how they learn new skills (D'Angour, 2013; Thomas, 2010). Processes that allow us to mentally represent environmental information and draw conclusions from what we perceive are typically referred to by the term cognition (Leahey, 2003). There is substantial evidence that cognitive growth in humans is extensive and varied during the life course, especially in young children (Johnson, 2020). However, it is mostly not evident how aspects of cognition develop and in what way early forms of cognition are relevant or necessary for later forms. Because cognition itself is abstract and unobservable, there are numerous theories and general frameworks that attempt at modeling cognitive development focusing on observable abilities and skills (for an overview in psychology, see Barrouillet, 2015). Thus, studying cognitive development typically necessitates addressing topics such as stability and continuity (Müller & Graves, 2017; Stein, 2020).

Cognition is considered a multidimensional construct, broadly referring to mental processes of all types, including encoding, manipulating, and storing information to acquire knowledge and develop skills (Kiely, 2014). These mental processes involve, among others, visual attention as a set of computations that comprise basic neural mechanisms (Oakes & Amso, 2018). Cognitive abilities and skills refer to components of cognitive functioning, typically involving means of applying various aspects of mental processes for learning and knowledge acquisition (VanLehn, 1996). In early childhood, the relation between earlier and later abilities and skills is critical because observable behaviors necessarily differ from those in later life, which is due to substantial maturational changes at neurological and functional levels in brain development (Stiles & Jernigan, 2010). In this context, stability refers to children's relative rank order in their performance on cognitive tasks over time when compared to others (Bjorklund & Causey, 2018). Continuity on the other hand refers to the shape of the developmental function and, more specifically, to whether individual sources of variation in early abilities and skills explain variation at later time points (Carey, 1995; for a discussion, see Courage & Howe, 2002). Although continuity and stability do not necessitate each other, there is a certain agreement in developmental psychology that cognitive development is both continuous and stable (Bornstein, 2020).

This notion is supported by neuroscientific research, highlighting that brain regions responsible for basic abilities in infants are also responsible for complex skill acquisition in adults (for a review, see Johnson, 2020). Thus, assuming continuity, complex forms of cognition should develop from basic cognitive processes. In this context, basic cognitive processes refer to information processing and memory that show a close relation to general intellectual functioning (Nettelbeck et al., 2020). Similarly, assuming stability, young children's interindividual differences in early cognitive abilities should also indicate differences in cognitive abilities and skills at later time points (Rose et al., 2012; Slater, 1995). It seems reasonable that although observable behaviors differ, they still conceptually draw on the same cognitive abilities and skills (i.e., learning, thinking, and reasoning) (Bornstein, 2020; Flavell, 1994). One example is children's looking behavior: Experimental research using fixation paradigms has shown that infants' looking behavior at a target can be interpreted analogously to that in adults, indicating preference, novelty, and expectations (Flavell, 1994).

Interestingly, many historical and philosophical accounts deal with the link between vision and cognition, at least since Plato's cave allegory (Squire, 2015). During the 1950-1960s, researchers began studying infants' observable behaviors, typically their looking behavior, as an indicator of otherwise unobservable mental processes. Children's reactions to different stimuli in experimental settings were seen as relevant for interpreting how they perceive and make sense of their environment. At this early phase, some but not all researchers already reasoned that these reactions reflect not only perceptual but also basic cognitive abilities (Bronshtein et al., 1958), namely early forms of learning (Clifton & Nelson, 1976). At the time, there was a historical shift in infant research, in which the infant was considered receptive, actively responsive, and cognitively competent (for an overview, see Haith & Campos, 1977).

It were Fantz' (1958; 1964) seminal experiments on preferential looking behavior in infants, in which he used a non-invasive method previously developed for studying cognition in chimpanzees, that proved to be highly influential (similarly Bartoshuk, 1962; Bridger, 1961). He referred to James' (1890) idea that infants perceive, organize, and represent the surrounding world through their senses, and demonstrated that looking patterns, as behavioral measures, are indicators of cognitive skills. The technique was useful, as it exploited infants' natural tendency to actively allocate attention to environmental stimuli to maximize learning (Poli et al., 2020; Richards, 2011). On a basic level, Fantz claimed that because infants show preferential looking patterns (i.e., "visual interest"), they have a rudimentary capacity to detect forms and differentiate between them (Banks & Ginsburg, 1985). In an early study on the origin of form perception (Fantz, 1961), he concluded that it is "reasonable to suppose that the early interest of infants in form and pattern […] plays an important role in the development of behavior by focusing attention on stimuli that will later have adaptive significance" (p. 72). In other words, infants selectively allocate visual attention to certain stimuli and compare novel stimuli with previous ones to adapt to their environment, which indicates a basic form of learning.

Since the 1960s, hundreds of studies have applied similar techniques to study how infants process environmental stimuli, how they mentally represent information, and how they use this information to acquire new skills (i.e., encoding, storing, and retrieving internal representations of environmental information). By investigating young children's looking behavior, much research has been devoted, among others, to how they process and learn language (Brody et al., 1984; Colombo et al., 2009; D'Souza et al., 2017; Rose et al., 2009; Tamis-LeMonda & Bornstein, 1989) and how they understand non-symbolic numerical magnitudes (Ceulemans et al., 2015; Cooper, 1984; McCrink & Wynn, 2007; Starr et al., 2013). While it can be reasoned that such cognitive abilities necessarily contribute to later knowledge acquisition and skill development, for example, regarding vocabulary development and mathematical competence, there is limited research comparing and contrasting such early precursor abilities. Overall, this line of research demonstrates that even at a young age, infants actively search for and encode information about their immediate environment, and remember these experiences, which means that habituation-dishabituation tasks may tap into precursor abilities of knowledge acquisition and skill development (Bornstein & Colombo, 2012).

However, even though an overwhelming number of researchers argue for stability and continuity in cognitive development (e.g., Bornstein, 2020; Colombo et al., 2004; McCall & Carriger, 1993; Sigman et al., 1997; Slater, 1995), namely that complex and specific cognitive skills develop from more basic and general abilities, existing studies have shortcomings. Some authors critically discuss that infant research typically focuses on small and selective samples with few attempts at replicating previous results (Cohen, 2009; Oakes, 2017). Thus, large-scale studies are rare because the identification, recruitment, and testing of infants are difficult and resourceful. Still, as the replication crisis in psychology forced many researchers to rethink conventional scientific practices (Open Science Collaboration, 2015), there is a recent interest in analyzing larger and more heterogeneous samples (Frank et al., 2017; Oakes, 2017). This interest is also fueled by findings on the effects of early social disparity, which highlight that even in the first two years of life, children's cognitive development is associated with their socioeconomic background (e.g., Farah et al., 2008). Potentially, such effects of social disparity in combination with small and selective samples could result in non-generalizable findings regarding, for example, the development of how young children learn language (Fernald et al., 2013) and how they understand non-symbolic numerical magnitudes (Fuhs & McNeil, 2013). This highlights the need for analyzing large-scale data to investigate young children's early cognitive abilities and skills as precursors for later competencies.

2. Theoretical background

Alongside a historic overview of how habituation and dishabituation have been studied, focusing on infant research, this section provides an introduction to the characteristics of habituation and dishabituation as basic reaction phenomena (**2.1 Habituation and dishabituation**). Although habituation and dishabituation are observable independent of the presentation mode, most studies discussed in the present context focus on infants' looking behavior to visually presented stimuli (i.e., "fixation paradigms"; Aslin, 2007). Next, important theoretical models are discussed that have been proposed in the last decades to relate observable characteristics to latent cognitive processes (**2.2 Theoretical models**). Although theoretical models are crucial for understanding how habituation and dishabituation reflect learning, many researchers hold that there is no conclusive framework (Colombo & Mitchell, 2009; Kucharský et al., 2022), which is why several approaches are presented. The following section touches on the discussion about in what way domain-general or domain-specific abilities and skills contribute to learning (**2.3 Domain-general and domain-specific skills**). While the debate over whether such basic cognitive mechanisms are innate is only briefly addressed, it is held that for skill acquisition in the domains of language and early numerical cognition, both domain-general and domain-specific abilities are typically needed. Thus, it is concluded that studying cognitive precursors of later skills and competencies requires exploring the relation between domain-general and domain-specific abilities and skills. Finally, it is discussed how structural aspects of children's socioeconomic background influence their cognitive development (**2.4 Influences of children's socioeconomic background on their cognitive development**). Arguing both from a psychological as well as from a sociological perspective, it is held that the socioeconomic background, which is associated with interindividual differences in family-related aspects (e.g., parent-child interactions), has a considerable impact on how infants develop cognitive abilities and skills in the first years of life, which is relevant for interpreting the findings from fixation paradigms.

2.1 Habituation and dishabituation

As infants have limited language and motor skills, assessing direct behavioral measures (e.g., looking behavior) at a very young age is taxing. However, even newborns frequently engage in visual exploration of their immediate environment, which is the basis for behavioral research, and their eye movements are one of the earliest behaviors to mature (Hunnius, 2007). This is why studying infants' looking behavior to environmental stimuli is the most prominent approach in infant research, although a range of behavioral responses such as auditory habituation, sucking behavior, or head orientation have also been used (Fennell, 2012). Fantz (1958; 1964) first observed that infants looked longer at complex surfaces compared to homogeneous surfaces (see also Bridger, 1961; Saayman et al., 1964). He used an adapted procedure originally developed for chimpanzees (Berkson & Fitz-Gerald, 1963) and the technique would later be known as the Preferential Looking Paradigm or Visual Preference Paradigm (Banks & Ginsburg, 1985; Spelke, 1985). In this context, preference refers to a perceptual bias, indicating that children's response to environmental stimuli is not random (Bjorklund & Causey, 2018). Thus, Fantz investigated children's basic ability to discriminate between different stimuli but the results also implied that infants extract information from their surroundings (Kagan et al., 1979).

In the following decades, many similar techniques have been developed to assess children's looking behavior that are typically summarized as "fixation paradigms" (Aslin, 2007). One major approach is the Habituation-Dishabituation Paradigm (Colombo et al., 2020). Habituation and dishabituation are general reaction phenomena that have been scientifically observed for a considerable time in a range of animals (Burrell & Sahley, 2001) and that are always observable when humans are exposed to environmental stimuli (Rankin et al., 2009). In principle, the reaction phenomena occur independently of the presentation mode, although infant research often concerns children's looking behavior toward visual stimulus material (Oakes, 2010). Essentially, habituation refers to a decreasing orienting response toward subsequently presented stimuli, whereas dishabituation refers to a renewed increasing orienting response toward novel stimuli. Both are forms of non-associative learning (Ioannou & Anastassiou-Hadjicharalambous, 2018; Tsang, 2012), as they are only impacted by aspects of the stimulation and not dependent on the context or modality (for a critical discussion, see Dissegna et al., 2021). Change in the organism (i.e., the behavioral response) occurs because of a prolonged stimulus presentation, which has a direct influence on the response due to its characteristics (e.g., frequency or intensity). From an evolutionary perspective, habituation is often understood as a form of adaptation ("behavioral plasticity"; Stanley, 1967). Unfamiliar and potentially dangerous stimuli elicit strong responses at first (i.e., initial defensive response), while familiar stimuli do not elicit comparable responses (for discussions, see McDiarmid et al., 2019; Ramaswami, 2014). Habituation supports appropriate responses to environmental stimuli and is thus related to exploratory (Light et al., 2011) and regulatory behavior (Bornstein & Suess, 2000).

Historically, habituation has been intensively studied in humans and animals since the beginning of the 20th century (Blumstein, 2016; Thompson, 2009) – although, in the beginning, several terms were used to refer to the same reaction phenomenon, namely "accommodation", "negative adaptation", or "fatigue" (Humphrey, 1933). By the early 20th century, researchers had generally agreed that habituation was a process of elementary learning (Christoffersen, 1997; Thompson, 2009). Thompson and Spencer (1966) listed an influential collection of habituation characteristics or parameters. Among others, they highlighted the decrease in response after repeated stimulus presentations, spontaneous recovery after withholding the stimulus, and the connection between stimulus criteria and speed of habituation. A more recent account of the characteristics of habituation reconfirmed this seminal list, with only slight updates or clarifications and one additional characteristic referring to the phenomenon of long-term habituation (Rankin et al., 2009).

Dishabituation (historically also "dehabituation"; Humphrey, 1933) is a reaction phenomenon strongly linked to habituation, which had also been researched since the early 20th century (e.g., Pavlov, 1927; „disinhibition“) and had been identified as a habituation characteristic (Thompson & Spencer, 1966). It refers to the response restoration after habituation, when novel extraneous stimulation occurs, namely, a post-deviant increase in response behavior (Steiner & Barry, 2014). Dishabituation is conceptually related to and requires the process of habituation; repeated presentation of novel stimuli after habituation again leads to habituation ("habituation of dishabituation" or "habituation reversibility"; Stanley, 1967; Thompson & Spencer, 1966). While habituation can technically be studied without a subsequent phase that presents deviant or novel stimuli (but see Sophian, 1980), dishabituation is always tied to a previous phase of habituation (Aslin, 2007). Because dishabituation can occur spontaneously, some researchers prefer using the term novelty effect for children’s reaction to novel stimulus material (Kucharský et al., 2022).

It is possible to observe young children’s responsiveness to familiar and novel stimuli because habituation and dishabituation to environmental stimuli were documented shortly after birth (e.g., looking behavior; Pascalis & de Schonen, 1994), while comparable physiological patterns were already reported pre-birth (e.g., fetal heart rate; Leader, 2016). This behavioral responsiveness concerns stimuli presented in several different ways (e.g., auditory, visual, or tactile). In addition, cross-cultural studies suggested that looking time patterns are similar in different regions of the world (Bornstein & Ludeman, 1989; Bornstein et al., 1988; Lloyd-Fox et al., 2019) and there is no conclusive evidence of gender differences (Creighton, 1984; Tighe & Powlison, 1978). Several studies have documented interindividual differences in habituation and dishabituation over time (Bornstein & Benasich, 1986; Colombo et al., 1987), indicating stability in these processes. Habituation-dishabituation tasks are versatile, flexible, non-invasive, and comparably easy to administer, as infants are usually attracted to meaningful stimuli in their immediate environment (Clohessy et al., 2001). Thus, they are frequently used to assess a broad range of abilities and skills in young children (Aslin, 2014) and have become a standard method in infant research (Colombo et al., 2020; Tsang, 2012).

From a theoretical standpoint, intellectual functioning draws on a variety of cognitive processes such as fluid reasoning, information storage and retrieval, visual processing, and processing speed (Carroll, 2003; Cattell, 1963; Horn, 1965). Many researchers argue that habituation and dishabituation reflect basic cognitive abilities in the sense of an adaptation to environmental stimuli (i.e., information processing, memory, and visual attention; Colombo, 2001). Information processing is regarded as the capacity and speed of identifying and discriminating different environmental stimuli, which is a global and mostly task-independent form of cognition (Fry & Hale, 2000). Memory refers to a neural capacity for encoding, consolidating, storing, and retrieving information (Cuevas & Davinson, 2022). Finally, visual attention is the ability to selectively initiate and maintain an orienting response to visually presented objects or events in the environment that serves to prioritize specific sources of external stimulation (Reynolds, 2015; Rueda & Conejero, 2020). Overall, these skills critically influence infants' responsiveness toward environmental stimuli and may be regarded as prerequisites of early learning. Likewise, Fagan (1984) holds that habituation and dishabituation are processes that guide early knowledge acquisition (also Berg & Sternberg, 1985; Gibson, 1988). Thus, when arguing for stability and continuity in cognitive development, the concepts of habituation and dishabituation are in concert with theoretical assumptions about general cognitive functioning (Bornstein et al., 2006; Slater, 1995).

2.2 Theoretical models

Historically, there have been numerous theoretical approaches, which embed habituation and dishabituation in broader explanatory frameworks (e.g., Thompson, 2009). Early examples are perceptual models that define habituation as a process of cellular (Dannemiller & Banks, 1982; but see Slater & Morison, 1985) or retinal (Bronson, 1974; but see Slater et al., 1984) adaption or fatigue. Similarly, synaptic theories propose a functional link between the motoneuron and the spinal cord that dampens the behavioral response upon repetition (Farel et al., 1973; Wickelgren, 1967). However, sensory or neural adaption would imply that fatigue effects indicate the organism's inability to efficiently encode any kind of environmental stimulus and most studies suggest a specific response to the original stimulus (see Rankin et al., 2009). While effects of local adaptation and state factors of the child do occur during habituation, attention recovery for novel stimuli during dishabituation cannot solely be explained by sensory adaptation (Mareschal et al., 2007). Thus, a consensus is that habituation and dishabituation are phenomena that reflect active or passive processes of stimulus encoding and the formation of mental representations (Bornstein & Sigman, 1986; Colombo & Mitchell, 2009; Kavšek, 2013). Consequently, several theoretical models highlight that habituation and dishabituation indicate basic cognitive abilities.

Groves and Thompson (1970), for example, proposed that both perceptual and cognitive processes contribute to the manifest behavior (i.e., the orientation response) in the habituation phase. Their Dual-Process Theory posits that the decrement in orientation response in the habituation phase is due to a combination of a specific decremental stimulus-reaction pathway (habituation) and a general incremental state of excitation (sensitization). Both processes have an independent effect, resulting in the typical looking time patterns in visual habituation-dishabituation tasks (e.g., Bashinski et al., 1985; Kaplan & Werner, 1986). Peterzell (1993), for example, reported that he found two factors in the children's looking patterns during a habituation task: One factor that increasingly inhibited looking times (i.e., habituation), while a second factor accounted for initial increments (i.e., sensitization). As the behavioral response depends on sensitization and habituation, this explains why different habituation measures do not always correlate (Mareschal et al., 2007). However, the study only found this incremental factor for complex patterns (i.e., fine-grained checkerboards), while it should generally relate to initial increases in attention or arousal. The model also stresses that dishabituation is a superimposed process, independent of previous habituation, relating to general sensitization (Groves & Thompson, 1970). However, the theory lacks a conceptual explanation of habituation to novel but weak stimuli as well as retention of habituation (Kahn-D'Angelo, 1987). In addition, dishabituation, which others hold as a central indicator of learning (Mather, 2013), is mainly explained as a sensory process of general excitation and the conditions of sensitization are not well understood (Peterzell, 1993), especially as empirical evidence could not find robust evidence for a sensitization mechanism in different infant groups (Bornstein & Benasich, 1986; Kaplan & Werner, 1986).

Another theoretical framework is the Wagner-Konorski Gnostic Unit Theory – a combination of two models (Konorski, 1967; Wagner, 1979). The basic form of the cognitive model states that through repeated exposure to the stimulus material an internal representation (i.e., a gnostic unit) is formed (Konorski, 1967). With the increased accuracy of the internal representation and the external stimulus, an inhibitory system is activated, effectively dampening the orientation response. In the updated version, Wagner (1979) added processes of circular memory feedback and highlighted the impact of characteristics of the associative network for memory formation. The model explains how stimuli are actively compared to previously formed memory traces and it incorporates context-specific long-term habituation (Thompson, 2009). Although habituation is generally regarded as a form of non-associative learning, there is evidence for context-specific habituation, especially in animal studies (Dissegna et al., 2021), which the theory may explain better than other models, as it implements associative elements in habituation and sensitization. Still, the model has seldom been applied in infant research, which means that there is a general lack of supporting data.

In his seminal research on neural processes and their relation to behavioral reactions, Sokolov (1963; 1975; 1990) described a probabilistic model that defines attentional distribution (Stimulus-Model Comparator Theory). The model was influenced by the discrepancy hypothesis that claimed that behavioral response is elicited by a comparison between external stimuli and internal hypotheses about the stimuli (Hebb, 1949) – a process that has been described as a basic form of neural learning (Brown & Milner, 2003). The system regulates attentional distribution in relation to the deviation of incoming information from previously generated expectations about the characteristics of future stimuli. For visual habituation tasks, this means that infants' looking time (behavioral output) is a function of the match between the stimulus and the children's internal mental representation of that stimulus ("memory engram"; Sokolov, 1977; Thompson, 1976). The model explains the decrease in looking times after prolonged stimulus exposure as a dampened orientation response mediated by the amplifying system. Repeated stimuli lead to an inhibition of the behavioral output and novel stimuli lead to a larger orientation response (for a discussion, see Dunham, 1990). The Wagner-Konorski Gnostic Unit Theory (Konorski, 1967; Wagner, 1979) or the Opponent-Process Theory (Solomon, 1980) also proposed comparable mechanisms of feedback inhibition. When a novel stimulus is presented in the dishabituation phase, children’s orientation response should be stronger because the internal representation does not match the unfamiliar stimulus. A relatively stronger orientation response also indicates that the infant discriminates between familiar and novel stimuli. In short, the model describes a general comparison of external information and internal representation ("comparator"), proposing that the orientation response is a function of attention and basic information processing (Colombo & Mitchell, 2009). The feedback loop also matches the central assumption of the Bayesian coding hypothesis (Gopnik & Tenenbaum, 2007), namely that the brain constantly makes predictions of incoming sensory input (i.e., predictive coding) by comparing it to previously stored information (Snyder & Keil, 2008). The model is often used as a theoretical framework in infant research (Kavšek, 2013), although certain phenomena cannot be explained by it (e.g., Malcuit & Pomerleau, 1994). It was shown, for example, that habituation may also occur without processes of the sensory cortex (e.g., regarding motor reflexes; Brackbill, 1971), which effectively criticizes a purely cognitive interpretation of the phenomenon. In addition, the model does not explain that infants – as opposed to adults – show habituation in sleep states (Kahn-D'Angelo, 1987), which is central to their learning (Tarullo et al., 2011). Finally, it was criticized that the model simply assumes an association between habituation and the efficiency of transmission between stimulus and response, for example when comparing global and local stimulus characteristics (Colombo et al., 1995), short-term with long-term habituation (Mackintosh, 1987), or stimulus generalization (Logan, 1988). Overall, the strong focus on the stimulus as unspecific and global information is criticized, while motivational factors such as the perceived importance or relevance of the stimulus are not considered (Velden, 1978). Still, in his general review, Kavšek (2013) summarizes that the model is supported by ample empirical evidence regarding interindividual differences in cognitive abilities (Kavšek & Bornstein, 2010).

The Stimulus-Model Comparator Theory was highly influential and many authors adopted the basic premise for understanding habituation as a process of comparison between an internal stimulus representation and externally presented stimuli. Sokolov (1966) revised and updated the basic model and brought the discrepancy between the anticipated and the presented stimulus to the forefront. Jeffrey (1976), for example, proposed that infants use distinct stimulus features to generate a mental model. When the mental model is sufficiently formed, the infant may expand the model to different features or form a new model. This idea of serial habituation was influenced by the Stimulus-Model Comparator Theory and is further supported by research in visual attention. Heart rate as an electrophysiological indicator of visual attention and information processing suggests persistent cognitive activity during habituation (Colombo et al., 2010). However, the propositions regarding serial habituation in infants have not been further investigated (Colombo & Mitchell, 2009). Neuroscientific research suggests that the Stimulus-Model Comparator Theory simplifies visual encoding in interpreting simple observable behavior directly as complex attentional processes (Colombo, 2002; Turk-Browne et al., 2008). How infants engage in attention to specific stimuli and disengage from others, how they shift attention, and how they perceive stimulus material quality is not accounted for in the original model (Sirois & Mareschal, 2004). The Simple HAB Model (Habituation, Autoassociation, and Brain) was influenced by this neuroscientific criticism and highlights both neural and behavioral markers to describe habituation and dishabituation (Sirois & Mareschal, 2004). Much like other summaries of habituation parameters (Groves & Thompson, 1970; Rankin et al., 2009; Sirois & Mareschal, 2002), the behavioral markers comprise general habituation characteristics (e.g., response decrement over time) as well as dishabituation characteristics (e.g., shift from familiarity preference to novelty preference). In addition, the authors incorporate specific neuroscientific findings, such as hippocampal processes of selective inhibition and the formation of memory traces (Sirois & Mareschal, 2004). This is in line with evidence from studies on the neural basis of recognition memory (e.g., De Haan, 2007; Snyder, 2010). The Simple HAB model describes these behavioral and neural markers. It formulates a processing loop between cortical areas and the hippocampus that reciprocally compares incoming input with previously formed memory traces and both modulate the response systems. Thus, the model explains behavioral profiles of habituation and dishabituation as modulations of the response systems via a cortical feedback loop. Concerning the feedback loop, the model is largely similar to the Stimulus-Model Comparator Theory.

Another theoretical framework of habituation and dishabituation adopts principles of Dynamic Field Theory (Lewin, 1963). One aspect of Dynamic Field Theory is embodied cognition, namely the conceptual link between neural processes and manifest behaviors. The theory holds that environmental stimuli result in continuous, rate-sensitive neural activation patterns that evolve over time (Multiple Time-Scales Theory; Staddon & Higa, 1996). Basic aspects of cognition such as stimulus detection, stimulus discrimination, and recognition memory result from the neural activation patterns that evolve dynamically (i.e., non-linearly) (Schöner & Schutte, 2015). The focus of Dynamic Field Theory lies on observable behavioral responses to repeated stimuli that are arranged in a space-time continuum. Formed memory traces, in the sense of mental representations of the stimuli, depend on the timescale of the presentation and generate neurophysiological activation patterns. On this level, activation patterns may be interpreted as a basic form of learning, as they facilitate later responses to the same stimuli (Schöner & Schutte, 2015). Applied to habituation-dishabituation tasks, the theory suggests that the mental representation is automatically formed given any kind of input, which generates a matching activation pattern. However, the memory trace of the sequentially presented stimuli decays over time. As the memory trace of earlier stimuli is still decaying and partially active when a subsequent stimulus is shown, this leads to competing locations in time. Given the repeated presentation of stimuli, memory traces converge, resulting in strengthened activation patterns, namely shorter response times to the stimulus material. Thus, Dynamic Field Theory can help explain habituation as a decrease in orientation response toward a series of identical or similar stimuli and dishabituation as the increase in orientation response toward subsequently shown novel stimuli (Staddon, 2001). Methodologically, the framework may explain how different aspects of the stimulus material (e.g., motion, visual patterns, intertrial intervals, colors) compete for children's attention (Schöner & Thelen, 2006; Staddon & Higa, 1999). However, there have been few attempts at integrating actual experimental data of infant habituation (Goldberg, 2009; Schöner & Thelen, 2006). In addition, because the theoretical framework assumes a priori differences in activation to result in differences in habituation patterns, interindividual differences in cognitive abilities cannot be explained well.

Overall, several theoretical frameworks aim at explaining habituation and dishabituation and most argue from a predominantly cognitive standpoint. While a selection of models has been presented, there are also other conceptualizations, such as Cohen's (1973) Two Process Model of Infant Visual Attention or Kavšek's (2000) Two+Three-Components Model, that have not seen large empirical coverage in infant research. Sokolov's Stimulus-Model Comparator Theory remains one of the most relevant theoretical frameworks to understand the global processes of habituation and dishabituation from the wealth of empirical data in infant research (Kavšek, 2013; Sicard-Cras et al., 2022), especially when focusing on how interindividual differences in early cognitive abilities are associated with conceptually related skills and competencies.

2.3 Domain-general and domain-specific skills

Cognitive abilities are a central factor driving child development and early learning as they are interrelated with different skills and contribute to how children acquire new content knowledge and develop competencies (National Research Council, 2015). This developmental learning process necessarily involves domain-general and domain-specific abilities (Bjorklund & Causey, 2018) that influence situational performance in different areas of cognition and draw on underlying cognitive mechanisms (Kail, 2004; Rakison & Yermolayeva, 2011). Two important domains in which both domain-general and domain-specific abilities are relevant for skill development are language acquisition (Gervain & Mehler, 2009; Kuhl, 2004; for a critical discussion, see Behme & Deacon, 2008) and numerical cognition (Baillargeon & Carey, 2012; Bynner & Parsons, 1997; Dehaene, 2009; Geary, 2000; for a critical discussion, see Núñez, 2017).

On a more abstract level, domain-general mechanisms refer to basic perceptual abilities that are not exclusive to any single domain and are important for decontextualizing and abstracting information in novel situations (Chiappe & MacDonald, 2005). Such processes are held to be universal and independent of any knowledge domain or modality and allow for information processing across different areas of knowledge (Rakison & Yermolayeva, 2011). Domain-specific mechanisms, on the other hand, reflect adaptive and efficient ways of processing in certain cognitive domains (Carey & Spelke, 1994). Typically, it is argued that domain-specific mechanisms enhance reproductive fitness or adaptedness from an evolutionary standpoint (Chiappe & MacDonald, 2005). There is an ongoing debate in what ways domain-general and domain-specific mechanisms are interrelated and contribute to skill development in certain domains (Jacobs & Gärdenfors, 2017; Karmiloff-Smith, 2015). The debate concerns the origins (i.e., innateness) and the emergence of the respective underlying cognitive mechanisms. On a more practical level, it is held that, although the transformation of cognitive abilities across development occurs, domain-general and domain-specific abilities exist and influence knowledge acquisition and skill development in certain domains to different extents (Bjorklund & Causey, 2018). Thus, many behavioral researchers are concerned with investigating the relation between these abilities across domains.

Depending on the stimulus material and task administration, habituation-dishabituation tasks tap into either domain-general or domain-specific skills. Habituation-dishabituation tasks have been an important method for studying aspects of emerging and maturing language skills in young children (Fennell, 2018; Johnson & Zamuner, 2010). Typically, children's processing and learning of single elements of speech are studied (e.g., the discrimination of vowels, syllables, or words) with concurrently presented visual and audio stimuli. One example is the switch task, a study design administered in the early second year of life (for an age-related discussion, see Taxitari et al., 2020) that features word-object pairings that are switched between the habituation and dishabituation phases (Stager & Werker, 1997). More specifically, the habituation phase features visual categorical stimulus material matched with pseudoword labels, whereas the dishabituation phase tests children's response to a novel, out-of-category stimulus in the dishabituation phase linked to the same word label (e.g., Werker et al., 1998). Thus, after repeated word-object presentation in the habituation phase, the dishabituation phase tests whether the matching was successfully learned (Rose et al., 2009; Thompson et al., 1991). This matching process is an abstract form of early word learning, which is the basis for vocabulary development (Samuelson, 2021). Although longitudinal research has been scarce, interindividual differences in early word learning were empirically shown to be predictive of later vocabulary (e.g., Kemp et al., 2017). Much like early numerical abilities, word learning is thought to draw on domain-general skills and domain-specific precursor abilities, although there is much debate over the relation between the underlying cognitive mechanisms (Gervain & Mehler, 2009; Samuelson & McMurray, 2017). However, considering early word learning is reciprocally tied to the processing and learning of categorical information (Ferguson & Waxman, 2017), it is surprising that few studies compared domain-general (e.g., categorical information processing) and domain-specific word-learning precursor abilities as predictors of vocabulary development using habituation-dishabituation tasks.

Tasks on numerical cognition on the other hand present children with non-symbolic magnitudes during the habituation phase and assess children's responses to changes in magnitude presentation in the dishabituation phase (i.e., the approximate representation of discrete quantities as continuous magnitudes; Cordes & Brannon, 2008; Xu et al., 2005). Typically, habituation-dishabituation tasks are used for studying number discrimination in infancy (e.g., varying ratios of discrete objects barring differences in shape, density, or contour length), although it should be noted that other fixation paradigms are also frequently used as many study designs do not require learning in the habituation phase (Cantrell & Smith, 2013). These designs usually involve a violation of children's expectations (Violation-of-Expectation Method), namely their prior knowledge, and thus error detection regarding numerosity as an indicator of early numeracy skills (Munakata, 2000; Stahl & Kibbe, 2022), although it should be noted that such designs probably cannot reliably disentangle prior knowledge and learning during the familiarization phase (Paulus, 2022; Rubio-Fernández, 2019).

Such early numeracy skills (i.e., the attention to and processing of magnitudes) are the basis for more complex magnitude representation (Libertus & Brannon, 2010; Siegler, 2016;

but see Núñez, 2017) and there are interindividual differences between children in these skills (Ceulemans et al., 2015; Chu et al., 2015). Thus, although the relation between intuitive numeracy for non-symbolic magnitudes and culturally learned arithmetic skills is not fully understood (De Cruz & De Smedt, 2010), such skills were empirically shown to be early predictors of later mathematical competence (Starr et al., 2013; Van Marle et al., 2014). For numerical cognition, it was shown that both domain-general (e.g., information processing or working memory) and domain-specific precursor abilities (e.g., non-symbolical magnitude comparison) influence early numerical cognition and, consequently, later mathematical competence (Hornung et al., 2014; Knops et al., 2017; Passolunghi et al., 2014). Still, studies comparing and contrasting domain-general skills with domain-specific skills in infancy and their association with later mathematical competence are rare (Starr et al., 2013).

2.4 Influences of children's socioeconomic background on their cognitive development

Given the first three years of life are considered crucial for functional brain development and generally a "sensitive period" for child development (Johnson, 2005; Skuse et al., 1994), it is reasonable that children's environments have a tremendous effect on their cognitive development. There are countless perspectives on how children's environments influence their cognitive development and many acknowledge that both family-related processes and societal influences are relevant and interdependent factors (for a psychological perspective, see Barrouillet, 2015). While theories in developmental psychology often stress family-related processes in the context of how children's socioeconomic background influences their cognitive development (Bradley & Corwyn, 2002), sociological perspectives typically focus on structural aspects of socialization and processes of intergenerational transmission (Mayer, 2009).

Modern theories in developmental psychology usually understand children as competent individuals who are actively engaged in reciprocal interactions with their environment, which facilitates their development. While psychological theories acknowledge structural aspects, their research focus is on family-related processes that are expected to mediate the effects of socialization on child development. Generally, it is held that variations in the behavior of children’s interaction partners (e.g., their parents) are systematically associated with aspects of their socioeconomic background, influencing children’s cognitive abilities and skills at later points in time (Conger & Donnellan, 2007). Thus, interaction partners shape the children’s immediate environment and, in turn, their learning opportunities. In addition, they are typically more experienced and engage the children in complex forms of collaboration, promoting internalized problem-solving behaviors and strategies, which consequently facilitates learning and skill development (Rogoff, 1990; Vygotsky, 1978). Thus, psychological theories highlight the functional relation between children’s immediate social environment and their cognitive development (Tudge & Winterhoff, 1993).

Sociological perspectives highlight broader environmental contexts, focusing on how the structural distribution of resources affects child development (Mortimer & Duke, 2017; Woodhead & Faulkner, 2008). In this context, parental socioeconomic status is a central societal factor for child development. This global construct is associated with access to wealth, social recognition, education, and other symbolic or materialistic privileges and refers to their position within a societal hierarchy (McLoyd, 1998). This position is associated with social capital (e.g., features of the social network that facilitate resource distribution) and child development is held to be mainly influenced by how parents pass such social capital assets on to their children (Leonard, 2005). Many authors argue that central components of parental SES (i.e., parental occupation, parental education, and household income; Duncan &

Magnuson, 2012) influence child development because they are associated with individual living conditions (Bornstein & Bradley, 2010). Furthermore, it is recognized that these structural components are interdependent and that their effect on child development is additive (Duncan & Magnuson, 2012).

Thus, perspectives from developmental psychology and life-course sociology both suggest that structural societal factors influence cognitive development in children and that family-related processes mediate this effect (e.g., parent-child interactions or transactions; Bornstein & Bradley, 2010). For one, parental occupational status indicates working conditions (e.g., simplistic or challenging work, fixed or flexible working hours) which influences parents' cognitive skills (Andel et al., 2011; Kohn & Schooler, 1982) and, in turn, the way they interact with their children in creating a stimulating home learning environment (Bornstein et al., 2010; Greenberger et al., 1994). Moreover, higher educated parents have a better knowledge about child development (September et al., 2016) and, consequently, enrich their children's environment more by supporting learning processes (Davis-Kean et al., 2021; Harding et al., 2015) and using language that is more complex and stimulating (Hoff, 2003). Finally, household income is primarily related to financial and material resources that enable parents to provide a healthy lifestyle (e.g., well-balanced nutrition or regular doctor's appointments) and a stimulating learning environment for their children (e.g., toys and activities) (Mayer, 2002; Votruba-Drzal, 2003; Yeung et al., 2002).

One theoretical framework that combines such structural aspects (i.e., distal) and family-related (i.e., proximal) processes is the Bioecological Model (e.g., Bronfenbrenner & Ceci, 1994; Bronfenbrenner & Morris, 2006). In the model, child environment is categorized into five concentrically nested systems that describe increasingly abstract levels of societal interaction. While the microsystem level is primarily shaped by proximal parenting behavior, the model acknowledges the relations with other microsystems (i.e., mesosystem) that are situated in complex societal structures (i.e., exosystem) and cultural contexts (i.e., macrosystem). Regarding child development, the model highlights that both children and parents shape and organize the immediate environment on a regular basis over an extended period of time (Bronfenbrenner & Morris, 1998), especially in the formative years.

Thus, the model highlights the role of early family-related processes in the context of the microsystem, such as parent-child interactions. There are two central dimensions to parent-child interactions when focusing on parents, namely emotional support and cognitive stimulation (Guralnick, 2006; see also Bradley, 1994). Emotional supportive parental behavior, also referred to as parental responsivity or sensitivity (for an overview, see Shin et al., 2008), is associated with warm and contingent behavior of parents when engaged in interactional settings with their children. This dimension originated from research on attachment theory (Bowlby, 1979), which holds that sensitive interaction behavior results in secure attachment relationships and, in turn, promotes child development (e.g., in cognition; Bornstein & Tamis-LeMonda, 1997). In general, emotional support is less parent-directed and highlights the active role of the children in parent-child play settings (Martin et al., 2007) and how parents respond to their children with affective cues (Shin et al., 2008). Theoretically, emotional support is also related to the concept of parental warmth as both highlight the central role of supportive, affectionate, empathic, and prompt responses to children's actions (Baumrind & Black, 1967).

On the other hand, stimulating parenting behavior is indicated by how parents actively shape an engaging and (cognitively) activating environment for their children in interactional settings (Hoff et al., 2002; Lugo-Gil & Tamis-LeMonda, 2008). It is expected that stimulating parent-child interactions promote child development by initiating or facilitating explorative behaviors and complex forms of communication (Bornstein & Bradley, 2010). Thus, this facet of parent-child interaction is marked by intentional teaching and is related to scaffolding (Mermelshtine, 2017). Such behaviors aim at providing appropriate information about specific cognitive tasks, supporting knowledge in specific domains, and explaining the use or relevance of certain tasks (i.e., cognitive assistance; Fagot & Gauvain, 1997). Thus, cognitive stimulation is thought to facilitate children's development in specific domains, such as dealing with magnitudes and numerosity, or language development by guiding children's understanding through a sufficiently large and complex input (Farah et al., 2008).

Observable behaviors associated with these two dimensions are expected to change during childhood as parents adapt their interaction behavior to the needs and developmental characteristics of their children, which drives the assumption of specificity in parenting behaviors (Bornstein & Tamis-LeMonda, 1997). Still, both emotional support and stimulation are rather stable dimensions of parenting behavior (Guralnick, 2006). Empirically, both dimensions are positively associated with each other (Martin et al., 2007) and have distinct positive predictive effects on children's cognitive development (Farah et al., 2008; Zeytinoglu et al., 2019). Moreover, parent-child interactions were shown to have an effect on later cognitive skills independent from basic cognitive abilities measured by habituation-dishabituation tasks (Tamis-LeMonda & Bornstein, 1989). In addition, emotional support and cognitive stimulation were shown to mediate cognitive development in young children (for a review, see Hackman et al., 2010). Overall, this line of research highlights the important role of such family-related processes.

Overall, these theoretical models and empirical findings point to a considerable impact of structural components of children's socioeconomic background on their development that are mediated by family-related processes (at least partly). Consequently, research found evidence for the effects of social disparity (or inequality) on children's cognitive development. Typically, such studies assess children's performance in standardized developmental tests or parental reports on children's cognitive abilities (e.g., Cohen & Parmelee, 1983; Fernald et al., 2013; Golden & Birns, 1983; Halle et al., 2009; Raizada & Kishiyama, 2010; Rubin & Balow, 1979). A consensus is that children from disadvantaged families often develop cognitive abilities slower, resulting in socioeconomically related achievement gaps (Bornstein & Bradley, 2010).

Finally, it should be noted that the effect of SES on the development of cognitive abilities is complex and there are competing hypotheses regarding this influence (i.e., stable, cumulative, compensatory). Studies focusing on the relation between genetic and environmental associations with young children's cognitive development suggest that even at an early age, there are reciprocal interactions between the genetic assets of the individual and environmental factors (Kweon et al., 2020; Tucker-Drob & Harden, 2012). These empirical findings typically draw on the concept that how people evoke their environments is to a certain degree associated with genetic variability (Petrill et al., 2004; Scarr & McCartney, 1983). However, as the current studies focus on the first four years of life, where empirical evidence suggests cumulative effects (Mollborn et al., 2014; Smith et al., 2002), these competing hypotheses are not further elaborated.

While habituation-dishabituation tasks are theoretically in concert with intellectual functioning (Bornstein et al., 2006; Slater, 1995), few studies have investigated how structural aspects of the children's environment (or family-related processes) influence their cognitive development as measured with habituation-dishabituation tasks. One study investigated SES-related effects on infant cognition relatively thoroughly and found no effects of maternal education on several habituation measures indicating information processing (e.g., total fixation time) in 3-month-old infants (Mayes & Bornstein, 1995). However, most studies do not provide detailed information on whether there were associations between parental SES and children's performance in habituation-dishabituation tasks (McCall & Carriger, 1993). A longitudinal study found that habituation looking patterns in infants predicted adolescent intellectual functioning at 18 years of age (Sigman et al., 1997). However, the effect was moderated by the quantity of parent-child interactions in such a way that children who habituated fast to the stimuli and who lived in a stimulating home learning environment also had higher intellectual functioning scores at 18 years than children who habituated more slowly and had a poor home learning environment.

Drawing on conceptually related research, comparative neurophysiological research highlights how complex environments foster cognitive abilities while environmental deprivation has an adverse effect (Hackman et al., 2010; Hodel, 2018). One neurophysiological study found effects of social disparity in activation patterns in the prefrontal cortex, typically associated with attentional modulation, executive function, and novelty processing (Kishiyama et al., 2009; similarly, Noble et al., 2015). Thus, children from low SES households showed significantly smaller attention spans than children from higher SES households, which should affect their performance in habituation-dishabituation tasks.

This lack of empirical studies regarding habituation-dishabituation tasks is because such studies are mostly conducted with small and socioeconomically selective samples (Fernald, 2010; Henrich et al., 2010), which is a central shortcoming from a methodological standpoint (Oakes, 2017). One of the consequences of publication bias is that a series of studies with small samples can lead to an overestimation or underestimation of the actual effect at the population level (Maxwell, 2004). The replication crisis in psychology (Open Science Collaboration, 2015) highlighted methodological problems that may arise from relying only on small-scale laboratory studies for inferring general insights into psychological processes. Statistical power, namely the probability to detect an existing effect (Lakens & Etz, 2017), is central for infant research, as many experimental studies are underpowered due to small samples sizes and high measurement error (DeBolt et al., 2020; Oakes, 2017). This reduces the probability of finding a true effect and, likewise, increases the probability of finding false positive results. Thus, low-powered experiments make non-significant and significant findings hard to interpret (Maxwell, 2004). However, as statistical power depends on the true effect size and sample size (Lakens & Etz, 2017), large studies might also produce statistically significant results that might be spurious or not meaningful. This is why Oakes (2017) argues for the combination of small and innovative experimental studies that make scientific discoveries and larger studies that replicate and corroborate these findings (also Byers-Heinlein et al., 2021). However, regarding young children's cognitive development, such large studies have been rare.

3. Empirical background

This section provides a methodological overview of habituation-dishabituation tasks, namely typical study designs and stimulus material that are used to assess various cognitive abilities and skills in young children (**3.1 The methodology of habituation-dishabituation tasks**). Next, forms of reliability and validity in habituation-dishabituation tasks are discussed with a focus on test-retest reliability of children's looking behavior and the predictive validity of measures drawn from the tasks (**3.2 The reliability and validity of habituation-dishabituation tasks**). It is highlighted that while such measures do not match the psychometric properties of diagnostic instruments in later childhood, empirical evidence suggests that they are useful for investigating early interindividual differences in cognitive development. Finally, information on what kind of measures are usually drawn from the tasks to indicate early cognitive abilities is given (**3.3 Measuring habituation and dishabituation**).

3.1 The methodology of habituation-dishabituation tasks

While habituation-dishabituation tasks have been used in various presentation modes, many studies measure infants' looking behavior toward visual stimuli because it offers a wide range of potential research opportunities (Oakes, 2010). Generally, looking behavior can be assessed in different environments with limited but controlled experimental setup and no need for training the babies. Like other fixation paradigms, habituation-dishabituation tasks are a non-invasive method of presenting children with a sequence of visual stimuli to elicit a behavioral orienting response (Colombo et al., 2020; Fennell, 2012; Oakes, 2010). Looking times on a target stimulus are also called fixation time or fixation duration, and the measure indicates the time viewers focus their foveal visual attention on the target (White et al., 2022). Although more fine-grained definitions of fixation time are used in visual attention research (Hendry et al., 2019), which often necessitates elaborate methods of assessment (i.e., eye tracking; Aslin & McMurray, 2004), in habituation research, it is mostly used as a global measure. In concert with theoretical expectations about habituation and dishabituation, the tasks focus on children's decrease in looking times for familiar stimuli and increase in looking times for novel stimuli. Thus, such tasks have an initial habituation phase that consists of a certain number of identical or similar stimuli (i.e., a sequence of trials) as well as a subsequent dishabituation phase with novel stimuli. It is expected that children process and encode the information of the habituation phase, resulting in a decrease in orienting response over time, while they should discriminate the learned information from the novel dishabituation phase, showing attention recovery (Colombo & Mitchell, 2009).

Importantly, habituation-dishabituation tasks are designed to induce learning (Aslin, 2007), while preferential looking tasks assess differences in visual preferences that indicate cognitive processes (e.g., visual short-term memory) or a priori preferences that are not learned over experimental trials (DeBolt et al., 2020). Consequently, the latter type of tasks mostly uses familiarization, which typically entails shorter stimulus exposure as it is reasoned that the ability to detect differences need not be learned (Colombo & Mitchell, 2009; Houston-Price & Nakai, 2004). While there is a difference between habituation and familiarization on a theoretical and conceptual level, empirical studies show that the shift from familiarity to novelty preference depends on the amount of exposure (e.g., Hunter et al., 1983; Schilling, 2000). In other words, while it is theoretically not expected that children learn during preferential looking tasks, with prolonged exposure to the stimulus material, the border between familiarization and habituation gets blurry. In this context, it has been suggested that instead of defining habituation as a dichotomous state, it should be viewed as a continuous process (Kucharský et al., 2022).

Various early studies on infant's ability to discriminate between different visual stimuli showed consistent results regarding the perception of brightness (Kessen & Bornstein, 1978), contrast colors (Adams et al., 1986), and stimulus orientation (Slater et al., 1988) as early as two months of age. In this phase, visual scanning and information processing of stimuli is believed to be immature (Reynolds, 2015), which is why the stimulus material is simple and rich in contrast. Between 3-6 months of age, infants can focus their looking behavior on specific objects and after 6 months, infants become more efficient in processing visual information as they look less at simple stimuli and longer at more complex ones (Courage et al., 2006). Infants in this age range are typically visually engaged in stimulus presentation and cooperative (Braddick & Atkinson, 2011). Overall, the ability to control and maintain visual attention develops fast during the first year of life (Colombo, 2001; Hunnius, 2007) and these gains are correlated with the maturation and functional growth of central brain areas as well as synapse formation and myelination (Casey et al., 2005). Thus, while basic visual preferences can be assessed even in newborns (Banks & Ginsburg, 1985; Streri et al., 2013), habituation-dishabituation tasks that assess complex cognitive abilities are typically used from the age of 3 months onwards (for an age-related discussion on dishabituation, see Kagan et al., 1979).

Habituation-dishabituation tasks are typically differentiated into fixed-trial and infant-control tasks (initially proposed by Horowitz et al., 1972). While fixed-trial tasks use the same stimulus presentation time for all children within a sample, in infant-control tasks, children's looking behavior is tracked and evaluated online to control when and how each individual infant is presented with another stimulus (Richards, 2011). Thus, by looking off-target for a certain amount of time, the next trial is automatically presented. This way, stimulus presentation and the transition from the habituation to the dishabituation phase are more adaptive. Although infant-control tasks are often considered more relevant to differentiate between different phases of attention (i.e., attention-getting and attention-holding; Richards, 2011), fixed-trial tasks also have certain advantages. As suggested by Werner and Perlmutter (1979), fixed-trial procedures can be useful for samples with a broad age range because they accommodate individual differences in encoding time. Additionally, when interpreting interindividual differences, infant-control tasks may prematurely define an infant as having habituated due to fluctuating looking times (Dannemiller, 1984; Slater et al., 1984), recruiting infants with large variations in performance while discriminating against those with less variable performance (Thomas & Gilmore, 2004). Thus, infant-control tasks have been discussed as having limited use for statistical models that make probabilistic statements of habituation and dishabituation (Kucharský et al., 2022). Finally, although fixed-trial designs are usually used in familiarization tasks, as habituation requires a clear cut-off criterion of decrement in looking time (Aslin, 2007; Fennell, 2012), under certain conditions fixed-trial designs can also be categorized as a form of the habituation-dishabituation paradigm (e.g., Dannemiller, 1984) as similar looking time patterns can be found (Schlingloff et al., 2020; Šimkovic & Träuble, 2021).

In comparison to familiarization tasks, one crucial aspect for interpreting children's looking times in habituation-dishabituation tasks is a previously defined habituation criterion (Oakes, 2010). Children usually spend more time looking at a novel stimulus and the habituation criterion marks the transition from novelty to familiarity (Dannemiller, 1984). Thus, children who meet this criterion are expected to show less orienting at the habituation phase and comparably more orienting at the dishabituation phase (Cohen, 2004; Houston-Price & Nakai, 2004; Slater, 2004). The contrasting processes of responsiveness to familiarity and novelty typically complicate the interpretation of the results, especially in very young infants and in tasks with complex stimulus material (Shinskey & Munakata, 2010). Some authors argue that observed looking time data for children who do not meet the habituation criterion should not be interpreted (Cohen, 2004; Oakes, 2010). However, it should also be noted that the habituation criterion is an arbitrary convention and a simple heuristic for ensuring a certain level of standardization (e.g., Fassbender, 2022; Kucharský et al., 2022), and that selective samples limit the generalizability of the findings. Typically, habituation is marked by a monotonous and exponential decrease, although it depends on stimulus characteristics, aspects of the presentation, and state factors of the infant (Mareschal et al., 2007) – and there is an ongoing debate about the pattern in general (Young & Hunter, 2015).

One advantage of habituation-dishabituation tasks is that the stimulus material can be adapted according to the needs of the study or the children's developmental stage. In general, longer looking times are expected for more complex stimuli (Colombo et al., 1997; Kaplan & Werner, 1986) and central aspects of complexity are contour density, object size and number, as well as the number of angles, pattern arrangement, and line thickness (Banks & Ginsburg, 1985). Categorical stimulus material that was introduced to test children's category learning (Fagan, 1976) is considered more complex than identical material. This is why categorical stimulus material is also useful for holding older infants' attention (Richard et al., 2004). During the first year of life, looking times generally decrease (Bornstein et al., 1988; Colombo & Mitchell, 2009). The latter finding is typically interpreted that the children are more efficient in encoding the stimuli (Courage et al., 2006). This is why early studies proposed that infants who prefer more complex stimuli (i.e., complex checkerboards in comparison to simple ones), are developmentally advanced (Greenberg et al., 1973). However, empirical findings are not straightforward. While many studies found an age-related decrease in looking times in the first year of life (e.g., Bornstein et al., 1988; Rose et al., 2002), interindividual looking time may also fluctuate (Colombo et al., 1999; Colombo et al., 1987), probably due to an increase in episodes of sustained attention (Courage et al., 2006). Finally, as looking times are an indicator of familiarity with the stimulus, the amount of previous exposure to the stimulus or stimulus category is considered central (Hunter & Ames, 1988). Thus, a longer familiarization phase typically leads to better object recognition (Fagan, 1974; Hunter et al., 1983).

3.2 The reliability and validity of habituation-dishabituation tasks

Observing and assessing psychometrically valid behavior in infants is notoriously challenging, as they cannot speak, sleep frequently, and only engage in rudimental interaction behavior (Bornstein, 2020). Still, habituation-dishabituation tasks need to meet certain requirements regarding reliability and validity to generate transparent and verifiable statements about child development. In infant research, a critical issue is measurement reliability, namely that a measure maximizes the detection of a true score and minimizes the amount of measurement error (Byers-Heinlein et al., 2021). Thus, it is expected in reliable studies that measures drawn from habituation-dishabituation tasks should detect children’s looking behavior with precision and consistency, that is, when children’s within-person variability in looking times during the trials is small (i.e., internal consistency) (DeBolt et al., 2020).

Generally, reliability refers to the consistency, accuracy, or stability of assessment results and it is expected that all assessments be necessarily affected by (random) measurement error (Reynolds et al., 2021a). Regarding infant research, this measurement error should be larger than in other samples, due to processes of maturation and physiological changes that affect the observable behavior (Byers-Heinlein et al., 2021). Potential sources of errors are content sampling (e.g., a poor calibration of the stimulus material), time sampling, and administrative errors (Reynolds et al., 2021a), all of which are prevalent in infant research

(Reinelt et al., 2022). Typically, test-retest reliability as an index of stability over time is assessed in studies using habituation-dishabituation tasks (Colombo et al., 1987).

There are several studies on the reliability of habituation measures that focus on repeated assessments of the same task in the first year of life (Bornstein & Benasich, 1986; Colombo et al., 1987; Lavoie & Desrochers, 2002; Mayes & Kessen, 1989; Pêcheux & Lécuyer, 1989; Pomerleau et al., 1989). Concerning the reliability of children's looking behavior in the second year of life, research is scarce. Overall, the available studies report moderate reliability in quantitative measures of habituation (e.g., index measures) that are only robust within a short time frame (about 1 month). Quantitative measures of dishabituation typically have low short-term reliability (Kavšek, 2004a). Physiological instabilities (Belsky et al., 1984) are likely responsible for the moderate reliability, as they increase measurement error (Thomas et al., 2012). In addition, due to the development and maturation of basic cognitive processes (Kail, 2000) and visual attention in the first year of life (Hendry et al., 2019), older infants will inevitably respond differently to the same stimuli as younger infants (e.g., Colombo et al., 2004).

Thus, habituation-dishabituation tasks do not meet the psychometric requirements for individual diagnostics (Kavšek, 2004a), although some report higher reliability in screening preterm children (Kavšek & Bornstein, 2010). Due to maturational processes, findings on intraindividual stability in looking time patterns (i.e., qualitative measures) are limited and group-level (rank order) stability during the first 6 months of life is more often documented (Hood et al., 1996; but see Gilmore et al., 2007). Consequently, while deviations and looking time fluctuations in habituation-dishabituation tasks are frequently reported (Bornstein et al., 1996), most authors argue for a certain conceptual and empirical stability of interindividual differences (Bornstein, 2020; Mareschal et al., 2007; Sigman et al., 1997; for a critical discussion, see Lécuyer, 1989).

Validity on the other hand refers to theoretical and conceptual evidence that supports certain interpretations of the assessment (Reynolds et al., 2021b). From the standpoint of cognitive theories and assuming developmental continuity, measures drawn from habituation-dishabituation tasks should allow for integrated evaluations about aspects of cognition usually referring predictively or concurrently to related constructs (Reynolds et al., 2021b). While several types of validity evidence are relevant for infant research in general (Kominsky et al., 2022), studies focusing on children's habituation and dishabituation typically examine validity evidence based on conceptually related research or the predictive validity of looking time measures for later skills and competencies.

Drawing on conceptually related research, a number of studies on visual attention reported the simultaneous occurrence of habituation and sustained attention (Colombo et al., 2010; Hendry et al., 2019; Reynolds, 2015), indicated by children's decelerating heart rate, which is typically interpreted as periods of active cognitive processing (Reynolds, 2015). Relatedly, neuroscientific research highlights the parallels between infant habituation and repetition attenuation in adults, indicating that the basic processes of neural activity in reaction to stimulus repetition are stable (Turk-Browne et al., 2008). In addition, experiments studying infants' hemodynamic responses to repeated environmental stimuli (i.e., blood oxygenation in certain brain regions) have highlighted similarities to response patterns in habituation-dishabituation tasks (Aslin et al., 2015; Issard & Gervain, 2018). Finally, early research on children's sensorimotor development also suggests that habituation rate in the first years of life and early developmental milestones (e.g., object permanence) are positively correlated (concurrently: Johnson & Brody, 1977; predictively: Ruddy & Bornstein, 1982).

Regarding evidence for the predictive validity of habituation-dishabituation tasks for later cognitive abilities, several reviews and meta-analyses (Bornstein & Sigman, 1986; Kavšek, 2004b; Kavšek & Bornstein, 2010; McCall & Carriger, 1993), as well as findings from a large-scale study (Bornstein et al., 2006; Bornstein et al., 2013) have shown considerable predictive validity of habituation and dishabituation measures for later intellectual functioning. Kavšek (2004b), for example, found an average predictive correlation coefficient of $r=.45$ in 43 studies reporting habituation measures in infants – with no correlations reporting effects in the opposite direction. Similar findings – albeit with smaller coefficients and drawing on a much more limited database – were also reported for early language abilities (Dixon & Smith, 2008; Rose et al., 2012) and mathematical competence (Ceulemans et al., 2015; Starr et al., 2013) during childhood years. Such correlations point toward a certain degree of continuity of cognitive development in childhood, even though predictive effects in later childhood are modest (i.e., explained variance of 4-10%; Colombo et al., 2009). Moreover, performance in habituation-dishabituation tasks was shown to be related to later achievement in educational settings (Alexander et al., 1993; Bornstein et al., 2013; Fagan et al., 2007) – although effects were small and indirect in later childhood.

In addition, it should also be noted that habituation-dishabituation tasks empirically have higher predictive validity than developmental tests such as the Bayley Scales of Infant Development (Bayley, 2006; Nellis & Gridley, 1994) or Griffith’s Scales of Child Development (Green et al., 2016). Such tests usually examine sensory discriminations, motor development, imitation of basic actions, and emotional reactions (Burakevych et al., 2017). At an early age, these measures are potentially unstable (Domsch et al., 2009) and show poor reliability (Yu et al., 2018), as they focus on sensorimotor milestones (Dunst & Rheingrover, 1981). Although more recent versions of these tests include attentional measures (e.g., aspects of habituation and novelty reaction; Piñon, 2010), they still have poor predictive validity for later cognitive functioning in the first 18 months of life (Aylward, 2013; Krogh & Væver, 2019). In addition, there have been few comprehensive studies on the predictive validity of these newer versions for later intellectual functioning. Previous meta-analyses of studies using different or older versions of these developmental tests reached the same conclusion (Bornstein & Sigman, 1986; Fagan & Singer, 1983; Hetherington et al., 2006).

3.3 Measuring habituation and dishabituation

Whereas researchers in the 1960s were primarily interested in the process of habituation from a conceptual and theoretical standpoint (Kagan & Lewis, 1965), this focus shifted in the following years to using habituation (and later dishabituation) for studying different aspects of cognitive abilities (Colombo & Mitchell, 2009). With this development, an abundance of index measures that gave a quantifiable approach to interpreting children's performance in the tasks was developed (Colombo et al., 1987; Kavšek, 2004a; for a critical discussion, see Jacobson et al., 1992). Such index measures are often unweighted combinations of orienting responses for various, a priori defined trials. While newer studies have implemented more elaborate statistical approaches for investigating children's habituation such as polynomial modeling (e.g., Dahlin, 2004; Lavoie & Desrochers, 2002), such model-based approaches have shortcomings regarding infant-control designs and the measurement of dishabituation (Kucharský et al., 2022). Thus, quantitative index measures are still prevalent in infant research, although there is a recent ongoing discussion about how to approach habituation and dishabituation from a methodological standpoint (Byers-Heinlein et al., 2021; Fassbender, 2022; Kucharský et al., 2022; Reinelt et al., 2022). In contrast to quantitative measures, qualitative measures of habituation (e.g., Bornstein & Benasich, 1986;

Mayes & Kessen, 1989) that describe looking time patterns are seldom studied (Kavšek, 2004a).

As habituation refers to the decrement in looking times during a sequence of similar or identical visual stimuli, index measures represent characteristics of this decrement. One of the most important measures is the habituation criterion (Fennell, 2012), which is a dichotomous measure of a 50% decrement in looking times during the habituation phase (Dannemiller, 1984). Although this threshold is an arbitrary heuristic and other cut-off criteria are frequently discussed (Fennell, 2012), the measure generally allows for discriminating between habituators and non-habituators, and only habituators are held to have sufficiently processed the information presented in the habituation phase. As most cognitive models hypothesize that a fast habituation rate indicates more efficient processing skills, not reaching the habituation criterion or prolonged looking times (i.e., smaller looking time decrement or longer total fixation time) are thought to approximately reflect poorer information processing skills (McCall & Carriger, 1993).

Similarly, dishabituation is the sensitivity or responsiveness to novel stimuli in comparison to familiar ones and it has been discussed that dishabituation indicates that the infant attempts to assimilate the novel stimulus into the previously formed habituation category (Kagan et al., 1979). It was established that a dishabituation phase is necessary when investigating young children's information processing, as a decrement in looking times during the habituation phase could otherwise reflect fatigue or negative affectivity (Sophian, 1980). The dishabituation phase tests whether the children discriminate between the familiar and novel stimuli, which indicates that the children remember the previously presented information (Bornstein, 1989). Thus, in habituation-dishabituation tasks, the dishabituation stimuli are trials for testing early learning. Therefore, index measures of dishabituation are typically calculated that compare children's response to the novel stimulus with the previous familiar stimuli (Oakes, 2010). The resulting measures, namely recognition memory or attention recovery, are interpreted as information processing skills, which is a core mechanism of learning (Mather, 2013). This is why habituation and dishabituation are conceptually related and empirically correlated with each other; children who encode visual information more efficiently should also have good discriminatory abilities (Rose et al., 2003).

Habituation-dishabituation tasks are adaptive, which is why they allow for testing specific skills and abilities. When assuming continuity in the cognitive development of young children, it can be reasoned that such tasks tap into early precursor abilities of later skills and competencies in conceptually related domains. Thus, habituation-dishabituation tasks may tap into aspects of language processing such as early word learning, which is a central precursor of vocabulary development. In such tasks, children in the early second year of life are habituated to a specific word-object association (for overviews, see Fennell, 2012; Johnson & Zamuner, 2010). In the dishabituation phase, a novel object is presented in combination with the habituated word label. Thus, the dishabituation phase tests whether the children detect a difference in the deviant word-object pairing, suggesting that they learned the word label.

Likewise, early quantitative abilities (i.e., numeracy skills) are regarded as precursor abilities of later mathematical competence because they facilitate children's understanding of discrete quantity or non-symbolic magnitudes (for overviews, see Schneider et al., 2017; Siegler & Braithwaite, 2017). In such studies, children are habituated to a certain amount of discrete objects, while the dishabituation phase features a deviant amount of objects, indicating an approximate understanding of quantities (Xu et al., 2005). However, it should be noted that habituation-dishabituation tasks are only one method for assessing quantitative abilities and similar techniques include familiarization and preferential looking (Cordes & Brannon, 2008).

4. Research gaps

To summarize, the reaction phenomena of habituation and dishabituation are considered by most researchers to reflect basic cognitive processes (i.e., stimulus encoding, storing, and retrieving) that indicate aspects of cognitive functioning at a young age. Habituation-dishabituation tasks are a standard method in infant research for investigating young children's behavioral responses to sequentially presented stimulus material. Typically, children's attention decrement during the habituation phase indicates information processing while their attention recovery during the dishabituation phase indicates early learning. Because the stimulus material is adaptive, the tasks tap into a broad range of early cognitive abilities that can be considered precursors of later skills and competencies (i.e., domain-general and domain-specific precursor abilities).

However, findings on young children's cognitive development using habituation-dishabituation tasks are typically from small and homogeneous samples, although it was shown that cognitive development in the first two years of life is already substantially influenced by socioeconomic background. Therefore, one central research gap is whether measures drawn from habituation-dishabituation tasks administered in a large and heterogeneous sample are associated with their socioeconomic background. More specifically, the present empirical studies aimed at answering two research questions: (I) Are there effects of social disparity in measures drawn from habituation-dishabituation tasks during the first two years of life and, if so, when do they emerge? (II) Are predictive effects of measures drawn from habituation-dishabituation tasks on later skills and competencies impeded when also considering children's socioeconomic background?

In addition, habituation-dishabituation tasks allow for assessing early precursor abilities in different domains of cognition such as language or mathematics. However, studies that compare and contrast more domain-general with domain-specific abilities in these two domains are rare. Thus, a second research gap addresses the relation between domain-general and domain-specific habituation-dishabituation tasks and later skills and competencies in the domains of language and mathematics. More specifically and in addition to the research questions on the effects of social disparity, the present empirical studies aimed at answering the following research question: (III) What is the relation of predictive effects of domain-general and domain-specific precursor abilities on later skills and competencies in the domains of language and mathematics?

5. Overview of empirical studies

This section provides an overview of the empirical studies that were conducted for answering the proposed research questions. In this context, empirical analyses that were prepared as research articles for publication in scientific journals are considered studies, although all analyses draw on data from the same large-scale panel study. First, details on the sample, design of the habituation-dishabituation tasks, and competence measures are given (**5.1 Methodological approach**). Then, the two research questions on the potential effects of social disparity on the performance in habituation-dishabituation tasks in the first two years of life are addressed (**5.2 Study 1: Social disparities in cognitive development: Evidence from habituation-dishabituation tasks**). In addition, two studies compared and contrasted the predictive effects of domain-general and domain-specific precursor abilities on later skills and competencies in two important domains of cognition. Regarding the domain of language, children's early word learning (domain-specific) and categorical information processing (domain-general) were examined using habituation-dishabituation tasks (**5.3 Study 2: Attention and early learning in infants as predictors of productive vocabulary**). Regarding the domain of mathematics, children's early understanding of numerical relations as measured with a domain-specific numerical habituation-dishabituation task was investigated and compared to a categorical information processing task (**5.4 Study 3: Numeracy skills in young children as predictors of mathematical competence**). Finally, broader information on the habituation-dishabituation tasks used for the current analyses is given (**5.3 Study 4: Visual habituation-dishabituation tasks in NEPS Starting Cohort 1: An approach to interpreting the data**). The study highlights, among others, that although many of the reported findings seem counterintuitive, the children's looking behavior in the tasks is generally consistent.

5.1 Methodological approach

The present empirical studies used data from the Newborn Cohort of the German National Educational Panel Study (NEPS SC1; Blossfeld & Roßbach, 2019). NEPS SC1 was conceptualized as a longitudinal panel study in Germany with a representatively drawn sample (Hachul et al., 2019; Weinert et al., 2016). Longitudinal panel studies typically involve repeated data collection of specific outcomes at different points in time in the same individual and are often used to address research questions on human development (Collins, 2006). NEPS SC1 started in 2012 and collected data yearly from the newborn children as target persons (i.e., survey waves; Hachul et al., 2019). Each year, several direct behavioral measures of the child were assessed (e.g., observational measures or competence data) and family-related information was gathered from parental interviews. In survey wave 2 (children on average 17 months), direct behavioral measures were only assessed in half of the sample, whereas a prior telephone interview was conducted with the full sample (parental interview). In all survey waves, data was collected nationwide by trained interviewers and data collection spanned several months due to logistic reasons. As of writing, NEPS SC1 was still ongoing, although in the context of the present empirical studies only data from the first five survey waves was used. Sample attrition in NEPS SC1 is in line with other panel studies (Lee, 2003; Watson & Wooden, 2009), with a year-on-year net sample coverage of at least 80% (Zinn et al., 2020). Table 1 provides an overview of selected measures relevant to the present empirical studies.

Table 1

Overview of Selected Child-Related Measures in NEPS SC1 (2012-2016)

Survey wave (average age of the children)	Direct child-related measures (child observations)	Indirect child-related measure (parent-reported)	Competence measure (standardized assessment)
1 (7 months)	Domain-general categorical visual habituation-dishabituation task (e.g., Pahnke, 2007) Parent-child interaction (Linberg et al., 2019)		
2 (17 months)	Domain-general categorical visual habituation-dishabituation task (e.g., Zhang, 2007) Domain-specific numerical habituation-dishabituation task (Freund, 2012) Domain-specific word-learning habituation-dishabituation task (Zhang, 2007)		
3 (26 months)		Productive vocabulary (Grimm & Doil, 2006)	
5 (4 years)			Mathematical competence (Grüßing et al., 2013)

Note. Only selected direct measures, indirect measures, and competence measures reported that were relevant in the context of the present empirical studies (survey wave 4 omitted); at each survey wave, information on the socioeconomic background of the child and family-related aspects was collected (parent-reported).

In the first two survey waves, visual habituation-dishabituation tasks with categorical stimulus material were chosen to assess early cognitive abilities in young children (Weinert et al., 2016). To increase ecological validity and maximize sample participation, the tasks were administered in the children's homes, which is why the setting was not as standardized as typical laboratories for experimental research. Experimental run-up tests were conducted to identify issues that could be a threat to the task administration (i.e., room lighting, furnishing, laptop, and camera setup). Before any household visits, all interviewers received wide-ranging training regarding these aspects, as most of them had no professional background in psychological testing. In addition, interviewers should report all factors disrupting stimulus presentation (e.g., disturbances or task interference).

For all habituation-dishabituation tasks, the basic setup and administration procedure were the same (for a detailed description, see Study 4). The children sat on the lap of the interviewee who was in most cases the biological mother. The stimulus material was presented on a notebook (model: Lenovo T60) and the children's looking behavior was recorded on a video camera (model: AIPTEK AHD Z700). The notebook was positioned on a cardboard box and both the setup and the screen were adjusted to the infants' ideal field of vision. The cardboard box was 10 centimeters from the edge of the table, with the screen being 1 meter away from the infant's ear. A foldable visual cover was placed over the notebook's keyboard, also masking the camera that recorded the children from a central angle. The interviewee was instructed to sit quietly and not distract the child, while other people or pets were generally not allowed in the room.

Most aspects of the task administration were similar for all tasks. All tasks started the same way: When the interviewer initiated the presentation, descending black numbers from "3" to "1" were shown on a purple colored screen (count in), followed by a subsequent eye-catcher or attention getter (i.e., an animated penguin accompanied by an audio cue). Including such an attention getter was shown to be associated with more focused attention on the target stimuli, as well as decreased attrition, especially in the first year of life (Domsch et al., 2009). After the attention getter, the habituation phase started immediately. In all tasks, a dishabituation phase and a subsequent attention control phase were presented following the habituation phase. The dishabituation phase tested for the children's attention recovery (novelty effect) regarding the stimulus material of the habituation phase and featured novel, out-of-category exemplars comparable to those previously shown. In contrast to the dishabituation phase, an attention control phase was included to check for the effects of linear fatigue in the children and featured completely different pictures. All habituation trials were presented for 10 seconds and were accompanied by an audio cue (i.e., a three-note jingle) to attract the children's attention, except for the word-learning task, which featured a pseudoword (i.e., "Ein Jalos"). The dishabituation trials were presented for 15 seconds (survey wave 1) or 10 seconds (Wave 2) and were also accompanied by the audio cue. For reasons of comparability, looking times in the trials of survey wave 1 were recoded to 10 seconds for the available data. Intertrial interval duration was 2 seconds, or 1 second between two trials of a dishabituation phase, respectively. There was a pause interval of 5 seconds between any two tasks. The habituation phases in most of the tasks featured 9 categorical stimuli (i.e., trials) (total presentation time at survey wave 1: 177 seconds; total presentation time at Wave 2: 157 seconds) and only the numerical task featured 4 trials (total presentation time: 102 seconds). A fixed-trial procedure was deemed useful for reasons of standardization in the large-scale context (Weinert et al., 2016). Thus, the sequence of stimulus pictures and the individual tasks at each survey wave were the same for all children, which allowed trained interviewers to administer the tasks in the households without on-line coding and with limited equipment. Because of potential disturbances in the households, a minimum number of trials was chosen that all children should be presented with, as children's performance degrades when they are tired, bored, or sleepy (DeBolt et al., 2020). At survey wave 2, only half of the original panel sample was by design asked to participate in the direct measures (child observations including the habituation-dishabituation tasks).

The children's looking time toward the presentation screen was recorded on a video camera in 30 frames per second and was coded offline by independent raters blind to the stimulus material. For each frame, the children's looking behavior was categorized as "toward the target" or "away from the target". The present studies used data on the accumulated fixation times at the target, namely the presented stimulus. Although videos from NEPS SC1 were generally coded within the NEPS project, part of the data was processed and coded under a different grant due to the high amount of necessary coding time[1]. Interrater reliability was tested on a subsample of 10% of all videos at each wave. Two independent raters coded randomly drawn videos and the rating agreement was generally high for looking events at the target and off-target (weighted interrater agreement of Cohen's κ=.92 for both survey waves; collapsed agreement reported for all tasks at the respective survey wave).

However, not all habituation-dishabituation tasks that were conducted in NEPS SC1 were used for the present analysis (for a complete overview, see Study 4). In Study 1, a domain-general categorical habituation-dishabituation task was analyzed that featured the same stimulus material at both survey waves (Zhang, 2007). The habituation phase featured one curvilinear cartoon bug with symmetrical antennae per trial, while the dishabituation

[1] ViVA; Video-Based Validity Analyses and Interrelations between Measures of Early Childhood Competencies and Learning Environment. Project funded by the German Research Foundation (DFG) within the priority programme 1646; grant awarded to S. Weinert: WE 1478/7-1.

phase featured an out-of-category exemplar per trial, namely a rectangular cartoon bug with asymmetrical antennae. The attention control phase was two identical photos of a pineapple.

In Study 2, a word-learning task was used in addition to the domain-general categorical habituation-dishabituation task, and it featured categorical stimuli in combination with an auditory pseudoword (Zhang, 2007). The word-learning task was only administered at survey wave 2. In the habituation phase, each trial featured one curvilinear cartoon creature. All creatures had the same facial features (i.e., eyes, nose, and mouth). In the two trials of the dishabituation phase, a rectangular creature was shown per trial. Because of the design, the facial features were markedly different from the previous trials (i.e., out-of-category exemplar). The attention control phase was two identical photos of a tree. A pseudoword as a language stimulus was played once per picture and was accompanied by a German indefinite article as an object identifier (i.e., "Ein Jalos"; "Ein" as a German article and "Jalos" as a pseudoword referring to the creature; Waxman & Kosowski, 1990; Zhang, 2007). There was no variation of the auditory stimulus, as this can be distracting for object labeling (Parmentier et al., 2011). As the pseudoword was also presented for the dishabituation trials, the task can be considered a word-learning task (e.g., Stekmachowicz et al., 2004).

In Study 3, a domain-specific numerical task was analyzed in addition to the domain-general categorical habituation-dishabituation task, and it featured numerical stimuli to test children's domain-specific understanding of non-symbolic magnitudes. The numerical task was only administered at survey wave 2 and featured an adapted version of Cooper's (1984) task design; pretests were conducted at the chair of developmental psychology at the University of Bamberg, Germany (Freund, 2012). A sequence of four pictures with varying amounts of cartoon sheep and bears was shown in the habituation phase. The sheep were always on the left side, whereas the bears were always on the right side (≤ 4 per category, below the subitizing threshold; Clements et al., 2019). The dishabituation stimulus reversed the ratio in favor of the bears and the second dishabituation picture had a balanced ratio. The attention control phase was two identical photos of a flower. Due to the short habituation phase and the focus on the children’s basic understanding of magnitudes instead of early learning, the task can be regarded as a familiarization task instead of a typical habituation-dishabituation task.

Regarding the quantitative indicators (index measures) of basic cognitive abilities drawn from the children’s looking times, Colombo and Mitchell (1990) argue that global measures are the most robust as they consider several trials (similarly Kavšek, 2004a), which reduces measurement error (Byers-Heinlein et al., 2021; Fassbender, 2022). As different measures mark separable processes during stimulus presentation, the analyses used three standard index measures of visual attention and general learning (Colombo et al., 1987; Kavšek, 2004a). First, a global measure of visual attention toward the target during the habituation phase was defined as the accumulated sum of all looking time events at the target (total fixation time). Second, a 50% attention decrement during the habituation phase compared to the initial looking time at the first trial was used (habituation criterion). Third, attention recovery was used as a difference measure of looking times at the transition to the dishabituation phase (Aslin, 2007; Fennell, 2012; Oakes, 2010). Technical information on the calculation of the measures is provided in Study 4.

As the present studies also focus on structural aspects of children’s socioeconomic background, indicators of parental occupation, parental education, and household income were included in the analyses where necessary. A measure of parental occupation was the highest International Socio-Economic Index of Occupational Status in the household. The measure considers the required education level and the mean income of a specific occupation to create a continuous classification scheme (Ganzeboom et al., 1992) and is a standard index for social stratification (e.g., Ehmke & Siegle, 2005). While professional workers (e.g., physicists) score higher on the scale, service workers (e.g., waiters) score lower (Ganzeboom et al., 1992). For parental education, the International Standard Classification of Education (ISCED 1997; United Nations Educational, Scientific, and Cultural Organization (UNESCO), 2012) or the overall years of formal education of the mother were chosen. Focusing on maternal education is standard procedure as in many Western countries mothers are still the primary caregivers in the formative years (Davis-Kean et al., 2021). Finally, for household income, the standard OECD (2013) approach of calculating a household-size adjusted score that weighs people below and above the age of 14 differentially was chosen (i.e., equivalized household income).

The analyses control for children's age because the age range at both survey waves in NEPS SC1 is broad when compared to typical samples in experimental studies (survey wave 1: M=7.00 months, SD=0.76, Min=5.15, Max=11.93; survey wave 2: M=17.05 months, SD=0.61, Min=15.77, Max=20.36). In addition, because gender differences in habituation and dishabituation were reported in fixed-trial designs (Tighe & Powlison, 1978), children's gender was included in all analyses as a control variable (parent-reported). Finally, preterm birth (i.e., <37 weeks of gestation) and low birth weight (i.e., <2000 g) are risk factors for delayed cognitive development (Anderson & Doyle, 2008) and deviant looking patterns in habituation-dishabituation tasks (Kavšek & Bornstein, 2010; Thomas et al., 1998). Thus, analyses of 7-month-old infants (survey wave 1) generally did not include preterm children. However, as the difference in looking time patterns between preterm and term-born children was found to diminish within the first year of life (Castillo et al., 2014), robustness checks were calculated in 17-month-old children (survey wave 2) before this subgroup of children was excluded.

5.2 Study 1: Social disparities in cognitive development: Evidence from habituation-dishabituation tasks

A central issue of infant research is that studies are typically conducted with small and selective samples (Oakes, 2017), although research found ample evidence for the effects of social disparity in early cognitive development (e.g., Farah et al., 2008). Thus, the aim of the study[2] was to investigate when effects of social disparity in young children's cognitive abilities emerge (research question I) and whether such disparities might be explained by the quantity and quality of parent-child interactions. Even though effects of social disparity were reported in cognitive abilities during the latter half of the first year of life (Halle et al., 2009), previous studies often rely on standardized developmental tests or parental reports (e.g., Golden & Birns, 1983; Rubin & Balow, 1979). Study 1 examined associations between components of young children's socioeconomic background (i.e., parental occupation, maternal education, and household income) and early cognitive abilities using habituation-dishabituation tasks (i.e., total fixation time and attention recovery). Previous studies using habituation-dishabituation tasks yielded mixed results regarding the potential effects of social disparity (e.g., Mayes & Bornstein, 1995), although few have analyzed multiple aspects of children's socioeconomic background and most relied on small and selective samples (Oakes, 2017). Because most authors argue that children's socioeconomic background has an indirect effect on their cognitive development (e.g., Bornstein & Bradley, 2010), mediated by family-related processes (e.g., Bronfenbrenner & Morris, 1998), the study also tested such mediation effects using measures on the quantity and quality of parent-child interactions.

[2] Seitz, M., Möwisch, D., Vogelbacher, M., Attig, M., & Weinert, S. *Social disparities in cognitive development: Evidence from habituation-dishabituation tasks.* Manuscript submitted for publication. A future published version may differ from this specific manuscript.

Data from NEPS SC1 was used (NEPS Network, 2021), in particular, a domain-general categorical habituation-dishabituation task administered in the children's homes when the children were on average 7 months old (survey wave 1) and 17 months old (survey wave 2). This specific task was chosen because it featured the same stimulus material at both survey waves, which allows for investigating children's development during the first two years of life and thus the potential emergence of social disparity in young children's cognitive abilities (for a detailed task description, see Study 4). As measures of early cognitive abilities, we used total fixation time during the habituation phase and attention recovery during the dishabituation phase. In addition, the study analyzed three different components of children's socioeconomic background, namely parental occupation, maternal education, and household income, because these components might refer to different family-related processes (Duncan & Magnuson, 2012). Finally, the sum of joint activities was used as the quantity of parent-child interactions, while emotional support and cognitive stimulation were used as dimensions of the quality of parent-child interactions.

At survey wave 1, the study found no significant bivariate correlations between the components of parental socioeconomic status and total fixation time in the habituation phase or attention recovery in the dishabituation phase. At survey wave 2, all components of parental socioeconomic status were positively correlated with total fixation time (ranging from $r=.07$ to $r=.13$; $p<.05$) but not with attention recovery. Associations between parental socioeconomic status and the quantity and quality of parent-child interactions were generally small but significant (ranging from $r=.08$ to $r=.21$; $p<.01$). Conversely, total fixation time and attention recovery were mostly not significantly correlated with the quantity or quality of parent-child interactions. Because we expected a predictive effect of family-related processes on later cognitive abilities (e.g., Lugo-Gil & Tamis-LeMonda, 2008), we only calculated the path models with the quantity or quality of parent-child interactions mediating effects of socioeconomic background for survey wave 2. Regarding total fixation time at 17 months, the path models revealed no effects of mediation of parental socioeconomic status. Similarly, there were no significant effects on attention recovery at 17 months.

Overall, the results point toward the emergence of effects of social disparity in early cognitive abilities measured by habituation-dishabituation tasks in the second year of life, which is in line with previous findings from neuroscientific studies (e.g., Farah et al., 2008; Hurt & Betancourt, 2016). The large and heterogeneous sample should have been adequate for addressing potential effects of social disparity. Still, it was surprising and counterintuitive that family-related processes (i.e., the quantity or quality of parent-child interactions) were not consistently correlated with the indicators of early cognitive abilities. It should be noted that regarding the influence of family-related processes on children's early cognitive abilities measured by habituation-dishabituation tasks, research is scarce (e.g., Riksen-Walraven, 1978; Tamis-LeMonda & Bornstein, 1989). The study concludes that due to the household setting, the habituation-dishabituation task potentially measured a global measure of sustained attention and the context-specific facet of the interaction behavior could have resulted in a failed mediation.

An important implication of the study was that even at an early age, parental socioeconomic status had a substantial influence on measures drawn from habituation-dishabituation tasks. A central limitation was that the dropout in the sample was shown to be associated with children's socioeconomic background (Zinn et al., 2020), indicating that the study might even underestimate the actual effects of social disparity. In addition, while household income was analyzed, the study could not go into detail regarding economic hardship (i.e., poverty), as the information in the database was limited to that account.

Moreover, sequence effects might have influenced the results as the tasks were administered at different positions in the sequence of direct measures at both waves. Finally, the study recommends that components of socioeconomic background should be investigated in depth and that other potentially mediating factors should be addressed (e.g., parental mental health or stressful home environment) to identify possibilities for interventions.

5.3 Study 2: Attention and early learning in toddlers as predictors of productive vocabulary

The primary aim of Study 2 was to address the relation between domain-general and domain-specific skills as predictors of later competency in the domain of language (research question III)[3]. More specifically, the study examined the predictive effects of measures drawn from a domain-general and a domain-specific word-learning habituation-dishabituation task (i.e., total fixation time, habituation criterion, and attention recovery). Based on the findings of Study 1, the association between these measures and children's socioeconomic background was tested and, where necessary, controlled for in subsequent analyses (research question II).

One central component in the domain of language is vocabulary development, for which domain-general (e.g., memory and learning) and domain-specific skills (e.g., language processing) are necessary (Samuelson, 2021). Thus, previous studies found that attention decrement during habituation (Colombo et al., 2009) and attention recovery during dishabituation (Mather & Plunkett, 2012) are predictive of later vocabulary (Rose et al., 2009). However, few studies compared and contrasted early domain-general and word-learning skills on later vocabulary development using habituation-dishabituation tasks. In addition, few studies controlled for children's socioeconomic background, even though previous findings

[3] Seitz, M., Möwisch, D., Attig, M., & Weinert, S. *Attention and early learning in toddlers as predictors of productive vocabulary.* Manuscript submitted for publication.
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suggest considerable associations between early word learning and parental socioeconomic status (Pace et al., 2017).

Data from NEPS SC1 (NEPS Network, 2019) was used in which a domain-general categorical habituation-dishabituation task and a categorical word-learning habituation-dishabituation task were administered in the children's homes when they were on average 17 months (for a detailed task description, see Study 4). The study investigated measures reflecting categorical information processing (i.e., total fixation time during the habituation phase and reaching the habituation criterion) and word learning (i.e., attention recovery in the word-learning task) regarding their predictive effects on later vocabulary development, which was operationalized as productive vocabulary reported by the parents when the children were on average 26 months old. In addition, the association between these measures and children's socioeconomic background (i.e., maternal education and household income) was tested and controlled.

Analyses suggested that while many children did not habituate (domain-general task: 28.30%; word-learning task: 46.85%), habituators had typical looking time patterns of attention decrement in the habituation phase and attention recovery in the dishabituation phase. Bivariate statistics indicated a significant positive correlation between total fixation time in habituators and productive vocabulary in both tasks (domain-general task: $r=.14$, $p<.05$; word-learning task: $r=.14$, $p<.01$). However, whereas there were no differences regarding productive vocabulary between habituators and non-habituators in the domain-general task, habituators had lower scores in the word-learning task. In addition, total fixation time was positively correlated with maternal education (domain-general task) and household income (both tasks). Models controlling for child characteristics (i.e., sex and age), children's socioeconomic background, and family language revealed that only total fixation time and not attention recovery in habituators in the word-learning task had a positive effect on productive vocabulary. A model in which total fixation time in both the domain-general and word-learning tasks were included simultaneously confirmed this.

Most of the findings were not expected. First, total fixation time was positively correlated with productive vocabulary, whereas previous research found that shorter total fixation times should be associated with better language outcomes (Colombo et al., 2004). Second, reaching the habituation criterion in the word-learning task was associated with lower productive vocabulary, although the measure typically indicates information processing and should be associated with higher productive vocabulary (Tamis-LeMonda & Bornstein, 1989). Third, attention recovery in habituators was not correlated with productive vocabulary, although the measure should indicate early (word) learning (Mather, 2013).

Thus, it was suggested that the habituation-dishabituation tasks did not measure early learning but rather sustained attention. This interpretation is supported by the fact that sequence effects can potentially explain differences in children's looking times in the domain-general and word-learning tasks. The familiar household setting probably activated the children more (Wass & Smith, 2014), resulting in the habituation measure indicating overall sustained attention (Rueda & Conejero, 2020). However, sustained attention is a multi-faceted construct (Reynolds, 2015; Wass & Smith, 2014) that could not be further investigated with the available data from NEPS SC1.

One limitation was that only a fraction of the overall sample of NEPS SC1 could be analyzed (63.95%), due to panel-related attrition (Zinn et al., 2020) and missing values. As the word-learning task was always administered after the domain-general task, sequence effects cannot be completely ruled out. In addition, only an indirect measure of the children's productive vocabulary was used and the household setting could have resulted in acoustic disturbances during the domain-specific habituation-dishabituation task, which could have made word learning more difficult.

Thus, the study concluded that although some findings were surprising, the pattern of results was robust, highlighting that overall level of attention – but not learning as indicated by attention decrement and subsequent attention recovery – predicts later productive vocabulary, even when individual child characteristics, children's socioeconomic background, and family language are controlled for. Finally, a recommendation for future research was that possible associations between children's socioeconomic background and early cognitive abilities should be studied more extensively, focusing on family-related aspects (e.g., parent-child interactions).

5.4 Study 3: Numeracy skills in young children as predictors of mathematical competence

Study 3 addressed the relation between domain-general and domain-specific skills as predictors of later competency in the domain of mathematics (research question III) while acknowledging that Study 1 established that measures drawn from habituation-dishabituation tasks in the second year of life are potentially associated with children's socioeconomic background (research question II)[4]. In previous studies, numeracy skills (i.e., early perception, processing, and reasoning about numbers) were usually investigated at later stages in childhood (i.e., starting at 4-5 years of age) (Chen & Li, 2014; Schneider et al., 2017), while the few studies in younger children failed to control for children's socioeconomic background (Ceulemans et al., 2015; Starr et al., 2013). In addition, the former studies established that both domain-general and domain-specific precursor skills are necessary for mathematical competence development (Hornung et al., 2014; Knops et al., 2017; Passolunghi et al., 2014).

[4] Seitz, M., & Weinert, S. (2022). Numeracy skills in young children as predictors of mathematical competence. *British Journal of Developmental Psychology*, *40*(2), 224-241. https://doi.org/10.1111/bjdp.12408

Thus, the study had two aims: First, analyzing and comparing domain-general and domain-specific precursor skills regarding their predictive effects on mathematical competence; second, controlling for children's socioeconomic background, which was shown to be relevant for young children's development of mathematical competence (Anders et al., 2012).

Data from NEPS SC1 (NEPS Network, 2019) was used in which a numerical habituation-dishabituation task was administered in the children's homes when the children were on average 17 months old (for a detailed task description, see Study 4). The task was an adapted version of a previously proposed method (Cooper, 1984) and tested for attention to numerical changes (i.e., numerical sensitivity; Feigenson et al., 2004). Previous studies have shown that such skills are precursors of later mathematical competence (Ceulemans et al., 2015; Starr et al., 2013). In contrast, a more domain-general categorical habituation-dishabituation task was analyzed that did not feature numerical stimuli (for a detailed task description, see Study 4). Mathematical competence, the outcome, was measured by a test spanning various subdomains of mathematical competence at the age of 4 years (i.e., knowledge of sets, numbers, and operations; units and measuring; space and shape; change and relations; data and chance) (Grüßing et al., 2013; Petersen & Gerken, 2018). As the sample was sufficiently large and heterogeneous, potential influences of children's social background were tested and controlled for (i.e., maternal education and household language). Early numeracy skills were operationalized as children's attention to numerical changes, namely their attention recovery during the dishabituation phase. In addition, the children's overall attention was controlled (i.e., total fixation time during the habituation phase). Similarly, the same measures were drawn from the domain-general habituation-dishabituation task.

A significant positive correlation between early numeracy skills and later mathematical competence was found ($r=.07$, $p<.05$). The predictive effect of early numeracy skills on later mathematical competence was robust in models controlling for total fixation time, individual child characteristics (i.e., age and gender), and children's socioeconomic background (i.e., maternal education, household language). The effect of the domain-specific precursor was small but comparable to previously found effects (Starr et al., 2013). A model with measures of the domain-general habituation-dishabituation task yielded no such predictive effects. In contrast to findings from Study 1, numeracy skills and total fixation time in the numerical habituation-dishabituation task were not significantly correlated with children's socioeconomic background. Finally, it should be noted that total fixation time had a small positive effect on mathematical competence in both tasks (numerical task: $\beta=.08$, $p<.05$; domain-general task: $\beta=.07$, $p<.05$).

Still, there were some limitations regarding the domain-specific numerical habituation-dishabituation task. As the stimulus material was not randomized or varied during the presentation, the analyses cannot rule out the effects of confounding factors such as space, contour shape, or density. In addition, both habituation-dishabituation tasks differed in the duration of the habituation phase, which is why the measures from both tasks cannot be directly compared. Similarly, sequence effects cannot be ruled out because the numerical task was always administered after the domain-general task.

The conclusion was that the numerical habituation-dishabituation task tested early numeracy skills in toddlers (i.e., attention toward numerical changes), highlighting a certain degree of continuity in interindividual differences in domain-specific precursor skills of mathematical competence. Although the analysis had several shortcomings, the large and heterogeneous sample and the task administration in the household setting, increasing ecological validity, were central strengths. Finally, a recommendation for future research was given that possible associations between children's socioeconomic background and their developing numeracy skills should be studied more thoroughly.

5.5 Study 4: Visual habituation-dishabituation tasks in NEPS Starting Cohort 1: An approach to interpreting the data

The analyses of the previous empirical studies suggest that overall attention to the stimulus material (i.e., total fixation time) and not attention decrement (e.g., reaching the habituation criterion) or attention recovery is relevant as a measure to investigate predictive effects for later skills and competencies in the present data. Because only certain tasks and subgroups were analyzed, it could be that the results are biased or represent statistical artifacts. Thus, Study 4 investigated overarching and methodological aspects of the complete habituation-dishabituation data in NEPS SC1[5].

The study provides detailed descriptions of the stimulus material and testing procedure, as well as approaches to interpreting the looking time data. Thus, it was also conceptualized as a documentation of the tasks in the context of NEPS SC1. Previous to NEPS SC1, there had been few large-scale studies that conducted habituation-dishabituation tasks for assessing young children's cognitive abilities (Hachul et al., 2019). Generally, most parents consented in participating in the task (survey wave 1: 89.89%; survey wave 2: 98.28%), although it should be noted that due to child-related disturbances and technical errors, not all video recordings could be coded. Still, at least 70% of the data for each task were included in the (planned) public data release, which is in line with laboratories that typically also have a

[5] Seitz, M., Attig, M., Möwisch, D., & Weinert, S. (2023). *Visual habituation-dishabituation tasks in NEPS Starting Cohort 1: Approaches to interpreting the data (NEPS Survey Paper 102).* Leibniz Institute for Educational Trajectories. https://doi.org/10.5157/NEPS:SP102:2.0

substantial amount of dropouts (Slaughter & Suddendorf, 2007), indicating that the household setting did not systematically produce higher dropout rates.

A number of quantitative index measures of habituation (i.e., total fixation time during the habituation phase, reaching the habituation criterion, and habituation strength) and dishabituation (i.e., attention recovery) were analyzed. In contrast, qualitative measures of habituation and dishabituation (e.g., identifying looking time patterns with data reduction techniques) were only briefly touched on because such approaches are seldom used in the research (Kavšek, 2004a). A descriptive overview suggests that there was a large within-child variability and looking times at the stimulus material in all tasks were generally long, which corroborates the evidence from previous analyses of the data distribution. Most children did not reach the habituation criterion in the respective tasks (50% decrement) due to prolonged looking at the target (i.e., 51.71%-72.41%). In contrast to non-habituators, who were the majority in all tasks, habituators showed a typical pattern of looking time, with a monotonic decrease during the habituation phase and a substantial increase during the dishabituation phase (novelty effect). Still, intercorrelations of the measures revealed consistent small to medium-sized coefficients between the tasks, with total fixation time having the largest correlations and attention recovery having the lowest.

While prolonged looking at the target is generally interpreted as poor information processing skills (e.g., Colombo & Mitchell, 2009), Study 4 shows that prolonged looking at the target in the context of NEPS SC1 was the rule rather than the exception. This can either be attributed to the categorical stimulus material, which elicits higher visual attention due to its complexity (Hunter et al., 1983), or to the familiar household environment, which facilitates children's attention (Wass & Smith, 2014). However, run-up tests before NEPS SC1 did not find comparable looking patterns in experimental settings using similar stimulus material (e.g., Freund, 2012; Pahnke, 2007, Zhang, 2007), which highlights the latter argument. Research on administrating habituation-dishabituation tasks at home is scarce (primarily: Bornstein & Ludeman, 1989), especially in a large-scale setting (see Hachul et al., 2019). Children's immediate environments were shown to have a large influence on their regulatory capacity (Bridgett et al., 2015), which is why the measure total fixation time probably reflects aspects of sustained attention and/or self-regulation (see also Dixon & Smith, 2008). As both sustained attention and self-regulation are typically positively correlated with cognitive abilities and skills (Rueda & Conejero, 2020), Study 4 argues that the measure may be used for examining predictive effects of interindividual differences in cognitive abilities – as was shown in Study 2 and Study 3.

Finally, Study 4 discusses methodological shortcomings of the household setting, namely that trained interviewers had to administer the tasks with limited means of standardization. Thus, it was expected that certain conditions regarding the lighting, furnishing, and experimental setup vary between households. However, Study 4 also reports that child-related disturbances, which could be associated with such unstandardized conditions (Slaughter & Suddendorf, 2007; but see Bornstein & Ludeman, 1989), were generally rare in cases where video recordings could be made during task administration.

6. Discussion

The section provides an overview and discussion of the central findings of the present empirical studies (**6.1 Integration and critical discussion**). Important shortcomings are reported from a practical as well as from a theoretical standpoint (**6.2 Limitations**). Furthermore, recommendations for future research are given (**6.3 Recommendations for future research**). Finally, this section ends with a general statement about the scientific contributions of the studies (**6.4 Verdict**).

6.1 Integration and critical discussion

Overall, the present empirical studies aimed at addressing two gaps that were identified in the research on the cognitive development of young children. Regarding the first research gap, the potential effects of social disparity in measures drawn from habituation-dishabituation tasks were investigated. The findings indicate that while there were no effects of social disparity in measures of habituation and dishabituation at 7 months, there were positive correlations between total fixation time and children's socioeconomic background at 17 months. Thus, Study 1 provided empirical evidence for the first research question: Effects of social disparity in cognitive measures drawn from visual habituation-dishabituation tasks emerge during the second year of life. In addition, the results of Study 2 and Study 3 also tentatively support this finding.

However, the analyses also showed that only total fixation time during the habituation phase was correlated with components of parental SES, while there were no significant associations between attention recovery during the dishabituation phase and parental SES. In addition, theoretical assumptions and previous empirical findings suggest that the measure total fixation time and children's socioeconomic background should be negatively correlated with each other, whereas we found positive associations. Regarding these two counterintuitive findings, Study 2 and Study 4 proposed that attention recovery in the context of the habituation-dishabituation tasks in NEPS SC1 probably does not reflect early learning and that total fixation time could indicate aspects of sustained attention and self-regulation. Sustained attention refers to an extended period of selective engagement that typically enhances information processing regarding the target stimulus (Atkinson & Braddick, 2012; Reynolds, 2015), while self-regulation refers to how we mentally represent, monitor, and adapt our behavior (Reynolds, 2015). For cognitive processes involved in sustained attention and aspects of self-regulation, the emergence of effects of social disparity within the first years of life was shown (for a review, Rueda & Conejero, 2020). One practical implication of this result is that habituation-dishabituation tasks (or other fixation paradigms) administered in the second year of life might provide socioeconomically biased results, especially considering the selective samples of many experimental studies (Oakes, 2017).

The second research question was about the robustness of the predictive effects of measures drawn from habituation-dishabituation tasks on later skills and competencies. While Study 2 found no significant effect of attention recovery on productive vocabulary, Study 3 found a small, significant effect of attention recovery on mathematical competence (i.e., numeracy). However, both studies found – more or less consistent – positive effects of total fixation time on the respective outcome measure. Again, these findings highlight that the tasks in NEPS SC1 probably did not measure early learning but rather aspects of sustained attention or self-regulation. Still, the (unexpected) predictive effects of total fixation time were not impeded by children's socioeconomic background. While no mediation analyses were conducted, the results of Study 2 and Study 3 suggest that the effects of total fixation time on the respective outcome measure were robust when components of parental SES were controlled for. This highlights that while there were certain associations between children's socioeconomic background and their total fixation time in the tasks, at 17 months, this association was too small to impede the predictive effects – although more complex associations were not tested.

The second research gap addressed the relation of predictive effects of domain-general and domain-specific precursor abilities on later skills and competencies in the domains of language and mathematics. Thus, Study 2 and Study 3 investigated the third research question and generally found that the effects of the domain-specific tasks were robust when the respective measures from the domain-general task were controlled for. This stresses that, while effects were small and counterintuitive, the domain-specific tasks tapped into precursor abilities in the domains of language and mathematics that contributed to interindividual differences in later skills and competencies beyond the domain-general tasks. While the empirical analyses do not allow for a contribution to the ongoing discussion about underlying domain-general and domain-specific cognitive mechanisms, the findings still document a certain stability in these precursor abilities concerning knowledge acquisition and skill development in the respective cognitive domain.

Overall, there was a general lack of findings regarding the dishabituation measure attention recovery and intercorrelations of the measure in all tasks were largely not significant (see Study 4). Theoretically, attention recovery in the dishabituation phase after attention decrement in the habituation phase indicates that the child discriminated between the novel stimuli and the familiar stimuli (Mather, 2013). Thus, attention recovery reflects learning and should be correlated with later cognitive outcomes. However, it has been discussed that a lack of renewed attention does not automatically imply that the child failed to extract a category from the stimuli in the habituation phase (Kagan et al., 1979). In drawing on the Curvilinear

Discrepancy Hypothesis, the authors argue that attention recovery relates to the individual schema that is formed during the habituation phase, rather than the assumed discrepancy. Stimuli that are too easily assimilated in the schema might result in no change in looking behavior (Kagan et al., 1979). Thus, the categorical stimulus material in the dishabituation phases could have been too similar to the respective previous habituation phase, resulting in negative attention recovery (familiarity effect). Although the stimulus material in the dishabituation phase featured various visual elements that should have set it apart from the habituation phase (i.e., form and colors), 7-month-old infants typically categorize stimuli at the global rather than at the subordinate level (for a review, see Rakison & Yermolayeva, 2010).

Even though typical habituation patterns (i.e., monotonic decrease) have generally been the focus of infant habituation studies, other looking patterns have frequently been reported. McCall (1979), for example, used cluster analysis to find interindividual patterns of looking time; most 5-month-olds and 10-month-olds did not fit the typical pattern of monotonic decrease. He summarized that these looking time patterns "do not appear to reflect the rate of information processing, as has often been assumed" (McCall, 1979, p. 567). Similarly, Greenberg and colleagues (1973) describe that one in four 3-month-old infants showed a deviant and erratic profile of habituation. While such variability in looking patterns is often attributed to unsystematic and random measurement error (e.g., Byers-Heinlein et al., 2021; Fassbender, 2022; conversely: a complex stimulus-specific pattern between habituation and sensitization, see Peterzell, 1993), such cases mark a substantial amount of children in many studies. The present results consistently showed that longer fixation times during the habituation phase are generally positively associated with later cognitive outcomes and children’s socioeconomic background – while reaching the habituation criterion was not associated with higher cognitive abilities. Thus, the reported results are deviant in the sense that they show for a large sample that the concept of a monotonic decrease in habituation as an indicator of information processing might not be as simple as often assumed.

6.2 Limitations

When studying early cognitive abilities with habituation-dishabituation tasks, a frequent criticism is that observations of manifest child behavior are over-interpreted. Considering visual fixation tasks were conceptualized to investigate basic cognitive abilities, such as stimulus discrimination (Banks & Ginsburg, 1985), interpreting looking behavior as an indicator of complex cognitive skills should be done carefully. This is often referred to as Morgan's canon, namely that behavioral outcomes should not readily be interpreted as higher psychological functioning if lower psychological processes explain the phenomenon just as well (e.g., Morgan, 1892). Although not often explicitly stated in infant research, many authors apply this rationale when criticizing interpretations of findings from habituation-dishabituation tasks (e.g., Cohen, 2004; Haith, 1998; Tissaw, 2013; Woodfield, 1991). The principle is frequently used in comparative psychology and can be compared to the more abstract concept of Ockham's razor, as both favor parsimonious theoretical explanations of seemingly complex phenomena. Indeed, habituation-dishabituation tasks were adapted from experiments on cognitive functioning in chimpanzees (Fantz, 1958), which highlights the comparative nature of the technique. Still, the separation between higher and lower cognitive functions (or faculties) was never made clear and remains to this day subject to interpretation (Fitzpatrick, 2008). In addition, a plethora of empirical work suggests that measures drawn from looking times predict later cognitive functioning, highlighting continuities in certain domains.

Descriptive information on the children's looking times reveals that there is a large within-child variability, which is why the present results cannot be interpreted at the level of the individual (Bornstein et al., 1996; Gilmore et al., 2007). Looking time aggregates typically assume that all individuals within a group have similar behavioral responses to the stimulus material, which is why such measures might obscure interindividual variability or dismiss it as measurement error (Byers-Heinlein et al., 2021; Fassbender, 2022). Although modeling fixation time more elaborately than calculating index measures was introduced to infant research decades ago (e.g., Ashmead & Davis, 1996), comparable analyses are still rare. Studies using polynomial modeling usually analyze the intercept and slope of children's looking times separately, which allows for a more detailed analysis of the habituation and the dishabituation phase, namely probabilistic statements about children's attention levels instead of a binary approximation (Dahlin, 2004; Lavoie & Desrochers, 2002; Šimkovic & Träuble, 2021; Thomas & Gilmore, 2004; Young & Hunter, 2015). More specifically, recent studies criticize that common approaches to interpreting children's looking times assume additive variances of the individual and the population, which seems implausible given their distribution characteristics (i.e., positive and with a non-arbitrary baseline; Csibra et al., 2016; Šimkovic & Träuble, 2021). Although the models still need theoretically based assumptions about a typical habituation pattern, such approaches could be less error-prone than the classic habituation criterion (Dannemiller, 1984), which both overestimates and underestimates whether a child habituated (Fassbender, 2022). In addition, habituation criteria follow the assumption that the process of habituation is the same for all children, namely that their attention decrement is similar, which negates residual attention (Kucharský et al., 2022; Young & Hunter, 2015). Still, modeling techniques also cannot estimate fluctuating looking patterns, which older studies simply categorized as "deviant" (Greenberg et al., 1973) or "atypical" (McCall, 1979).

Newer techniques to collect looking time data have been employed, such as eye tracking (e.g., Hessels & Hooge, 2019). While traditional methods typically rely on manual coding procedures (as was done in NEPS SC1), in recent years eye tracking has made automated data collection possible, even in infants (Aslin & McMurray, 2004). Apart from advantages in practical aspects (e.g., interrater reliability), eye tracking is a more objective and precise technique (Gredebäck et al., 2009) – although it should be noted that in NEPS SC1, interrater reliability was high (see Study 4). In addition, the technique allows for a methodological replication and deeper understanding of existing findings in infant research (e.g., Slater et al., 2010 as a conceptual re-investigation of Wynn, 1992) as well as the advent of new measures that give additional insight into infant cognition (e.g., pupillometry; Kaldy & Blaser, 2020). In NEPS SC1, eye-tracking devices were not used as the potential for experimenter error was deemed too risky for the large-scale sample, especially considering device calibration, its applicability in large-scale household-based testing situations, and potential data loss (Hessels & Hooge, 2019; Wass, 2016). In addition, eye-tracking studies are plagued by a general lack of replications, as findings and interpretations rely on the technical aspects and performance of the set-up, namely the default algorithms and settings, which are often not reported (Holmqvist et al., 2022). Overall, using eye-tracking devices does not automatically solve typical problems of studies with manual coding procedures such as distractions, the influence of the parents, or infant-related attrition (e.g., fussiness, crying, or sleeping; Holmqvist et al., 2022). While the technique may help capture aspects of attention in more detail, it does not guarantee a deeper psychological understanding of more underlying processes (Bremner, 2011).

Summarizing potential solutions to underpowered studies in infant research, Byers-Heinlein and colleagues (2021) argue for stricter exclusion criteria (similarly, Oakes, 2010). More specifically, they state that excluding cases with low quality (e.g., child-related disturbances during the task; Slaughter & Suddendorf, 2007), should usually increase effect sizes and decrease the necessary sample size. Although this leads to an exclusion of a large part of the original sample, they conclude that a subsample with high data quality should increase reliability. However, they also note that strict exclusion criteria, especially concerning missing values, could lead to an inflated effect size. As infant research is typically plagued by selective and homogeneous samples (Fernald, 2010), and previous studies showed that sample attrition is associated with children's socioeconomic background (Bell et al., 2002; Oates, 1998), this suggestion can be criticized as producing socioeconomically biased results.

The reported findings are the results of secondary data analyses, which entail several advantages and disadvantages that need to be discussed. Secondary data involves all kinds of aggregated, mostly quantitative information that was not specifically collected for the present purpose and is used by researchers not involved in the original study conception and data collection (Greenhoot & Dowsett, 2012; Pienta et al., 2011). Using such existing data typically implies a trade-off between controlling conditions and quality of how the data is collected and increased accessibility, convenience, and economic efficiency (Vartanian, 2010), which is why mostly broad and global constructs are investigated in such large-scale studies (McCall & Appelbaum, 1991). A prominent criticism is that data availability constrains the research process to the degree where recursive and data-driven scientific reasoning is probable (Vartanian, 2010). In addition, a central concern is that large-scale studies assess many domains superficially and with shortened or simplified instruments and, thus, cannot provide in-depth information about most constructs (Greenhoot & Dowsett, 2012; Vartanian, 2010).

In developmental psychology, secondary data analysis was traditionally not popular, although the last decades have seen considerable change (Brooks-Gunn et al., 2000; Greenhoot & Dowsett, 2012; McCall & Appelbaum, 1991). There has been rising interest in secondary data analysis, driven by calls for more transparency and replicability in psychological research (Greenhoot & Dowsett, 2012) and maximizing the scientific output of already collected data (Pienta et al., 2011).

Drawing on secondary data from an existing large-scale study allowed the present studies to investigate a relatively heterogeneous sample of young children, which is not always given in infant research (Oakes, 2017). It should be noted that although NEPS SC1 was designed as a representative population of infants born in Germany in 2012, longitudinal attrition suggests a biased sample structure at later time points, especially concerning children's socioeconomic backgrounds (Zinn et al., 2020). Still, as the focus of the panel study was on global predictors of learning and early cognitive abilities (Hachul et al., 2019; Weinert et al., 2016) the sample size, long-term follow-up assessments, and availability of relevant correlates point to the fact that NEPS SC1 provides valuable insights into young children's cognitive abilities from a developmental standpoint.

Finally, methodological shortcomings of the present studies concern the implementation of the habituation-dishabituation tasks in NEPS SC1. First, it can be reasoned that the tasks, which were planned as habituation-dishabituation tasks, were poorly calibrated for the age range or the familiar household setting. The word-learning task, for example, was administered in older children than typically done (i.e., 14-month-olds; Werker & Yeung, 2005), while the categorical stimulus material in the domain-general task in survey wave 1 could have been too similar for category extraction at a subordinate level (Rakison & Yermolayeva, 2010). The generally long looking times at the habituation, dishabituation, and attention control phases suggest that most children were attentive throughout the tasks and, probably due to the categorical stimulus material, a large number of children did not reach a dichotomous state of habituation. More specifically, between 51.71% and 72.41% of all children did not habituate in the tasks (see Study 4). Thus, a criticism is that more habituation trials should have been needed, which has been discussed as a way to maximize habituators (Oakes, 2010) and increase reliability (DeBolt et al., 2020). However, comparable conclusions were not drawn from previous run-up tests (e.g., Freund, 2012; Pahnke, 2007; Zhang, 2007). Furthermore, sequence effects could have confounded the present findings, as the order of presented tasks was the same for all children. If the tasks measured aspects of sustained attention and self-regulation, this could explain why the predictive effects of the domain-specific tasks in Study 2 and Study 3 explained more variance than the domain-general task, which was always administered first.

6.3 Recommendations for future research

In their study on attention predictors of vocabulary, Colombo and colleagues (2009) note that "all short looking is not alike and that, depending on the underlying attentional mechanisms […], some short looking can also be related to less optimal outcomes" (p. 161). Similarly, in a longitudinal study on infant habituation predicting adolescent intellectual functioning, Sigman and colleagues (1997) conclude that the "fact that brief looking times were advantageous in early infancy to unchanging stimuli does not mean that brief fixations are advantageous at all ages and to all stimuli" (p. 139). The present findings show that – at least in a household setting and using categorical stimulus material – prolonged looking should not be prematurely discarded as an indicator of poor visual information processing. As previous research showed, the attentional focus might be an important mediator and key to understanding the latent cognitive processes behind looking behavior (Dixon & Smith, 2008).

In addition, rather than expecting unidimensional stability of attentional processes in infants or toddlers and later skills, assuming developmental cascades seems more reasonable. Similarly, the comparably low predictability of intellectual functioning from infant measures might be due to dynamic models linking cognitive processes with aspects of the environment (Van der Maas et al., 2006). This way, theoretical expectations of how such early attentional skills predict later competencies can be more parsimonious, meaning more open to intraindividual changes and the dynamic nature of developmental trajectories, as well as the possibility that early attention predictors might only reflect rudimentary abilities that have an indirect effect on later abilities (Bornstein et al., 2013).

Furthermore, the present studies suggest that habituation-dishabituation tasks should be studied more extensively in familiar settings. From a theoretical standpoint, it seems reasonable that attention allocation differs in naturalistic and standardized laboratory settings (Dunham, 1990). Thus, standardized laboratory settings deprived of distracting stimuli (i.e., stimuli not relevant to the present task) might result in infants focusing and maximizing their learning behavior regarding the stimulus material (Poll et al., 2020). This way, laboratory studies might systematically overestimate the predictive effects of early attentional measures on later cognitive outcomes (Oakes, 2017), although this concern was not addressed in a previous meta-analysis (Kavšek, 2004b). In addition, from a practical standpoint, conducting habituation-dishabituation tasks in children's homes has several advantages yet to be exploited in infant research. As data from NEPS SC1 show, the number of child-related distractions and dropouts due to sleepiness, restlessness, or fussiness was low, which may be a result of the children's reactivity to the stimulus material in the familiar environment (Kagan, 1997). In addition, task administration at home mitigates certain barriers associated with participation in experimental research (e.g., traveling costs and unfamiliar environment; see Sheskin et al., 2020).

Thus, the pattern of results from the present empirical studies suggests that habituation-dishabituation tasks administered in a household setting in a large-scale sample lend another perspective to findings acquired from small samples in highly controlled laboratory settings. Regarding a potential publication bias (Oakes, 2017), the present research highlights that more comparison studies should be conducted, focusing on how attentional processes and self-regulation are influenced by environmental features, ultimately resulting in different outcomes of looking behavior in visual habituation-dishabituation tasks. One example is virtual methods for gathering observations on infant looking that have gained momentum in recent years, either with a live experimenter (i.e., synchronous) or with an asynchronous video protocol (Smith-Flores et al., 2022). Still, because parameters such as participants' screen size, viewing distance and angle, lighting conditions as well as audio and video quality are even harder to control, high attrition rates were reported in previous studies (Scott & Schulz, 2017; Tran et al., 2017). Thus, although recent years have seen the emergence of these new methods and early studies point to comparable findings, they do not provide enough information about the household situation for a detailed investigation.

Finally, child temperament (e.g., effortful control and negative affect) should be investigated more thoroughly concerning potential associations with children's visual attention (Papageorgiou et al., 2015). This should be relevant to get a better understanding of looking behavior, as research in primates shows that personality traits are linked to habituation (Allan et al., 2020), highlighting that how the a priori assumed "neutral" stimulus is perceived may depend on personality traits. It was found, for example, that infants with an agitated temperament were less likely to complete a habituation task at 4 months (Bell et al., 1998; Bell et al., 2002); also, non-completion had considerable stability during the first year of life (Bell et al., 1994; in Oates, 1998). These findings originate from a large-scale setting, namely the ALSPAC study (Golding et al., 2001), and mixed results regarding sample attrition were obtained in a laboratory setting (Mink et al., 2013; Treiber, 1982; Wachs & Smitherman, 1985). In previous analyses of NEPS SC1, child temperament (i.e., negative affectivity) was positively associated with total looking time during the habituation phase at survey wave 1 (Weinert et al., 2017) but not at survey wave 2 (Attig & Weinert, 2018). Another methodological study compared children's cognitive abilities with aspects of their temperament and dropout in habituation tasks (Klein-Radukic & Zmyj, 2015). The authors found that while dropout was not associated with cognitive abilities, there were significant associations of negative affect (i.e., distress) with dropout (similarly Oates, 1998) – although the dropout did not affect the final sample structure. Theoretically, children's temperament could also help explain different reactions of children to disturbances in non-standardized settings such as children's homes. Overall, it is reasonable that certain aspects of infant temperament should be associated with how well the children handle the unfamiliar test environment, which might result in biased attrition or response patterns. Thus, future research should investigate the association of children's temperament, attrition, and habituation in depth.

One recent study investigated aspects of temperament and self-regulation by observing children's behavioral reactions aside from their looking at the stimulus material. In their exploratory study, Tomalski and Malinowska-Korczak (2020) examined the relation between not task-relevant behaviors (e.g., body movement, self-touching, and non-nutritive sucking) and children's looking time, among others, in a habituation task. The authors reported that while 5-6-month-old infants spend most of the time looking at the target, they also showed a high variability of body movement. The consistency of the results suggests that such not task-relevant behaviors may not be simple error terms but an active component of children's visual attention (Robertson et al., 2001). Specifically, the authors discuss displayed behaviors as mechanisms for reducing arousal or negative affect (i.e., self-distraction and self-comforting as early aspects of self-regulation; Ekas et al., 2013).

However, one central recommendation for future research remains that habituation and dishabituation should be investigated more from a theoretical approach. While there is a consensus on interindividual stability and continuity in cognitive abilities (Bornstein et al., 2006; Rose et al., 2012; Sigman et al., 1997; Slater, 1995), many researchers also argue that the processes of habituation and dishabituation are not sufficiently understood (Aslin & Fiser, 2005; Banks & Ginsburg, 1985; Colombo & Mitchell, 2009; Kucharský et al., 2022). It is reasoned that it is theoretically not clear what the measures drawn from such tasks indicate as they blend various aspects of visual attention, learning abilities, memory capacity, and behavioral self-regulation. This perspective often includes the realization that habituation patterns might not be the same for all children (Byers-Heinlein et al., 2021; Fassbender, 2022; Reinelt et al., 2022) and that socioeconomic background may have a considerable impact on how children develop early cognitive abilities (Noble et al., 2015). This is mainly because, from a theoretical perspective, the Stimulus-Model Comparator Theory is used as a general framework (Kavšek, 2013; Sicard-Cras et al., 2022), although empirical evidence highlights several shortcomings of the model in explaining the reaction phenomena in connection to basic cognitive abilities (Colombo et al., 2010).

6.4 Verdict

The present empirical studies used data from a large-scale panel study to investigate research questions regarding the potential effects of social disparity in measures drawn from habituation-dishabituation tasks as well as regarding the relation between domain-general and domain-specific precursor abilities of later skills and competencies. A central strength of the studies was the large and heterogeneous sample that allowed for uncovering that children's socioeconomic background has a substantial effect on children's looking behavior in such tasks. While findings on the predictive validity of the domain-general and domain-specific tasks were partly counterintuitive, the results suggest that habituation patterns might not be the same for all children (Byers-Heinlein et al., 2021; Fassbender, 2022; Reinelt et al., 2022) and that socioeconomic background may have a considerable impact on how children develop early cognitive abilities (Noble et al., 2015). Thus, the large-scale data contributes to the present research in a way that raises fundamental questions regarding the social selectivity and generalizability of findings of small-scale laboratory experiments as well as regarding children's prolonged looking at sequentially presented stimuli, which might reflect aspects of sustained attention and self-regulation. Thus, large-scale studies such as NEPS SC1 (Blossfeld & Roßbach, 2019) or ALSPAC (Golding et al., 2001) and laboratory collaborations (ManyBabies; Frank et al., 2017), should provide exciting possibilities for future research opportunities in infant studies. Such collaborative projects try to strengthen efforts to share data, create large samples, and promote reproducibility with open science practices as well as highlighting diversity in samples and scientists (Frank et al., 2017), which should inform our understanding of children's cognitive development on a practical as well as on a theoretical level.

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Appendix A: Study 1[6]

Social disparities in cognitive development: Evidence from habituation-dishabituation tasks

Maximilian Seitz[1], Dave Möwisch[1], Markus Vogelbacher[1], Manja Attig[1], and Sabine Weinert[2]

[1]Leibniz Institute for Educational Trajectories, Bamberg, Germany

[2]Department of Developmental Psychology, University of Bamberg, Bamberg, Germany

Corresponding author:

Maximilian Seitz

maximilian.seitz@lifbi.de

Leibniz Institute for Educational Trajectories

Wilhelmsplatz 3, 96047 Bamberg

Germany

Data availability statement:

This paper uses data from the National Educational Panel Study (NEPS): Starting Cohort Newborns, doi:10.5157/NEPS:SC1:8.0.0. From 2008 to 2013, NEPS data was collected as part of the Framework Program for the Promotion of Empirical Educational Research funded by the German Federal Ministry of Education and Research (BMBF). As of 2014, NEPS has been carried out by the Leibniz Institute for Educational Trajectories (LIfBi, Bamberg) in cooperation with a nationwide network. Data of the language-specific habituation-dishabituation task was also collected by the NEPS but processed under a different grant by the project ViVA and will be added in future scientific use files. The data is available on reasonable request to the authors.

[6] A revised version of this study will be submitted for future publication.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Author Contributions

Maximilian Seitz: Conceptualization, Data curation, Methodology, Writing – Original draft preparation. **Dave Möwisch:** Conceptualization, Writing – Review & Editing. **Markus Vogelbacher:** Conceptualization, Writing – Review & Editing. **Manja Attig:** Conceptualization, Writing – Review & Editing. **Sabine Weinert:** Funding acquisition, Conceptualization, Writing – Review & Editing, Supervision. All authors approved the final version of the manuscript for submission.

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Abstract

Several studies on young children's cognitive development reported considerable effects of social disparity, namely how parental socioeconomic status is associated with children's early cognitive abilities. A consensus is that parental socioeconomic status has an indirect effect on children's cognitive development, mediated through parent-child interactions. However, few studies used habituation-dishabituation tasks although such tasks indicate basic cognitive abilities more validly than developmental tests. The aim of the present study was to investigate how aspects of parental socioeconomic status are associated with measures of a habituation-dishabituation task administered at 7 months and at 17 months. Using a large-scale data set, we found no effect of social disparity at 7 months. Although we found an affect at 17 months, it was not mediated by the quality or quantity of parent-child interactions. The results are discussed with regard to the specificities of the data, as the habituation-dishabituation tasks were administered in a household setting.

Keywords: Cognitive development, infant habituation, social disparities

Social disparities in cognitive development: Evidence from habituation-dishabituation tasks

The last decades have accumulated a large body of research on social disparities in the cognitive development of young children (e.g., Halle et al., 2009; Rubin & Balow, 1979). Social disparities (or inequalities) refer to the phenomenon that interindividual differences in how children develop are significantly associated with aspects of the children's social background (Elenbaas et al., 2020). From a theoretical standpoint as well as from a practical, policy-making standpoint, researchers are interested in when such disparities emerge and in what way the children's socioeconomic background influences their cognitive development. Empirical evidence and findings from neuroscientific studies suggest that children's socioeconomic background has profound and possibly cumulative effects on functional brain development in the first years of life (Hurt & Betancourt, 2016; Tomalski et al., 2013). Among other, such social disparities emerge due to differences parent-child interactions (e.g., Bornstein & Bradley, 2010; Conger & Donnellan, 2007). However, while most studies assessed children's cognitive development with standardized developmental tests, habituation-dishabituation tasks have seldom been used. This is why the current study investigated the emergence of social disparities in early cognitive abilities as measured by habituation-dishabituation tasks using a large-scale data set. Moreover, we also examined the relationship between potential effects of social disparity and quantitative and qualitative aspects of parent-child interactions.

Emerging social disparities in cognitive development

For decades, studies have demonstrated effects of young children's socioeconomic background on their development. Children's socioeconomic background is indicated by the socioeconomic status (SES) of their parents, which refers to their position within a societal hierarchy. SES is associated with access to wealth, social recognition, and other symbolic or materialistic privileges (McLoyd, 1998). People's relative position with regard to these status values can be categorized and compared to each other. In young childhood research, many authors argue that central components of parental SES (i.e., parental occupation, parental education, and household income) are associated with interindividual differences in living conditions (Bornstein & Bradley, 2010; Duncan & Magnuson, 2012). It is held that children from low SES households are more at risk to be impoverished of social and cognitive stimulation (Burger, 2010) and to develop cognitive abilities slower (Noble et al., 2007), resulting in SES-related differences in early academic achievement (García, 2015). Although parental occupation, parental education, and household income are highly correlated with each other, each component is associated with different aspects of family processes (Duncan & Magnuson, 2012), which is why composite factors are not adequate for a detailed analysis of social effects on child development (Conger & Donnellan, 2007).

Regarding the emergence of socioeconomic disparities in early cognitive development, usually the second year of life is identified at the latest (e.g., Hillemeier et al., 2009), either with behavioral or neurophysiological paradigms (Hurt & Betancourt, 2016). Regarding the former, Halle and colleagues (2009) found income-related disparities in early cognitive skills using the Bayley Scales of Infant Development (Bayley, 1993; see also Hurt & Betancourt, 2016) at 24 months. Regarding the latter, many studies identified the first two years of life as central for emerging associations between SES and information processing (Waber et al., 1984), recognition memory (Hackman & Farah, 2009), declarative memory (Noble et al., 2015), and visual attention (Clearfield & Jedd, 2013), which are basic processes of cognitive functioning (Rose et al., 2004).

Social disparities in habituation and dishabituation

Few studies on social disparities in young children's cognitive abilities have used habituation-dishabituation tasks, which have been shown to be more predictive of later intellectual functioning than developmental tests or parental reports on children's cognitive abilities in the first two years of life (Kavšek, 2004; McCall, 1994). In such tasks, a sequence of either identical or similar stimuli is presented to infants or toddlers. This marks the habituation phase, which is usually followed by a dishabituation phase with a novel stimulus that is presented either concurrently with the familiar stimulus or on its own (Aslin, 2007). In tasks with visual stimuli, children's looking behavior (e.g., fixation times on target) is recorded and analyzed. Attention decrement (familiarity) in the habituation phase and attention recovery in the dishabituation phase (novelty) are generally thought to reflect mental processes such as visual information processing, stimulus encoding, and recognition memory (Colombo & Mitchell, 2009). These basic mental processes reflect early learning and predict later intellectual functioning better than developmental tests that often focus on sensorimotor milestones (McCall, 1994).

Regarding habituation, early studies found that infants in the first year of life from high SES families, operationalized as paternal education and occupation, showed faster information processing (Lewis et al., 1969; McCall, 1972), namely a higher decrement in looking times during the habituation phase. However, in a later review on the predictability of intelligence, McCall and Carriger (1993) found no relation of any habituation measure and SES in samples aged between 2-8 months. Still, most studies only included SES as a control variable and provided little further information, hampering a detailed analysis of SES-related effects. Similarly, Bornstein and Tamis-LeMonda (1994) only parenthetically report that characteristics of the mother (e.g., education and SES) were not related to information processing in 5-month-old infants. One study investigating SES-related effects on infant information processing relatively thoroughly found no effects of maternal education on a number of habituation measures indicating information processing (e.g., total fixation time) in 3 month-old infants (Mayes & Bornstein, 1995).

Regarding dishabituation, several studies found no SES-related effects for novelty reaction in 3-month-old infants (Mayes & Bornstein, 1995), 5-month-old infants (Bornstein & Tamis-LeMonda, 1994; Fagan & Singer, 1983), and 8-month-old infants (McCall & Carriger, 1993). The earliest reported effect of social disparity was in 12-month-old children (Rose et al., 1978). Similarly, Smith and colleagues (2002) found that, while parental education was not associated with novelty reaction at 7 months, there was a small, positive correlation at 13 months ($r=.20$, $p>.05$). The authors interpreted the finding as a cumulative influence of socioeconomic aspects on children’s cognitive development, indicating the emergence of social disparities in cognitive development in the second year of life. However, as the authors did not control for children’s cognitive abilities at 7 months (i.e., the earlier time point as a baseline), the study did not properly address the variance unique to the later time point. In addition, although the sample was carefully selected regarding the children’s socioeconomic background, the study focused on children born preterm, which is why the effects are not generalizable (Kavšek & Bornstein, 2010).

Thus, it could be argued that due to a cumulative influence of the children’s environment on their cognitive development, (I) there are no significant social disparities in cognitive development in the first year of life and that they emerge later on, or (II) that habituation-dishabituation tasks cannot reliably detect them. Regarding the first argument, empirical findings from other behavioral paradigms suggest social disparities in early cognitive abilities in the first year of life (Clearfield & Jedd, 2013; Halle et al., 2009). Regarding the second argument, previous studies might lack the statistical power to detect differential effects. As usual in infant research, most studies are conducted with small samples in highly standardized laboratory settings. Consequently, many studies using habituation-dishabituation tasks to investigate early cognitive abilities might lack heterogeneity (Oakes, 2017), especially if the children's socioeconomic background is not the main research interest.

Although large-scale studies should remedy the problem, few included habituation-dishabituation tasks. While Bell and colleagues (Bell & Slater, 2002; Bell et al., 1998) found that non-completion of the habituation task of the Avon Longitudinal Study of Parents and Children study (Golding et al., 2001) was associated with lower levels of maternal education, the children's performance in the task was not further investigated with regard to their socioeconomic background. By analyzing another large-scale study, namely the Newborn Cohort of the German National Educational Panel Study (NEPS SC1; Blossfeld & Roßbach, 2019), Weinert and colleagues (2017) drew on the same data set as the present study. Habituation strength (Laucht et al., 1994) and total fixation time (Colombo et al., 1987) were included as indicators of information processing. The authors found no significant effects of maternal education and household income on these measures in 7-month-old infants. Similar results were reported when the children were 17 months old (Attig & Weinert 2018). These analyses indicate that in NEPS SC1, which was conceptualized as a representative sample of the German population (Weinert et al., 2016), there are no SES-related differences in cognitive abilities in the first two years of life. However, we argue that a closer look at the data is warranted: Both analyses only focused on children's habituation and neither used the full NEPS SC1 sample but excluded children from non-German speaking households, which might result in the findings not being generalizable.

The interplay of socioeconomic background and parent-child interactions

The notion of a cumulative influence of children's socioeconomic background on their cognitive development highlights the importance of early family processes. As a theoretical framework, the bioecological model of human development (e.g., Bronfenbrenner & Ceci, 1994) hypothesizes that parenting behavior is a central influential factor for early child development. This is because parents organize young children's immediate environment on a regular basis over an extended period, especially in the formative years (Bronfenbrenner & Morris, 1998). Thus, associations between children's early cognitive abilities and components of their socioeconomic background are usually attributed to interindividual differences in such family-related processes (Bornstein & Bradley, 2010).

These family-related processes typically comprise, among others, the quantity and quality of parent-child interactions – both aspects, when detrimental, are regarded as risk factors for child development (Bradley & Corwyn, 2002; Conger & Donnellan, 2007). The quantity of parent-child interactions is indicated by the overall frequency of joint activities that foster early learning. Joint activities are a range of play activities where parents and children are engaged in the same task (Chandani et al., 1999). Activities relevant for child development in the first year of life typically involve, among others, physical play (e.g., cuddling or romping), playing with objects (e.g., building blocks or dolls), and early literacy-related activities (e.g., joint picture book reading or singing songs) in dyadic (i.e., parent-child) or triadic (i.e., parent-child-object) situations (e.g., Bornstein & Tamis-LeMonda, 2001; Gutman & Feinstein, 2010). The frequency and starting point of activities such as joint picture book reading (Fletcher & Reese, 2005) or playing with building blocks (Christakis et al., 2007) were shown to be indicators of stimulating parenting behavior.

Complementary to quantitative aspects of parent-child interactions, quality is a necessary facet. Central dimensions of parent-child interaction quality are emotional support and cognitive stimulation in parent-child interactions (Rodriguez et al., 2009; Smith, 2011), that have been argued to be relevant for children's cognitive development (e.g., Farah et al., 2008). Emotional supportive parenting behavior is associated with warm and contingent behavior of parents when engaged in interactional settings with their children (e.g., Hubbs-Tait et al., 2002). While cognitive stimulation focuses on parents' intentional teaching through verbal stimulation, emotional support is less parent-directed and highlights the active role of the children in parent-child interactions (Martin et al., 2007) and the way in which parents respond to their children with affective cues (Shin et al., 2008). Stimulating parenting behavior relates to how parents shape an engaging environment for their children in reciprocal interactions beyond the current developmental level of the child (Lugo-Gil & Tamis-LeMonda, 2008) and it is conceptually related to scaffolding (Foley, 1994).

Central components of SES (i.e., parental occupation, parental education, and household income) are related to interindividual differences in how parents interact with their children. Parental occupation is associated with creating learning opportunities in parent-child interactions (Bornstein et al., 2010) because occupational complexity and job autonomy have a positive effect on responsive and stimulating parenting behavior, even when controlled for income (Whitbeck et al., 1997). Likewise, parental education was shown to be associated with supportive and sensitive behavior (Tamis-LeMonda et al., 2004) because higher educated parents acquire more knowledge about child development (Bornstein & Bradley, 2010). Thus, higher educated parents typically spend more time promoting their children's development (Guryan et al., 2008; Kalil, 2014) and engage in more stimulating activities with their children (e.g., Harding et al., 2015). Finally, because household income is related to material resources for providing a stimulating learning environment (Bradley & Corwyn, 2002), low income is negatively related to emotional support and cognitive stimulation in interactional settings (e.g., Portnow & Hussain, 2016).

The current study

Overall, the current state of research on social disparities in young children's cognitive development using habituation-dishabituation tasks is limited and has several shortcomings. To the knowledge of the authors, few studies provide a thorough examination and comparison of SES-related differences in habituation and dishabituation measures. This might be because the few studies that specifically addressed this topic had small sample sizes with children from potentially homogeneous social backgrounds. Thus, the present study used large-scale data of a representatively drawn German newborn cohort to investigate effects of different components of SES on children's performance in a habituation-dishabituation task administered at 7 months and at 17 months. Overall, we were interested in when social disparities in indicators of early cognitive abilities emerge and whether such disparities might be explained by the quantity and quality of parent-child interactions.

We had several expectations regarding SES-related differences in habituation and dishabituation measures. At 7 months, we did not expect an effect of social disparity. Thus, the results should generally replicate previous analyses (Weinert et al., 2017). However, at 17 months, we expected social disparities to have emerged. More specifically, we expected an SES-related gap for measures of habituation (i.e., total fixation time) and dishabituation (i.e., attention recovery), although effects should be small (Smith et al., 2002). We were interested in the empirical effects of different SES components because the actual mechanisms of how individual SES components contribute to child development are yet to be theoretically explored. Lastly, we hypothesized that the quantity (i.e., joint activities) and quality (i.e., emotional support and cognitive stimulation) of parent-child interactions mediates SES-related effects, controlling for children's gender, age, and cognitive abilities at 7 months. The latter control variable was included to address the development of cognition from the first to the second year of life.

Method

Sample

The study used data collected in NEPS SC1 (Blossfeld & Roßbach, 2019)[7]. NEPS SC1 (NEPS Network, 2021) started with a sample of N=3481 participants (i.e., newborn children as target persons) at the first measurement point (Wave 1; children on average 7 months old). Of the N=3481 initial cases, N=3129 respondents gave informed consent to the habituation-dishabituation tasks, while N=2945 children finished the task. Video recordings with reported technical errors, multiple or severe child-related disturbances, or parental interferences were dropped (N=462). All children born before 37 weeks of gestation were defined as having premature birth status (Kavšek & Bornstein, 2010) and were dropped from the analyses (N=196). Thus, in the final sample at Wave 1 are N=2287 children (51.35% male). At the second measurement point (Wave 2; children on average 17 months old), only half of the sample respondents (N=1510) were by design asked to participate. N=1484 gave informed consent to the habituation-dishabituation tasks, while N=1315 children finished the task. Video recordings with reported technical errors, multiple or severe child-related disturbances, or parental interferences were dropped (N=96). Preterm children were not excluded from the analysis of Wave 2 as looking time patterns in the second year of life are comparable to term

[7] Parts of the collected data were processed under a different grant: "Video-based Validity Analyses of Measures of Early Childhood Competencies and Home Learning Environment" (ViVA project) – project funded by the German Research Foundation (DFG; grant to S. Weinert) within the priority program 1646. We thank Jan-David Freund for his contribution to the project and the coding.

children (Kavšek & Bornstein, 2010). Overall, in the final sample at Wave 2 are N=1219 children (50.08% male).

Assessment of early cognitive abilities: Habituation-dishabituation task

NEPS SC1 used, among others, a habituation-dishabituation task with categorical stimulus material at the first two waves. Both at 7 months and at 17 months, the task featured the same stimulus material and only details of the task administration differed. The categorical stimulus material was deemed useful for facilitating children's visual attention in both age groups (Fennell, 2012). A fixed-trial procedure was used and the sequence of stimulus pictures was the same for all children. This approach was chosen to ensure standardization in the large-scale sample (Weinert et al., 2016). The task featured one cartoon bug[8] per trial, accompanied by a short three-note jingle each time a new trial was shown (Supplement A). In the nine trials of the habituation phase, all bugs were circular and symmetrical. In the two trials of the dishabituation phase, one rectangular and asymmetrical bug was presented per trial without a distractor of the familiarized category. A subsequent attention control phase featured two identical pictures of a pineapple to check for the children's general attentiveness. After an initial check for unexpected decrements in looking times from the dishabituation to the attention control phase, possibly indicating that the children fell asleep or were distracted, these trials were not further considered in the present study. Each trial was shown for 10 seconds, the only exception were the trials of the dishabituation and attention control phase at Wave 1, which were shown for 15 seconds each. However, these values were recoded to 10 seconds in the public data release. Consequently, presentation time was 177 seconds at Wave 1 and 157 seconds at Wave 2. Finally, there were other habituation-dishabituation tasks

[8] The stimulus material was tested in previous studies at the chair of developmental psychology at the University of Bamberg, Germany (Zhang, 2007).

administered at both waves, which were not considered in the present study because they featured different stimulus material.

Trained interviewers administered the tasks in the children's homes (Weinert et al., 2017). The children's looking times were recorded and coding was done offline and event based, which means that for every single frame the coders had to rate the children's looking behavior as either on or off target (30 frames per second) using the software Mangold INTERACT. Interrater reliability was tested on a randomized subsample of 10% of all videos (κ=.92 for both tasks). The present study uses the accumulated fixation times for each trial, which could range from 0-10 seconds. Looking times were not truncated, so there was no cut-off criterion for short looking time events (Colombo & Mitchell, 1990).

Indicators of habituation and dishabituation

We used the accumulated looking time on target during the habituation phase (e.g., Bornstein & Tamis-LeMonda, 1994) as an indicator of visual information processing (i.e., total fixation time). As looking time decrement is considered a positive indicator of information processing (Colombo & Mitchell, 2009), longer looking times should be associated with poorer cognitive abilities. However, because the categorical stimulus material was deemed relatively complex, we expected that overall looking times should be comparably high (Fennell, 2012; Slater et al., 1984). Due to the data distribution, we did not choose the measure "habituation strength" (Attig & Weinert, 2018; Supplement C). For interpreting dishabituation task performance, we defined attention recovery (Kavšek & Bornstein, 2010; Rose et al., 2004) as a difference measure between the first dishabituation and the last habituation trial (Oakes, 2010).

Children's socioeconomic background and control variables

Regarding children's socioeconomic background, we investigated highest parental occupation, maternal education, and household income. As an indicator of parental occupation, we used the highest International Socio-Economic Index of Occupational Status (HISEI) in the household. The measure considers the required education level for and the mean income of a specific occupation to create a continuous classification scheme and is a standard index for social stratification (Ganzeboom et al., 1992). For maternal education, we chose overall years of formal education, as it is more comparable than qualifications, which can be specific to certain countries/regions of origin, and we treated the variable continuously. Finally, for household income, we used the standard OECD approach of calculating a household-size adjusted score that weighs people below and above the age of 14 differentially (i.e., equivalized household income). For all analyses, we used data of Wave 1 for these variables. As further control variables, we included children's gender and age. For children's gender, we used a dichotomous indicator of the children's biological sex, as reported by the parents.

Quantitative and qualitative aspects of parent-child interaction

As indicators of parental behavior, the present study used quantitative and qualitative aspects of parent-child interactions – compare Linberg and colleagues (2020) for a similar approach. Regarding quantitative aspects, we used information on joint activities related to the developmental stage of the child (e.g., looking at picture books, singing songs, or playing with building blocks; Supplement D). Overall, the items refer to a global measure of accumulated parent-child interactions and are comparable to established instruments (e.g., Chandani et al., 1999). We used a sum score for overall joint activities, as the assessment in

NEPS SC1 focused on a global measure of a broad range of activities; therefore, specific factors that might be differentially associated with components of SES could not be investigated.

In addition, we chose a qualitative indicator of parent-child interaction, which was assessed in a semi-standardized interactional play setting between the parent and the child. As early waves in NEPS SC1 included, among others, questions about the pregnancy, the mother was typically the respondent, which is why in most cases the mother also participated in the interactional play situation. The interactional play situation was observed in the children's homes during a 5-minute period in which the parent had to play with his or her child with standardized set of toys. NEPS SC1 assessed the quality of parental interaction behavior with an instrument adapted from the NICHD-SECCYD study (e.g., NICHD Early Child Care Research Network, 1999; see Sommer et al., 2016). Trained raters coded the video recordings of the play situation dichotomously for each fixed-time interval (i.e., 30 10-second intervals) of the total playtime (5 minutes). Inter-rater agreement was checked with a randomized subsample of about 12% and was deemed acceptable (on average 83%) (Linberg et al., in press). For the present analysis, we used aspects of emotional support and cognitive stimulation of the macro-analytic and micro-analytic rating instruments at Wave 1 (Linberg, 2018)[2] to define a latent factor. The macro-analytic instrument rated the overall quality of the displayed interaction on qualitatively defined 5-point Likert scales (i.e., cognitive-verbal stimulation, positive regard, and emotional support). In contrast, the micro-analytic instrument indicates the percentage of how often the respective type of behavior was shown in all intervals (i.e., cognitive-verbal stimulation) (Linberg et al., in press).

Missing values

There was a certain amount of missing values for most variables (Table 1). Missing values were generally low with the exception of parent-child interaction quality. Here, missing cases were due to child-related reasons (e.g., discomfort or sleepiness) or because the video recording of the play setting failed to meet the quality criteria (e.g., certain interactions were not visible) (Linberg et al., 2019). All four items had the same amount of missing values; thus, collapsed results are reported. In contrast, there were no missing cases for the items on children's gender. Full Information Maximum Likelihood (FIML) was used to estimate missing values as the method was shown to produce comparable results to multiple imputation (Lee & Shin, 2021).

Table 1

Missing Values of Independent and Control Variables

Variable	Missing values
HISEI	11.98%
Maternal education	0.98%
Equivalized household income	1.80%
Parent-child interaction quantity	0.04%
Parent-child interaction quality	26.65%
Children's age (Wave 2)	0.82%

Note. Reported for the final sample at Wave 2; all variables refer to Wave 1, except for children's age.

Data analysis

First, Pearson correlation was used to find associations between the habituation (i.e., total fixation time) and dishabituation measures (i.e., attention recovery) and each component of the children's socioeconomic background. Next, we used path analysis for investigating direct and indirect relationships among the individual components of the children's socioeconomic background (i.e., HISEI, maternal education, and household income), quantitative and qualitative aspects of parent-child interactions, and total fixation time and attention recovery, respectively. As we expected parent-child interactions to have a prospective influence on child development, we only calculated path analysis for Wave 2. In the analyses, we additionally included Wave 1 indicators (i.e., a baseline of the children's cognitive abilities) to address the development from Wave 1 to Wave 2 and to account for potential adaptive effects of parental behavior in Wave 1 to children's developmental status. Thus, the models test the mediation (MacKinnon et al., 2012; Preacher & Hayes, 2008) of SES-related effects via quantitative and qualitative aspects of parent-child interaction in 17-month-old toddlers. In addition, we controlled for children's gender and age.

Results

First, we examined the measures drawn from the habituation-dishabituation tasks at both 7 months and 17 months; a descriptive overview of the children's looking times can be found in Supplement B. Table 2 reports descriptive information on total fixation time and attention recovery as indicators of the children's cognitive abilities at both waves. As total fixation time and attention recovery were on a different scale (i.e., aggregated looking times vs. looking time differences), we standardized them in further analyses. Children showed higher total fixation times at Wave 2 ($M=69.79$, $SD=12.70$) than at Wave 1 ($M=60.67$, $SD=16.26$; $t(986)=-14.58$, $p<.01$). Likewise, children showed higher attention recovery at Wave 2 ($M=0.09$, $SD=2.41$) than at Wave 1 ($M=-0.40$, $SD=2.64$; $t(986)=-4.35$, $p<.01$). Total fixation time and attention recovery were only positively correlated at Wave 1 (Supplement B).

Table 2

Descriptive Information on the Dependent Measures

		Mean	SD	Min	Max
Wave 1	Habituation: Total fixation time	60.19	16.67	3.40	90.27
	Dishabituation: Attention recovery	-0.38	2.59	-10.03	10.03
Wave 2	Habituation: Total fixation time	69.54	12.87	12.60	90.27
	Dishabituation: Attention recovery	0.06	2.51	-8.57	9.93

Note. N=2287 at Wave 1 and N=1219 at Wave 2.

Table 3 reports descriptive information on the SES components (i.e., HISEI, maternal education, and household income), parent-child interaction quality, as well as children' age, which was used as a control variable. For parent-child interaction quality, descriptive statistics of all items are reported. These items were used to calculate a latent factor in later analyses. As there were outliers for equivalized household income, we log-transformed the variable in further analyses. An overview of all items that comprised parent-child interaction quantity can be found in Supplement D.

Table 3

Descriptive Information on the Independent and Control Variables

	Mean	SD	Min	Max
HISEI	62.11	20.25	11.74	88.96
Maternal education	14.53	2.65	9	18
Equivalized household income	1620.02	891.68	95.24	15555.56
Parent-child interaction quantity	36.25	3.74	20	45
Parent-child interaction quality: Cognitive stimulation (macro coding)	2.72	0.93	1	5

Parent-child interaction quality: Positive regard (macro coding)	3.23	0.93	1	5
Parent-child interaction quality: Emotional support (macro coding)	2.66	1.07	1	5
Parent-child interaction quality: Cognitive stimulation (micro coding)	39.97	22.90	0	96.67
Children's age (months)	17.05	0.61	15.77	20.36

Note. Children's age refers to Wave 2.

Table 4 reports data of correlative associations between each component of SES (i.e., HISEI, maternal education, and equivalized household income), the quantity and quality of parent-child interactions, and cognitive measures for both waves. At Wave 1, total fixation time and attention recovery were not significantly correlated with any component of SES. Likewise, the measures were not significantly correlated with the quantity and quality of parent-child interactions. At Wave 2, total fixation time but not attention recovery was positively correlated with all components of SES as well as with parent-child interaction quantity. Regarding the relation between components of SES and the quantity and quality of parent-child interactions, all correlations were significant and positive, ranging from low to medium. Finally, there were no significant correlations between the control variables (i.e., children's gender and age) and total fixation time and attention recovery (not reported).

Table 4

Correlations of SES and Parent-child Interaction with Early Cognitive Measures

	1. Habituation: Total fixation time (Wave 1)	2	3	4	5	6	7	8	9	10	11
2. Habituation: Total fixation time (Wave 2)	.08*										
3. Dishabituation: Attention recovery (Wave 1)	-.13**	-.05									
4. Dishabituation: Attention recovery (Wave 2)	.04	.04	.03								
5. HISEI	.02	.13**	-.01	-.01							
6. Maternal education	.01	.08**	.01	.01	.65**						
7. Equivalized household income	.00	.07*	.01	.00	.55**	.50**					
8. Parent-child interaction quantity	.02	.08**	-.02	-.05	.15**	.12**	.14**				
9. Parent-child interaction quality: Cognitive stimulation (macro coding)	-.01	.02	-.01	-.06	.08**	.09**	.15**	.14**			

10. Parent-child interaction quality: Positive regard (macro coding)	.00	.00	.05	-.01	.15**	.14**	.15**	.07**	.53**		
11. Parent-child interaction quality: Emotional support (macro coding)	.00	.03	-.01	-.01	.15**	.14**	.17**	.08**	.64**	.71**	
12. Parent-child interaction quality: Cognitive stimulation (micro coding)	.02	.01	.00	-.06	.17**	.20**	.21**	.10**	.60**	.51**	.63**

Note. Pearson correlation coefficients reported; *p<.05, **p<.01.

Next, we used path analysis for examining the relation between components of SES, the quantity and quality of parent-child interactions, and the cognitive measures more thoroughly. Thus, although there was a general lack of significant correlations among many of these variables, we effectively calculated mediation models. The first model predicted children's total fixation time at 17 months with parent-child interaction mediating effects of SES components (Figure 1). We defined a latent factor for parent-child interaction quality using cognitive stimulation (macro and micro coding), positive regard, and emotional support. HISEI had a positive effect on parent-child interaction quantity, while household income had a positive effect on both the quantity and quality of parent-child interactions. However, maternal education did not reach significance. Controlling for children's gender and age, and total fixation time at Wave 1, HISEI and parent-child interaction quantity had a significant positive effect on total fixation time at Wave 2. Indirect effects of SES components via the quantity and quality of parent-child interactions were not significant, which means that the effect of HISEI on total fixation time was not mediated (Table 5). Overall, explained variance of total fixation time in the mediation model was low (R^2=.09). A robustness check without total fixation time at 7 months as a control variable revealed no differences in the direction or significance of the effects.

Figure 1

Model A: Mediation model of the pathways from SES to total fixation time at Wave 2 via parent-child interaction; standardized coefficients reported (direct effects).

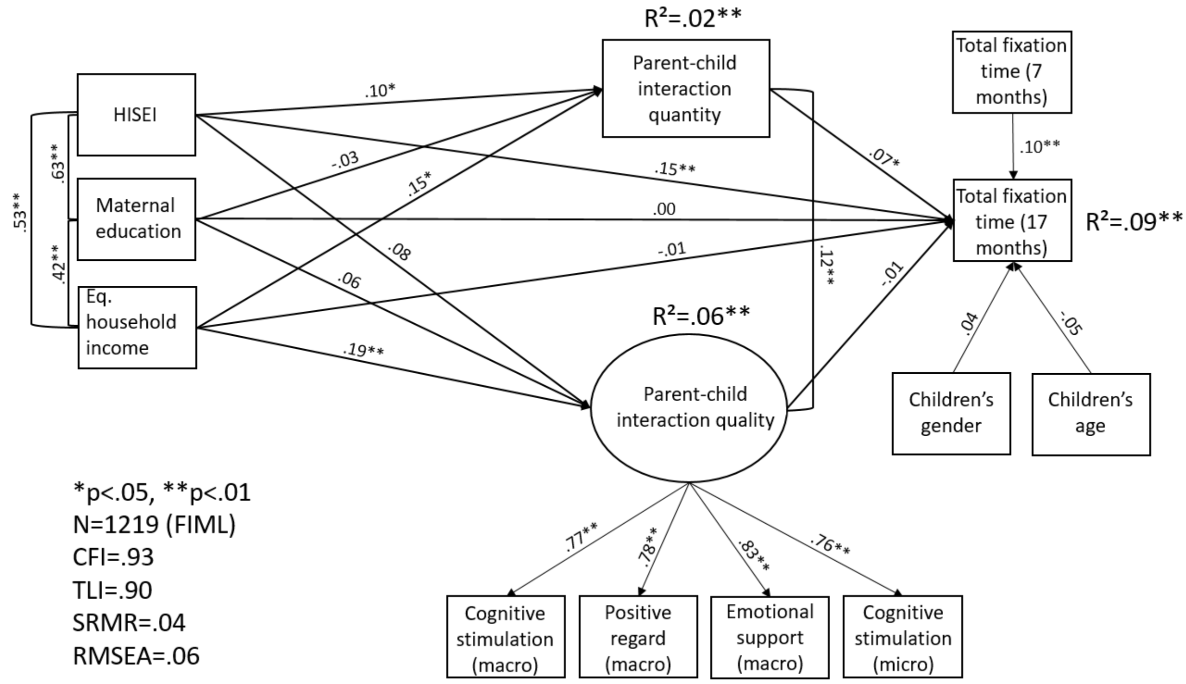

Table 5

Model A: Effect Decomposition of Components of SES on Total Fixation Time

	Indirect effect via parent-child interaction quantity	Indirect effect via parent-child interaction quality
HISEI	.01	.00
Maternal education	.00	.00
Eq. household income	.00	.00

Note. Standardized coefficients reported.

The second model predicted attention recovery at 17 months with parent-child interaction mediating effects of SES components (Figure 2). Comparable to Model A, HISEI and household income were positively associated with the quantity and quality of parent-child interactions. However, neither the components of SES nor parent-child interaction had a significant effect on attention recovery. Indirect effects of SES components via the quantity and quality of parent-child interactions were also not significant, ruling out the possibility of suppressor effects (Table 6). Overall explained variance was low (R^2=.07). A robustness check without attention recovery at 7 months as a control variable revealed no differences in the direction or significance of the effects.

Figure 2

Model B: Mediation model of the pathways from SES to attention recovery at Wave 2 via parent-child interaction; standardized coefficients reported (direct effects).

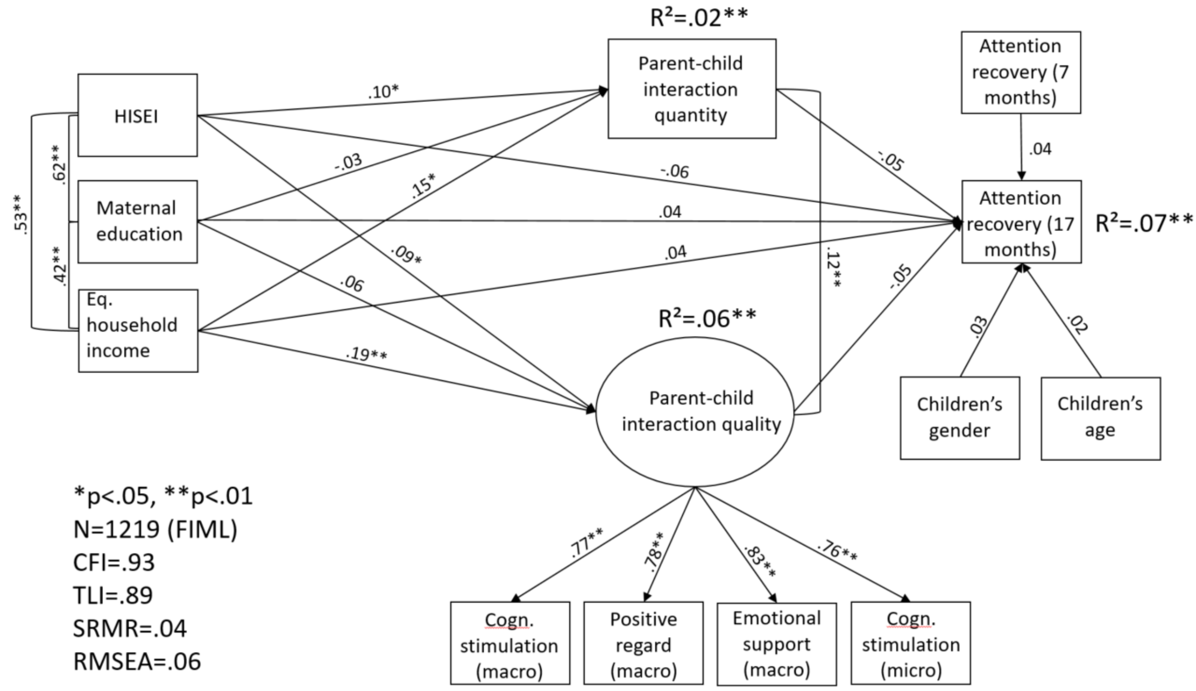

Table 6

Model B: Effect Decomposition of Components of SES on Attention Recovery

	Indirect effect via parent-child interaction quantity	Indirect effect via parent-child interaction quality

HISEI	.00	.00
Maternal education	.00	.00
Eq. household income	.00	-.01

Note. Standardized coefficients reported.

Discussion

Summary

The aim of the present study was to investigate SES-related effects on measures of a habituation-dishabituation task administered at 7 months and at 17 months. More specifically, we were interested in the emergence of social disparities in early cognitive abilities, as well as in the relation between components of SES (i.e., parental occupation, maternal education, and household income), the quantity and quality of parent-child interactions, and indicators of children's early cognitive abilities (i.e., information processing and attention recovery). As hypothesized, there were no effects of social disparity in total fixation time and attention recovery at 7 months. In other words, structural aspects of the children's socioeconomic background were not systematically associated with interindividual differences in habituation and dishabituation in a categorical fixed-trial task. We used a large-scale sample, which should be more heterogeneous than typical laboratory studies, so we consider this finding robust and in line with previous analyses of the sample (Weinert et al., 2017).

At 17 months, we found consistent effects of social disparities in total fixation time for each component of SES. HISEI tended to have a large effect in comparison to maternal education and household income – probably because this indicator includes a large variance of maternal education, paternal education, as well as other aspects of social capital and can thus be regarded an omnibus measure. Path analysis revealed that there were no mediating effects through parent-child interactions, probably due to the lack of significant correlations between these variables and total fixation time and attention recovery. Finally, there were no social disparities in attention recovery and a mediation model found no significant direct or indirect effects of SES components on attention recovery via parent-child interactions.

Implications

Due to the comparably large database and the inclusion of different components of SES, the present results are a thorough investigation of how structural aspects of the children's socioeconomic background contribute to interindividual differences in indicators of early cognitive abilities. The findings pinpoint the emergence of social disparities in early cognitive development during the second year of life. In contrast, there were no associations between components of SES and early cognitive measures at 7 months, which can be regarded a large-scale replication of existing results (Mayes & Bornstein, 1995). This supports the idea of a cumulative influence of structural aspects of the children's socioeconomic background on their cognitive development (Smith et al., 2002), especially as we controlled for total fixation time at Wave 1.

Regarding the effects of SES on total fixation time, we made a strong argument about analyzing multiple components to capture different aspects of the children's socioeconomic background. Indeed, regarding the quantity and quality of parent-child interactions, we found distinct effects of HISEI and household income. However, regarding total fixation time, only HISEI had robust effects, probably because the omnibus measure considers aspects of education and occupation. In addition, HISEI also includes socioeconomic aspects of the partner – who was in most cases the biological father of the children (90.54%) living in the same household (93.49%). It was shown that fathers' involvement in raising their children is associated with their cognitive development (Rollè et al., 2019) and that paternal education is distinctly associated with children's early cognitive skills (Tamis-LeMonda et al., 2004). Thus, we reason that the effect over and above maternal education and household income may be attributed to socioeconomic aspects of the father.

The measure we used for indicating visual information processing, namely total fixation time during the habituation phase, is usually negatively related to later cognitive outcomes (Colombo & Mitchell, 2009) which is why previous studies found negative correlations with SES components (e.g., Lewis et al., 1969; McCall, 1972) and stimulating parenting behavior (Riksen-Walraven, 1978). Interestingly, we found positive correlations between total fixation time, SES components, and parent-child interaction quantity at 17 months. However, because of the categorical stimulus material and the familiar household setting, we reason that the measure indicates a form of sustained attention (Ruff, 1986), which is why longer fixation times should – on average – probably be interpreted as better overall attention skills. Overall, we suspect complex interrelations of children's visual attention and the context of assessment (Wass & Leong, 2016), which can range from calm settings activating children to stressful settings distracting them. This could also be the reason why the interpretation of attention recovery might not be as straightforward as in typical laboratory studies. Because of the high levels of overall looking times, the measure might indicate sustained attention for some children and recognition memory for others.

For mediation analysis, there should typically be a consistent correlational pattern between independent variables, dependent variables, and mediating variables (MacKinnon et al., 2012; Preacher & Hayes, 2008). However, Table 4 reveals that although total fixation time (but not attention recovery) is correlated with components of SES, the measure is not significantly associated with parent-child interaction quality. However, previous studies found significant associations of parent-child interaction quality with cognitive abilities (Lugo-Gil &

Tamis-LeMonda, 2008) at the same age. With the same data, parent-child interaction quality was also shown to be significantly associated with early language skills (Attig & Weinert, 2018). Still, regarding the influence of parent-child interactions on children's early cognitive abilities measured by habituation-dishabituation tasks, little is known. In an early study on the relation of habituation rate and stimulating parenting behavior in 9-month-old infants, Riksen-Walraven (1978) found that only behavior related to explicit instructions (i.e., naming objects or showing objects) was significantly correlated with habituation rate. Likewise, Ruddy and Bornstein (1982) found that cognitive stimulation of the mother at 4 months was positively related to habituation rate in a simultaneously assessed habituation task. Moreover, as the task probably measured sustained attention, it should be noted that the relationship between sustained attention and the quantity and quality of parent-child interactions have not been thoroughly investigated in this age group.

Laboratory studies are often criticized for potentially biased samples (Oakes, 2017) and large-scale studies using habituation-dishabituation tasks have been rare. Thus, our findings on emerging social disparities during the latter half of the children's second year of life highlight the need to draw from samples that are more heterogeneous and control for central structural components of the children's socioeconomic background. We argue that the reported social disparities could even be underestimated, as attrition in NEPS SC1 was associated with the children's socioeconomic background (Zinn et al., 2020). Similarly, Bell and Slater (2002) showed that, in the Avon Longitudinal Study of Parents and Children, participating in a habituation task was associated with maternal education, which could render results non-generalizable.

Strengths and limitations

To the knowledge of the authors, this study is the first large-scale investigation of SES-related effects on early cognitive abilities in young children drawn from habituation-dishabituation tasks. The heterogeneous sample should be adequate for addressing potential social disparities, which is one of the strengths of the present study. Investigating effects of the children's social background requires a certain amount of heterogeneity in the sample, which is not always given in small laboratory settings (Oakes, 2017). In addition, having conducted the interactional play situation and habituation-dishabituation tasks at home should have increased the ecological validity of the results. As the dropout in NEPS SC1 during the early waves was also associated with the children's socioeconomic background (Zinn et al., 2020), the present results might even underestimate the actual social disparities. Still, our study has several limitations that highlight the need for future investigations of social disparities in young children's cognitive development.

As an indicator of financial and material resources, we included household income. However, as household income is often volatile over the years (Votruba-Drzal, 2003) and the measure is not sensitive to transitional poverty (Strohschein, 2005) or total family assets, the indicator has several shortcomings. More specifically, about 18% of the households in the present sample can be categorized below the official poverty threshold (i.e., "relative poverty"; Deutscher Bundestag, 2016). Although relative poverty is an indicator of social stratification, it does not automatically imply economic hardship in the sense of severe material deprivation, which is considered detrimental for children's development (Bornstein & Bradley, 2010; Noble et al., 2007). Thus, comparing children below and above the poverty threshold may lead to different results; future studies should assess economic aspects as components of the children's socioeconomic background in more detail to address income-specific effects on early cognitive development more adequately.

Because the present analyses only consider two waves, we cannot make assumptions about the longitudinal nature of the relationship between structural characteristics, parent-child interaction, and the development cognitive abilities, especially because the stability and reliability of habituation-dishabituation tasks are typically only moderate (Kavšek, 2004). Thus, our findings cannot comment on possible mechanisms of social causation or social selection (see Conger & Donnellan, 2007). Likewise, no aspects of the children's temperament and behavior were controlled for (e.g., frustration, impulsivity, and effortful control), even though child temperament has been shown to be associated with SES (Bornstein et al., 2015), parent-child interactions (Kiff et al., 2011), and the performance in habituation-dishabituation tasks (Weinert et al., 2017).

Alongside the tasks used in the present analyses, other habituation-dishabituation tasks were administered at the first two waves in NEPS SC1. There could be possible sequence effects as the present task was administered last at Wave 1 and first at Wave 2, possibly influencing children's attentional skills. Indeed, children's looking times were generally higher at Wave 2 (Supplement B), while the increases in looking times for the dishabituation at Wave 1 were smaller than expected (Table 2). Together with the relatively complex stimulus material, this could indicate that, at least for 7 month-old children, the task was too challenging. This also supports the notion that the task measured a form of sustained attention and not information processing.

Finally, the general lack of significant associations between parent-child interaction and indicators of early cognitive abilities were unexpected. Consequently, neither the quantity nor the quality of parent-child interactions mediated SES-related effects on total fixation time. The former measure was a sum score of a broad range of different activities that parents engaged in with the infant during the week before. Hence, the limited period could have led to non-valid responses in some cases; in addition, there were ceiling effects for some items (Supplement D). The latter measure was only assessed during a short play situation (5 minutes), which might reflect social bias as parental SES might have been associated with different interaction behavior. However, other analyses of these measures in NEPS SC1 have found systematic effects of social disparity (Attig & Weinert, 2018; Linberg et al., 2020; Weinert et al., 2017) and the ecological validity of the parent-child interaction quality was also thoroughly investigated (Linberg et al., 2019). Thus, we hold that the measures did not generally lead to invalid results.

Future research

The main results of the present study were that while we found no social disparities in cognitive abilities measured with habituation-dishabituation tasks at 7 months, we found social disparities for a habituation measure (i.e., total fixation time) at 17 months. In addition, SES-related effects were not mediated by the quantity or quality of parent-child interactions because there was a general lack of significant correlations between these variables. However, due to the children’s looking time patterns, we reason that the task measured a form of sustained attention. Still, finding such robust effects of the children’s socioeconomic background on their attention is noteworthy and should be relevant for many studies that rely on behavioral assessments of children’s visual attention. Future research should build upon these findings in several ways.

Regarding social disparities, differences between parental education and parental occupation should be investigated in more detail, especially with the focus on distinct effects between influences of the mother and of the father/partner. Regarding potential mediating effects aside from the quantity and quality of parent-child interactions, a central concept of bioecological theories is that social systems are dynamic (Bronfenbrenner & Morris, 2006), meaning that children's development is influenced by enduring patterns of environmental factors that interact with the person (Bronfenbrenner & Ceci, 1994). Thus, there should also be other factors relevant for early child development that could serve as mediating variables. Relevant examples of influential structural aspects on child development are (institutional) childcare, living conditions in the household and in the direct neighborhood. In addition, there are also socio-emotional aspects such as parental conflict and mental health that result in stressful environments that should be considered for future investigations (Conger & Donnellan, 2007).

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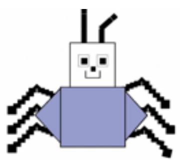
Supplement

A. Stimulus material

Habituation-dishabituation task with categorical stimuli

Example stimulus of the categorical habituation phase (trial 1-9)

Example stimulus of the categorical dishabituation phase (trial 10-11)



B. Descriptive information on the habituation-dishabituation tasks

Table 1

Looking Times for All Trials of the Habituation-Dishabituation Task (Wave 1)

	Mean	SD	Min	Max
Trial 1	7.71	2.20	0	10.03
Trial 2	7.38	2.33	0	10.03
Trial 3	6.77	2.49	0	10.03
Trial 4	6.82	2.61	0	10.03
Trial 5	6.56	2.60	0	10.03

Trial 6	6.33	2.65	0	10.03
Trial 7	6.22	2.73	0	10.03
Trial 8	6.22	2.68	0	10.03
Trial 9	6.19	2.69	0	10.03
Trial 10	5.81	2.72	0	10.03
Trial 11	5.41	2.69	0	10.03
Trial 12	5.38	2.66	0	10.03
Trial 13	4.42	2.51	0	10.03

Note. N=2287; in seconds.

Table 2

Looking Times for All Trials of the Habituation-Dishabituation Task (Wave 2)

	Mean	SD	Min	Max
Trial 1	8.20	1.85	0	10.03
Trial 2	8.10	1.87	0	10.03
Trial 3	7.94	2.02	0	10.03
Trial 4	7.96	2.06	0	10.03
Trial 5	7.63	2.18	0	10.03
Trial 6	7.48	2.29	0	10.03
Trial 7	7.44	2.28	0	10.03
Trial 8	7.41	2.31	0	10.03
Trial 9	7.38	2.37	0	10.03
Trial 10	7.44	2.33	0	10.03
Trial 11	6.77	2.48	0	10.03
Trial 12	7.17	2.31	0	10.03
Trial 13	5.89	2.56	0	10.03

Note. N=1219; in seconds.

Table 3

Associations between Total Fixation Time and Attention Recovery

	Total fixation time (Wave 1)	Attention recovery (Wave 1)	Total fixation time (Wave 2)
Attention recovery (Wave 1)	.10**		
Total fixation time (Wave 2)	.01	.00	
Total fixation time (Wave 2)	.04	.00	-.01

Note. Pearson correlation coefficients reported; **p<.01.

C. Robustness check for "habituation strength"

Based on often-used indicators of cognitive abilities in habituation-dishabituation research (Colombo et al., 1987; Kavšek, 2004), we opted against using the measure "habituation strength" (Laucht et al., 1994). Due to the flat looking time patterns in the present data, we expected that the measure should have limited variance (Wave 1: M=0.09, SD=0.19, Min=-0.84, Max=1; Wave 2: M=0.05, SD=0.14, Min=-0.46, Max=1). However, for making the present results comparable to previous analyses (Attig & Weinert, 2018; Weinert et al., 2017), we also checked associations between habituation strength and all independent and control variables. Habituation strength did not show significant correlations with any variable (Table 4). Thus – at least in comparison to total fixation time – the measure might underestimate SES-related effects.

Table 4

Associations between Habituation Strength, Independent Variables, and Control Variables

	Habituation strength (Wave 1)	Habituation strength (Wave 2)

HISEI	.00	-.01
Maternal education	.00	.02
Equivalized household income	-.03	-.01
Parent-child interaction quantity	-.02	-.05
Parent-child interaction quality: Cognitive stimulation (macro coding)	.02	-.01
Parent-child interaction quality: Positive regard (macro coding)	.00	.02
Parent-child interaction quality: Emotional support (macro coding)	.00	-.02
Parent-child interaction quality: Cognitive stimulation (micro coding)	.01	.02
Children's age	.03	.04
Children's gender	.02	.01

Note. Pearson correlation coefficients reported; point-biserial correlation coefficients reported for children's gender (0=male; 1=female).

D. Parent-child interaction quantity (Wave 1)

At Wave 1 (children on average 7 months-old), the parents were asked about age appropriate joint activities they typically engage in with their child. Table 5 reports a list of all activities. A five-point Likert scale was used: 1 = not at all; 2 = once a week; 3 = several times a week; 4 = once a day; 5 = several times a day; refusals were counted as missing values. However, in the sample used in the mediation models (N=1219), there were no missing values for joint activities. Although the descriptive information in Table 5 indicate ceiling effects and, thus, limited variance for some items, we chose to include all joint activities for representing a global measure.

Table 5

Parental Report of Joint Activities at Wave 1

Prompt text: I'd now like to find out about situations in the last week where you or someone else in your home had the time to exclusively interact with <child>. I'm now going to mention a few situations and would like you to assess how often you or someone else in your home did those things together with <child> in the last week. You can choose between the following responses: several times per day, once per day, several times per week, once per week or not at all.
Item 1: Looked at picture books together. M=3.07, SD=1.47, Min=1, Max=5
Item 2: Playing together with an object which <child> can pull, push or purposefully grab and hold onto, e.g. a teething ring, a rattle, an activities arch / baby gym, a ball or a spoon. M=4.93, SD=0.34, Min=3, Max=5
Item 3: Played together in or even with water, e.g. in the bathtub or splashing at the washbasin. M=2.79, SD=0.83, Min=1, Max=5
Item 4: Playing together with dolls, cuddly toys, animal figurines or similar items. M=4.26, SD=1.11, Min=1, Max=5
Item 5: Playing together with building blocks or other things for inserting, stacking or building. M=2.42, SD=1.64, Min=1, Max=5
Item 6: Playing together with an item that makes noise, e.g. a rattle, a squeaky toy or a bunch of keys. M=4.86, SD=0.50, Min=1, Max=5
Item 7: Interacting with <child> without using any objects or toys, e.g. singing, telling or showing something. M=4.86, SD=0.49, Min=1, Max=5
Item 8: Romping, cuddling or simply fooling around with <child>. M=4.95, SD=0.27, Min=3, Max=5
Item 9: Gone out together to enjoy the fresh air.

M=4.27, SD=0.71, Min=1, Max=5

Note. N=1220.

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Appendix B: Study 2[9]

Attention and early learning in toddlers as predictors of productive vocabulary

Maximilian Seitz[1], Dave Möwisch[1], Manja Attig[1], and Sabine Weinert[2]

[1]Leibniz Institute for Educational Trajectories, Bamberg, Germany

[2]Department of Developmental Psychology, University of Bamberg, Bamberg, Germany

Corresponding author:

Maximilian Seitz

maximilian.seitz@lifbi.de

Leibniz Institute for Educational Trajectories

Wilhelmsplatz 3, 96047 Bamberg

Germany

Data availability statement:

This paper uses data from the National Educational Panel Study (NEPS): Starting Cohort Newborns, doi:10.5157/NEPS:SC1:8.0.0. From 2008 to 2013, NEPS data was collected as part of the Framework Program for the Promotion of Empirical Educational Research funded by the German Federal Ministry of Education and Research (BMBF). As of 2014, NEPS has been carried out by the Leibniz Institute for Educational Trajectories (LIfBi, Bamberg) in cooperation with a nationwide network. Data of the language-specific habituation-dishabituation task was also collected by the NEPS but coded by the project ViVA and will be added in future scientific use files. The data is available on reasonable request to the authors.

[9] A revised version of this study will be submitted for future publication.

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Author Contributions

Maximilian Seitz: Conceptualization, Data curation, Methodology, Writing – Original draft preparation. **Dave Möwisch:** Conceptualization, Writing – Review & Editing. **Manja Attig:** Conceptualization, Writing – Review & Editing. **Sabine Weinert:** Funding acquisition, Conceptualization, Writing – Review & Editing, Supervision. All authors approved the final version of the manuscript for submission.

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Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Manuscript word count: 7161 words

Abstract

In young children, basic cognitive abilities and early word learning typically predict later vocabulary development. During the first two years of life, such abilities are often investigated with habituation-dishabituation tasks. However, most studies analyze small and selective samples, although children's socioeconomic backgrounds are known to be related to their vocabulary development. In addition, the predictive effects of basic cognitive abilities and early word learning is seldom contrasted. Therefore, the present study used a large-scale data set to compare measures drawn from two conceptually similar categorical habituation-dishabituation tasks in 17-month-olds. Whereas one task focused on children's basic cognitive abilities, the other assessed their early word learning. First, we investigated children's performance in both tasks; next, we examined predictive effects on productive vocabulary when the children were 26 months old. We found that in both tasks, most children did not show the expected looking pattern in the habituation phase. In habituated children, total fixation time but not attention recovery was positively correlated with productive vocabulary. This association was robust in regression models, in which aspects of the children's socioeconomic backgrounds were controlled for. The present results are discussed with regard to the specificities of the data set, as the habituation-dishabituation tasks were administered in a household setting.

Keywords: Productive vocabulary, cognitive development, word learning, social disparities

Attention and early learning in toddlers as predictors of productive vocabulary

Young children begin to understand the world by making observations and extracting information from everyday situations such as when unexpected things happen or when they hear people talking. To process this information, they must rely on many general cognitive abilities such as memorizing the features of events or objects and forming categories. These general processes are also relevant for early language learning, facilitating vocabulary development (Samuelson, 2021; Waxman & Leddon, 2011). Prominent methods for assessing early learning in infants are habituation-dishabituation tasks, in which visual attention to sequentially presented stimuli is measured (Colombo & Mitchell, 2009). Typically, attention decrement for familiar stimuli and attention recovery for novel stimuli can be used to predict later language skills (e.g., Colombo et al., 2009). However, infant research typically relies on small and often homogeneous samples (Oakes, 2017), although it has been shown that early word processing in 18-month-olds is related to their socioeconomic background (Fernald et al., 2013). Therefore, the present study used data from a large-scale German panel study to compare the predictive effects of children's performance in two categorical habituation-dishabituation tasks administered at 17 months on later vocabulary at 26 months. We examined measures of visual attention and early learning to investigate whether predictive effects on productive vocabulary are robust when controlling for children's socioeconomic background.

Theoretical background

Visual attention is a central mechanism for gathering information about the environment, influencing child development at various levels (Hendry et al., 2020). It is fundamentally important for basic cognitive abilities such as early memory and learning (Fisher, 2019). In the domain of language learning, Samuelson (2021) stated that young children rely on both visual and acoustic information for processing input. When a novel object is presented, children form a mental representation of the object, which they subsequently link to the word form to create initial word-object mappings. Through repetition, these mappings may become robust in creating individual entries in the (long-term) vocabulary. In other words, when we repeatedly see objects with the same set of qualities while hearing a specific word, we establish an association between the mental category and label (Ferguson & Waxman, 2017). Simultaneously, hearing a new word draws the child's attention to categorical relations (e.g., Waxman & Leddon, 2011). Thus, there is a reciprocal relationship between how children attend to categorical information and how efficiently they link a new word to its corresponding category (von Koss Torkildsen et al., 2009; Waxman & Leddon, 2011). As individual differences in visual attention indicate early learning (Smith & Yu, 2013), and there is a certain degree of stability in cognitive and language abilities (e.g., Rose et al., 2009), tasks tapping into processes of early learning should predict later vocabulary.

Predicting children's vocabulary with habituation-dishabituation tasks

Habituation-dishabituation tasks are among a number of paradigms, such as visual-paired comparison or visual expectation (e.g., Colombo, 2002), which observe young children's looking behavior to investigate basic cognitive abilities and attentional skills (Colombo & Mitchell, 2009; Johnson, 2016). Such tasks tap into the processes of early learning as children's performance is interpreted as stimulus encoding, storage, and retrieval (Kavšek, 2013). Typically, infants are presented with a series of identical or similar stimuli during the habituation phase while their visual attention to these stimuli is recorded. While categorical stimulus material is typically used for assessing early categorization skills, it is also more complex, which is useful when investigating older infants (Fennell, 2012), and elicits greater engagement in the tasks (Courage et al., 2006). Subsequently, by presenting a novel and dissimilar stimulus, the post-habituation (dishabituation) phase tests for retention, discrimination, or categorization by observing attention recovery or stimulus preference. Thus, this phase tests whether the infant has formed a mental representation of the previous stimuli, and whether the child can successfully compare this memory trace with a novel stimulus (Sokolov, 1990). In other words, dishabituation indicates learning in children who have previously shown an attention decrement (Cohen, 2004). Consequently, habituation-dishabituation tasks have been used to predict vocabulary (e.g., Colombo et al., 2004), often in an adapted form, featuring language-related stimuli to test language learning processes (e.g., Mather & Plunkett, 2012; Waxman & Markow, 1995).

Children's looking times in habituation-dishabituation tasks are interpreted using various performance measures (Kavšek, 2004). Typically, attention decrement is measured during the habituation phase and attention recovery in the dishabituation phase. Such measures have been shown to predict early vocabulary development (Colombo et al., 2009), with a higher attention decrement usually being associated with a larger vocabulary (Marino & Gervain, 2019; Ortiz-Mantilla et al., 2008; Tamis-LeMonda & Bornstein, 1989). Hence, longer total fixation time during the habituation phase is interpreted as an indicator of poorer information-processing skills (Colombo et al., 2009). In contrast, reaching a predefined habituation criterion is usually interpreted as an indicator of higher information processing efficiency (e.g., a 50% decrement in looking times; Oakes, 2010). In habituated children, attention recovery during the dishabituation phase indicates whether the child has successfully encoded novel information and discriminated it from previous stimuli (Mather & Plunkett, 2012). Thus, positive attention recovery in habituators should indicate that children successfully learned the respective categories in the tasks. Regarding word learning, the ability to detect a novel stimulus-word pairing during the dishabituation phase should signal that word object category mapping was successfully formed (Rose et al., 2009; Thompson et al., 1991).

Vocabulary development and children’s socioeconomic background

Most studies on predicting vocabulary with basic cognitive abilities and early language skills have been conducted in small laboratory settings, resulting in an unwanted focus on children from middle-class socioeconomic backgrounds (Oakes, 2017). Relying on such selective samples could potentially lead to biased findings on young children’s language development (Fernald et al., 2013; Halle et al., 2009) because SES is related to interindividual differences in cognitive and verbal stimulation (Attig & Weinert, 2020; Davis-Kean et al., 2021; Hoff, 2003). Likewise, Bronfenbrenner’s bioecological theory of human development (e.g., Bronfenbrenner & Morris, 2007) stresses the importance of the family at the microsystem level, especially the effect of parental social class (e.g., parental education and household income) in the first years of childhood. It can be argued that highly educated parents enrich their children’s environment by supporting learning processes (Hoff, 2003), whereas financial resources are needed to provide materials for a safe and stimulating learning environment (e.g., Yeung et al., 2002). As a result, socioeconomic differences in early childhood are associated with interindividual differences in children’s language development (Pace et al., 2017). The effects of social disparity are complex and structural aspects are thought to only have an indirect effect on child development, which is why parental education and household income represent approximations of actual family processes (Conger & Donnellan, 2007). Still, for language development in young children in their second year of life, maternal education and household income are often considered central (Davis-Kean et al., 2021; Duncan & Magnuson, 2012). However, studies using habituation-dishabituation tasks rarely control for

SES-related effects (e.g., Mayes & Bornstein, 1995), typically because of limited sample sizes or homogeneous samples.

The current study

We investigated young children's learning using two categorical habituation-dishabituation tasks. For this purpose, we examined data from a German longitudinal large-scale study in which the tasks were administered to a sample of 17-month-old toddlers. Both tasks featured categorical stimulus material and the main difference was that one task was accompanied by language stimuli. Thus, both tasks tap into the general mechanisms of learning, remembering, and perceiving (Oakes et al., 2008), although the language-specific task could relate more strongly to the processing of language input in combination with a visual category (Johnson & Zamuner, 2010). In the first step, children's performance in the tasks was examined with regard to attention decrement and attention recovery (i.e., measures of total fixation time, habituation criterion, and attention recovery). In the second step, predictive effects on later productive vocabulary at 26 months were investigated, controlling for aspects of the children's socioeconomic backgrounds (i.e., maternal education and household income). We expected that reaching the habituation criterion would be positively associated with later productive vocabulary in both tasks. In addition, attention recovery during the dishabituation phase in habituators should be positively associated with later productive vocabulary in both tasks (Marino & Gervain, 2019; Rose et al., 2009). Consequently, total fixation time should be negatively related to later productive vocabulary. Overall, we expected higher predictive effects of the performance measures for the language-specific task (for an alternative hypothesis, see Perry et al., 2010). In general, previous research in this age group showed rather small effects (Colombo et al., 2009; Rose et al., 2009). Children's socioeconomic background should be significantly associated with productive vocabulary (e.g., Attig & Weinert, 2020), but we assumed that the predictive effects on productive vocabulary remain significant when SES was controlled for (Fernald et al., 2013).

Method

Sample

This study used data from the Newborn Cohort of the German National Educational Panel Study (NEPS SC1) (Blossfeld & Roßbach, 2019; Hachul et al., 2019; NEPS Network, 2021). NEPS SC1 is a longitudinal large-scale study with annual data collection that was drawn representatively and nationwide in Germany. By design, the habituation-dishabituation tasks were administered to N=1315 17-month-old children (i.e., about half the panel sample). Furthermore, we excluded cases with technical problems, experimenter errors, or incomplete coding (e.g., due to insufficient lighting conditions) (N=282). Data on productive vocabulary was collected when the children were 26 months old. Thus, owing to sample attrition (Zinn et al., 2020), the final sample for our analyses was N=841 children.

Assessment of the habituation-dishabituation tasks

At 17 months of age, two categorical habituation-dishabituation tasks were used to study children's early learning: a general task and a language-specific task (for examples of the stimulus material, see Supplement A). For both tasks, a fixed-trial procedure was used, meaning that the sequence of the individual stimulus pictures (i.e., trials) and the presentation time of the stimulus pictures were the same for all children. The general task was administered before the language-specific task and featured categorical cartoon pictures of imaginary bugs[10] accompanied by a short three-note jingle each time a new trial was shown. In the nine habituation trials, the bugs were circular, symmetrical, and bright colored. In the two dishabituation trials, the bugs were rectangular, with asymmetrical feet and antennae, and had a blue color scheme. Due to the rectangular design, the facial features of the bugs were also different. The subsequent attention control phase featured two identical photorealistic images of a pineapple. The language-specific task featured categorical cartoon pictures of imaginary creatures, accompanied by a verbal stimulus, played one time each trial was shown (i.e., "Ein Jalos"; "Ein" is a German article and "Jalos" is a noun pseudoword referring to the creatures; Zhang, 2007). In the nine habituation trials, the creatures consisted of varying numbers of circular shapes. All creatures had the same facial features (i.e., eyes, nose, and mouth) and the same colors as in the general task were used. In the two trials of the dishabituation phase, the creatures consisted of rectangular shapes in a blue color scheme. Because of the rectangular design, the body shapes and the facial features were markedly different from those in the habituation trials. These out-of-category exemplars were accompanied by the same pseudoword that was used in the habituation phase. Thus, the task was a violation-of-expectation paradigm that tested word learning (e.g., Munakata, 2000; Werker & Yeung, 2005). The subsequent attention-control phase featured two identical, photorealistic pictures of a tree. Both tasks lasted 157 s each. Thus, apart from the pseudoword, both tasks were comparable in design and identical in administration.

Trained interviewers administered the tasks in the children's homes, which is why a fixed-trial procedure was chosen to achieve standardization, given the heterogeneous household conditions and focus on group-level differences (Weinert et al., 2016). Each trial of

[10] The stimulus material was tested in previous studies at the chair of developmental psychology at the University of Bamberg, Germany (Zhang, 2007).

the habituation phase (i.e., nine trials) and the dishabituation phase (i.e., two trials) was shown for 10 s; the inter-trial interval was 2 s (i.e., a white screen). In both tasks, there were two additional trials at the end to check for the children's general attentiveness (i.e., the attention control phase). These trials were analyzed to check for an expected increase in looking time at group level. The tasks were recorded on video, and the children's looking behavior towards the target was coded offline (30 frames per second). The present study used accumulated fixation times for each trial, which could range from 0-10 seconds per trial. Looking times were not truncated, so there was no cutoff criterion for short looking time events. Although commonly used, truncated looking times can bias results and distort linear relationships by excluding valid but low events (Ulrich & Miller, 1994), which is why we decided against a cut-off criterion for the main analyses. Robustness checks with a cutoff criterion can be found in the supplement (Supplement E).

Measures of early learning

As an indicator of overall visual attention, we used the sum of all looking time events on target as a continuous measure for all relevant trials (i.e., total fixation time) (Colombo et al., 1987; Kavšek, 2004). Thus, the measure included all habituation trials and the first dishabituation trial. Because categorical stimulus material was relatively complex, we expected looking times to be generally high and, consequently, a certain number of children who did not habituate (Fennell, 2012). We grouped the children according to a habituation criterion of a 50% decrement in looking time during the habituation phase when compared to the first trial (Fennell, 2012; Oakes, 2010), which had the longest mean looking time (Supplement B). For the dishabituation phase, we used a difference measure that compared the looking times of the last habituation trial and the first dishabituation trial (i.e., attention recovery) (Kavšek & Bornstein, 2010). The second dishabituation trial was not considered because a meta-analysis found that the first novel stimulus was the most robust (Kavšek, 2004). Negative values indicate decreasing looking times towards the novel stimulus, whereas positive values indicate an increase. We used the habituation criterion to investigate the differences in total fixation time and attention recovery between habituators and non-habituators as a collapsed sample would obscure differences between children who showed familiarity or novelty effects (Oakes, 2010).

Productive vocabulary

As an outcome measure of later language skills, we used the productive vocabulary scale of a normed, standardized, and validated parent report checklist of 260 items regarding children's productive vocabulary administered at 26 months (ELFRA-2; Grimm & Doil, 2006). The checklist is based on the widely used MacArthur Communicative Development Inventories – CDI, Toddler Form (Fenson et al., 1993), and is one of the most commonly used early language checklists in German-speaking countries (Rosenfeld & Kiese-Himmel, 2011) with good concurrent (Sachse et al., 2007) and prognostic validity (Grimm & Doil, 2006). We used raw scores for all analyses and treated the variable continuously.

Control variables

For the structural aspects of children's socioeconomic backgrounds, we chose maternal education and household income. For maternal education, we chose overall years of formal education, as it can be compared better than qualifications, which can be specific to certain countries. Household income was defined as another aspect of children's socioeconomic background (Yeung et al., 2002), which is an indicator of the equivalized monthly net income of the families. In line with the standard OECD approach, we weighted persons living in households below and above the age of 14 differentially and used the resulting factor for adjusting household income (e.g., OECD - Organisation for Economic Co-operation and Development, 2013). Both maternal education and household income were treated as continuous variables.

In addition, we used age in months and gender, as reported by the parents (1=male; 2=female), as further control variables. Children's age was deemed relevant because of the age range of NEPS SC1 (Table 1). Regarding children's family language, we used a dichotomous indicator of the household interaction language (0=primarily German; 1=primarily another language). If until the children were 26 months old, the parents reported a primary household language other than German, the children were grouped into the latter category. We also considered grouping children into German, bilingual, and non-German groups because the language-specific task featured a German article. However, because the non-German group was marginal (3.57%), we opted against this segmentation.

Statistical analyses

First, we investigated children's performance in the two tasks by calculating Welch's t-test to compare looking times between habituators and non-habituators during the transition towards the dishabituation and attention control phases. To investigate the predictive effects of total fixation time and attention recovery on productive vocabulary in both tasks, we calculated Pearson's correlation as well as Welch's t-test for differences between habituators and non-habituators. Finally, we used path analysis to compare the predictive effects of the measures for habituators and non-habituators in a linear regression framework, controlling for child characteristics (i.e., age and gender), SES (i.e., maternal education and household income), and family language. In the final sample (N=841), there were cases with missing values for maternal education (5.71%) and household income (14.27%). We used a full information maximum likelihood estimator (Acock, 2005; Lee & Shi, 2021) because this approach was shown to introduce less bias to the data than listwise deletion (Enders, 2001).

Results

Table 1 reports descriptive information on the outcome (i.e., productive vocabulary sum scores) and all control variables, namely maternal education, equivalized household income, children's age, children's gender, and family language. Due to the right-skewed distribution, equivalized household income was log-transformed in all further analyses.

Table 1

Descriptive Information on Productive Vocabulary and Control Variables

Variable	Mean	SD	Min	Max
Productive vocabulary	139.69	65.42	2	260
Maternal education (years)	15.23	2.33	9	18
Equivalized household income (€)	1955.62	948.61	333.33	10833.33
Children's age (months)	26.30	0.98	24.20	31.67
Children's gender	Male: 50.18%			
Family language	Primarily German: 91.56%			

Note. N=841; raw scores reported for productive vocabulary.

Next, we calculated differences in total fixation time, attention recovery, and habituation criterion in both tasks for the whole sample. Overall, looking times in the general task ($M=78.22$, $SD=13.75$) were higher than in the language-specific task ($M=73.72$, $SD=15.14$; $t(840)=7.81$, $p<.01$, $d=0.31$). In contrast, there were no differences in attention recovery in the general task ($M=0.01$, $SD=0.23$) and language specific-task ($M=0.02$, $SD=0.29$; $t(840)=-1.03$, $p=.30$). In the general task, there were N=238 (28.30%) habituators, and in the language-specific task, there were N=394 (46.85%) habituators, which was significantly more, $X^2(1, N=841)=19.11$, $p<.01$. Table 2 presents a descriptive overview of total fixation time and attention recovery for both habituators and non-habituators. As expected, habituators had shorter total fixation times and higher attention recovery than non-habituators in both tasks. As a substantial number of children did not habituate, we calculated a post-hoc analysis comparing age differences between habituators and non-habituators. In the general task, habituators (M=17.12, SD=0.58) were significantly older than non-habituators (M=17.01, SD=0.59; t(446.03)=-2.46, p=.01, d=0.19). In the language-specific task, there were no age differences between habituators (M=17.05, SD=0.59) and non-habituators (M=17.03, SD=0.59, t(823.76)=-0.45, p=.65). In addition, another post-hoc test addressed the question whether children discriminated between the habituation and dishabituation stimuli and whether they showed sufficient attention throughout the attention control phase (Supplement D).

Table 2

Descriptive Information on Total Fixation Time and Attention Recovery in Both Tasks

	Habituators		Non-habituators	
	Mean	SD	Mean	SD
Total fixation time (general task)	68.19	14.07	82.17	11.42
Total fixation time (language-specific task)	63.65	13.46	82.59	10.17
Attention recovery (general task)	0.06	0.35	-0.01	0.15
Attention recovery (language-specific task)	0.06	0.38	-0.01	0.17

Note. Standardized values reported for attention recovery.

Regarding the hypothesized predictive effects, there were no overall differences in productive vocabulary between habituators (M=142.37, SD=65.35) and non-habituators

(M=138.64, SD=65.47; t(436.64)=-0.74, p=.46) in the general task. However, there were significant overall differences in productive vocabulary between habituators (M=134.00, SD=66.98) and non-habituators (M=144.71, SD=63.66; t(815.47)=2.37, p=.02, d=0.16) in the language-specific task. Non-habituators had a significantly larger productive vocabulary than habituators. Table 3 presents the correlative associations between total fixation time and attention recovery in the general task and the language-specific task for habituators and non-habituators. In the general task, the positive correlation between total fixation time and productive vocabulary was significant for habituators and non-habituators. Conversely, in the language-specific task, total fixation time was only significantly associated with productive vocabulary for habituators. Overall, the coefficients were small. For both habituators and non-habituators, attention recovery showed no significant association with productive vocabulary in either task. For a complete overview of the bivariate correlations among all variables, see Supplement C.

Table 3

Correlative Associations between the Independent Variables and Productive Vocabulary

	Productive vocabulary	
	Habituators	Non-habituators
Total fixation time (general task)	.14*	.08*
Total fixation time (language-specific task)	.14**	.02
Attention recovery (general task)	.06	-.06
Attention recovery (language-specific task)	-.02	.02

Note. N=841; Pearson correlation coefficients; *p<.05, **p<.01.

Next, we used path analysis to calculate a group comparison between habituators and non-habituators to predict productive vocabulary. Table 4 presents an overview of group comparisons for the general task. While total fixation time failed to reach significance, attention recovery in non-habituators had a marginally significant negative effect on productive vocabulary. In both groups, most control variables had a significant effect on productive vocabulary, except maternal education in habituators. Likewise, most control variables were not significantly associated with total fixation time or attention recovery (Supplement C). The model explained a modest amount of variance (R^2=.23).

Table 4

Model to Predict Productive Vocabulary (General Task)

	Habituators		Non-habituators	
	β	SE B	β	SE B
Total fixation time	.09	0.28	.05	0.21
Attention recovery	.04	10.64	-.07†	16.26
Children's age	.21**	3.63	.15**	2.54
Children's gender (1=male; 2=female)	.18**	7.56	.11**	4.84
Maternal education (years)	.03	1.89	.17**	1.17
Equivalized household income	.13*	9.46	.09*	6.11
Family language (0=German; 1=Not-German)	-.30**	14.64	-.24**	8.96
R^2				.23**

Note. N=841, †p<.10, *p<.05, **p<.01.

We used a similar approach to analyze the measures of the language-specific task. In habituators, total fixation time had a significant positive effect on productive vocabulary

(Table 5). Consequently, only in children with a 50% decrease in looking time was a longer total looking time associated with higher productive vocabulary at 26 months. Attention recovery had no significant effect on productive vocabulary in either of the groups. In both groups, most control variables had a significant effect on productive vocabulary, with the exception of household income. Most control variables were not significantly associated with total fixation time or attention recovery (Supplement C). The model explained a modest amount of variance (R^2=.19). To draw a direct comparison between both tasks, we also calculated a collapsed model with measures of both tasks (Supplement F).

Table 5

Model to Predict Productive Vocabulary (Language-specific Task)

	Habituators		Non-habituators	
	β	SE B	β	SE B
Total fixation time	.12**	0.23	.02	0.27
Attention recovery	-.02	7.96	.01	15.87
Children's age	.21**	3.16	.13**	2.77
Children's gender (1=male; 2=female)	.11*	6.04	.13**	5.49
Maternal education (years)	.19**	1.48	.10*	1.34
Equivalized household income	.08	7.55	.12*	6.97
Family language (0=German; 1=Not-German)	-.23**	11.13	-.28**	10.44
R^2				.19**

Note. N=841, *p<.05, **p<.01.

Discussion

The aims of our study were to investigate the potential predictive effects of children's visual attention and early learning in two categorical habituation-dishabituation tasks on later productive vocabulary while controlling for child characteristics, SES, and family language. As expected, we found positive attention recovery during the dishabituation phase for habituators in both tasks and an analysis of the attention control phase ruled out group-level fatigue effects. However, a substantial number of the children did not habituate in the tasks. Regarding the predictive effects for later productive vocabulary, habituators in the language-specific task had lower scores than non-habituators, which was unexpected. While there were positive correlations between total fixation time in both tasks and productive vocabulary in habituators, attention recovery was not significantly correlated with the outcome. Finally, total fixation time in habituators in the language-specific task had a robust positive effect on productive vocabulary when child-related aspects and children's socioeconomic backgrounds were controlled.

Thus, our findings did not show the expected pattern that attention recovery in habituators, indicating successful stimulus encoding, category formation, and stimulus comparison, predicts later productive vocabulary. For habituators, the measure should represent a basic form of learning, which is why the lack of significant effects in both tasks is surprising, especially because habituators showed a typical looking time pattern. Thus, we cannot conclude that attention recovery in the present tasks indicates early learning or, more generally, that the measure reflects interindividual differences in cognitive resources. As the measure is dependent on the previous habituation phase (Cohen, 2004), we reason that the differentiation between habituators and non-habituators could be more complex than assumed.

The effect of total fixation time could mean that children who are more attentive to the auditory content of the task (i.e., the language label) may develop vocabulary more efficiently, independent of other influential factors regarding children's socioeconomic backgrounds. This counterintuitive finding can be explained by comparable evidence from Dixon and Smith (2008). The authors found that in a sample of 20-month-old toddlers with low attentional focus, total fixation time was negatively correlated with language skills, whereas total fixation time was positively correlated with language skills in toddlers with high attentional focus. To interpret the present data, this could mean that the measure indicates, at least for some children, a form of sustained attention (Ruff, 1986), a general cognitive resource known to be positively predictive of early language skills (Yu et al., 2019). Consequently, reaching the habituation criterion in our study probably does not indicate faster information processing skills but poorer overall attention, which is why few children habituated and habituators in the language-specific task also had lower productive vocabulary scores.

There are two possible explanations for these unexpected findings. First, the stimulus material or task administration were inadequate, that is, too complex or poorly calibrated for the children's age range. Second, the task administration at home resulted in different attentional responses than expected. Regarding the first explanation, previous experiments (Zhang, 2007) and a series of pilot studies conducted with nearly identical materials and procedures in the preliminary stages of NEPS SC1 revealed no such issues. However, the stimulus presentation could have been too short, especially for the age of the sample (e.g., Dixon & Smith, 2008), resulting in familiarization rather than habituation (Aslin, 2007; Fennell, 2018). Indeed, a comparison of looking time data from a previous experiment with 18-month-old toddlers (Zhang, 2007; Experiment B) showed that looking times in the present sample were on average higher. However, it should also be considered that at group level, looking times in the attention control phase did not indicate that the children were inattentive. This leads to the second explanation: Few studies have compared children's performance in habituation-dishabituation tasks (or attentional processes in general) in laboratory and household settings (Bornstein & Ludeman, 1989). Drawing on findings on infants' attention, it could be that the familiar household setting activated the children more (Wass & Leong, 2016), which means that a comparably large decrement during the habituation phase in the general task and language-specific task suggests a small attention span rather than more efficient information processing.

Limitations

Despite the rather high panel stability in NEPS SC1 there was nevertheless longitudinal dropout (i.e., panel-related) as well as missing values (Zinn et al., 2020). Missing values were partly due to technical errors or parental interference in the habituation-dishabituation tasks; however, in the videos that could be used for coding, child-related disturbances (e.g., fussiness, falling asleep) were rare when compared to laboratory studies. Together with external distractions, such disturbances accumulated to marginal intermittent missing values (general task: 1.48%; language-specific task: 2.29%). Thus, we could analyze approximately 80% of the children who were by design selected to participate in the habituation-dishabituation tasks.

In addition, the task administration probably introduced sequence effects. As the general task was always administered before the language-specific task, the latter may have differentiated better between children with low and high attention spans. One could interpret the attentional decrement during the habituation phase as a sign of fatigue, lack of attention, or low attentional focus (Dixon & Smith, 2008), especially as the unstandardized household situation could have drawn children's attention away from the stimulus material. However, as the children's initial looking times in both tasks were comparable and both habituators and non-habituators showed a similar attention recovery during the attention control phase, a linear effect of fatigue seems unlikely for the majority of the children.

As parents reported their children's productive vocabulary, the measure could be prone to response desirability bias. However, as the ELFRA-2 has convergent and prognostic validity for direct measures of language development (Grimm et al., 2019), we considered the instrument adequate. Regarding our control variables, household income was on average higher than that of the general German population (Deutscher Bundestag, 2016). It can be reasoned that the number of people affected by economic hardship or poverty, which is known to negatively influence child development (Conger & Donnellan, 2007), is comparably low. Thus, our analyses may underestimate the effects of household income, especially in low-income groups, where material deprivation and a lack of basic (educational) resources affect child development more severely than in groups with higher income (Yeung et al., 2002).

Finally, the household settings were not standardized. Although experimenters were trained to ensure standardization in the experimental setup and the coders of the videos flagged critical cases, the situation was not identical for all children. This could potentially bias the results, as some children might not have heard the audio cue in the language-specific task as clearly as others, or improper lighting conditions might have made it difficult to identify differences in the categorical stimulus material. Even though great attention was paid to the training of the interviewers, this could have introduced considerable noise into the data. Considering that the predictive validity and reliability of habituation-dishabituation tasks are usually only low to medium (Kavšek, 2004), the present results regarding visual attention should not be surprising. We assume that the familiar environment positively affected children's attention, which is why total fixation time but not attention recovery in the dishabituation phase was positively predictive of productive vocabulary.

Implications and future research

Although the present findings regarding children's looking time patterns were surprising, this is not unprecedented in infant research (Colombo et al., 2009; Dixon & Smith, 2008). Similarly, the present results suggest that processes of stimulus encoding, retrieval and comparison in the habituation phase and visual attention are linked in a complex way that cannot be disentangled with the present data. Overall, the robust sample size of the present results suggests that long looking times should be reconsidered, especially when the habituation-dishabituation tasks are administered in a familiar environment. Consequently, future research on habituation-dishabituation tasks administered in the children's homes (or any familiar environment) should use more trials in the habituation phase (e.g., 13-15; Dixon & Smith, 2008), a longer exposure to the stimulus material (e.g., Colombo et al., 2009), and novelty preference instead of attention recovery in the dishabituation phase (Oakes, 2010). Therefore, future research should investigate how certain socioeconomic aspects of the household (e.g., noise, room arrangement, and crowding) influence children's attentional responses (e.g., Tomalski et al., 2017) and how that affects the interpretation of habituation-dishabituation measures, especially when compared to typical findings from standardized laboratory settings.

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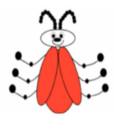
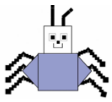
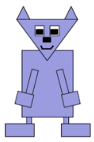
Supplement

A. Stimulus material

General task

Habituation phase (trial 1-9; example)	Dishabituation phase (trial 10-11; example)	Attention control phase (trial 12-13)
		

Language-specific task

Habituation phase (trial 1-9; example)	Dishabituation phase (trial 10-11; example)	Attention control phase (trial 12-13)
		

B. Children's looking times

Table 1

Descriptive Information on Looking Times in the General Task

	Habituators		Non-habituators	
	M	SD	M	SD
Habituation: Trial 1	8.41	1.76	8.20	1.87
Habituation: Trial 2	7.55	2.11	8.47	1.60

Habituation: Trial 3	7.21	2.33	8.38	1.61
Habituation: Trial 4	7.04	2.45	8.50	1.57
Habituation: Trial 5	6.51	2.75	8.20	1.67
Habituation: Trial 6	6.31	2.72	8.10	1.75
Habituation: Trial 7	6.08	2.70	8.15	1.71
Habituation: Trial 8	6.07	2.74	8.10	1.77
Habituation: Trial 9	6.17	2.79	8.08	1.73
Dishabituation: Trial 10	6.85	2.61	8.00	1.92
Dishabituation: Trial 11	5.94	2.75	7.40	2.18
Attention control: Trial 12	6.48	2.61	7.64	1.95
Attention control: Trial 13	5.33	2.58	6.44	2.32

Note. N=841; looking times reported in seconds.

Table 2

Descriptive Information on Looking Times in the Language-specific Task

	Habituators		Non-habituators	
	M	SD	M	SD
Habituation: Trial 1	8.59	1.59	8.84	1.50
Habituation: Trial 2	7.45	2.19	8.63	1.50
Habituation: Trial 3	7.07	2.38	8.57	1.53
Habituation: Trial 4	6.37	2.47	8.08	1.65
Habituation: Trial 5	6.24	2.51	8.29	1.62
Habituation: Trial 6	6.35	2.53	8.40	1.59
Habituation: Trial 7	5.68	2.74	8.15	1.65
Habituation: Trial 8	5.01	2.66	7.99	1.69
Habituation: Trial 9	5.06	2.65	7.84	1.74
Dishabituation: Trial 10	5.82	2.74	7.80	1.99
Dishabituation: Trial 11	5.30	2.83	6.98	2.45
Attention control: Trial 12	6.40	2.77	7.60	2.28
Attention control: Trial 13	5.49	2.71	6.62	2.50

Note. N=841; looking times reported in seconds.

C. Correlative associations

Table 3

Overview of Bivariate Correlations between Variables

	Productive vocabulary	TFT (general)	ATR (general)	TFT (language-specific)	ATR (language-specific)	Children's age	Children's gender	Maternal education	Household income
TFT (general)	.08*								
ATR (general)	.00	.05							
TFT (language-specific)	.12**	.33**	.01						
ATR (language-specific)	-.02	.01	.07*	-.01					
Children's age	.17**	.00	.00	.02	.00				
Children's gender	.13**	.02	.00	.06	.01	-.03			
Maternal education	.26**	.07*	.03	.02	-.03	.06	.02		
Household income	.23**	.13**	.00	.08*	-.02	.03	.02	.43**	
Family language	-.31**	.00	-.02	-.02	-.01	.04	.00	-.26**	-.21**

Note. N=841; TFT=total fixation time; ATR=attention recovery; children's gender (1=male; 2=female); family language (0=primarily German; 1=primarily another language).

D. Dishabituation and attention control

Attention recovery in habituated children is typically interpreted as successful stimulus encoding and discrimination. Hence, at the group level, children should have longer looking times at novel stimuli (novelty effect). However, owing to the fixed-trial design, it can be expected that a certain number of children did not habituate in the nine habituation trials, which should result in a familiarity effect (i.e., a lack of attention recovery). Thus, we tested whether children, on average, spent more time looking at the first dishabituation trial than the last habituation trial. In both the general task (Table 4) and language-specific task (Table 5), habituators looked on average longer at the first dishabituation trial, whereas non-habituators remained stable.

Table 4

Dishabituation Phase: Looking Time Comparison (General Task)

	Habituators		Non-habituators	
	M	SD	M	SD
Trial 9	6.17	2.79	8.08	1.73
Trial 10	6.85	2.61	8.00	1.92
Paired t test	$t(237)=3.15$, $p<.01$, $d=0.25$		$t(602)=1.04$, $p=.30$	

Note. N=841.

Table 5

Dishabituation Phase: Looking Time Comparison (Language-specific Task)

	Habituators		Non-habituators	
	M	SD	M	SD

Trial 9	5.06	2.45	7.84	1.74
Trial 10	5.82	2.74	7.80	1.99
Paired t test	t(393)=5.24, p<.01, d=0.28		t(446)=0.35, p=.73	

Note. N=841.

In addition, we tested for differences in looking times between the last dishabituation trial and the first attention control trial to check for possible effects of fatigue. In both the general task and language-specific task, habituators (Table 6) as well as non-habituators (Table 7) looked on average longer at the first attention control trial when compared to the previous dishabituation trial. Although the effect sizes were larger in habituators, this implies that at group-level, the children showed significant attention recovery towards the novel stimulus. Thus, we reasoned that there were no linear effects of fatigue.

Table 6

Attention Control Phase: Looking Time Comparison (General Task)

	Habituators		Non-habituators	
	M	SD	M	SD
Trial 11	5.94	2.75	7.40	2.18
Trial 12	6.48	2.61	7.64	1.95
Paired t test	t(237)=2.76, p<.01, d=0.20		t(602)=2.43, p=.02, d=0.12	

Note. N=841.

Table 7

Attention Control Phase: Looking Time Comparison (Language-specific Task)

	Habituators		Non-habituators	
	M	SD	M	SD
Trial 11	5.30	2.83	6.98	2.45
Trial 12	6.40	2.77	7.60	2.28
Paired t test	t(393)=7.03, p<.01, d=0.39		t(446)=4.84, p<.01, d=0.26	

Note. N=841.

E. Cut-off criterion

To make sure that the children's fixation times can be interpreted as a valid indicator for having processed the presented stimuli adequately, cut-off criteria for short fixation times (i.e., short episodes of looking at the target) are often used. However, there is no consensus on what cut-off criterion to use in the literature (Colombo & Mitchell, 2009). Typically, a range of 0.5-1 seconds is suggested (Colombo & Mitchell, 1990; Kavšek, 2013), which is why the present robustness checks of the final models to predict productive vocabulary were calculated with a 0.5 seconds cut-off criterion. As values below this criterion were per definition invalid and no full maximum likelihood estimator was used, the sample was considerably smaller (N=737).

Table 8 and Table 9 present results that correspond to Table 4 and Table 5 in the main manuscript. Generally, the effects are similar and the explained variances are comparable to the full sample when no cut-off criterion was applied. The main difference was that total fixation time in the language-specific task did not reach significance (Table 9). This could be due to the reduced sample size or because shorter looking time events also contribute to how the children processed the stimulus material. Thus, implementing a cut-off criterion and consequently applying listwise deletion for cases with short looking times for single trials, could have resulted in a biased subsample because children with fluctuating looking patterns were dropped from further analyses.

Table 8

Model to Predict Productive Vocabulary (General Task)

	Habituators (N=171)		Non-habituators (N=566)	
	β	SE B	β	SE B
Total fixation time	.02	0.42	.01	0.23
Attention recovery	.05	17.38	-.06	17.38
Children’s age	.23**	4.31	.15**	2.60
Children’s gender (1=male; 2=female)	.20**	8.96	.11**	4.97
Maternal education (years)	-.01	2.29	.20**	1.20
Equivalized household income	.02	10.57	.04	5.26
Family language (0=German; 1=Not-German)	-.36**	16.48	-.26**	9.14
R^2				.22**

Note. N=737, **p<.01.

Table 9

Model to Predict Productive Vocabulary (Language-specific Task)

	Habituators (N=316)		Non-habituators (N=421)	
	β	SE B	β	SE B
Total fixation time	.07	0.28	.04	0.29
Attention recovery	-.04	11.0	-.01	17.15
Children’s age	.19**	3.47	.13**	2.91

Children's gender (1=male; 2=female)	.13**	6.66	.11*	5.72
Maternal education (years)	.23**	1.71	.10*	1.37
Equivalized household income	-.02	7.04	.09	6.35
Family language (0=German; 1=Not-German)	-.28**	12.03	-.30**	10.61
R^2				.21**

Note. N=737, *p<.05, **p<.01.

F. Collapsed analyses to predict productive vocabulary

To draw a direct comparison between both the general task and language-specific task, we calculated a collapsed model with measures of both tasks. However, the match between children who habituated in both tasks was low (N=140, N=16.65%). Because the group of non-habituators was more heterogeneous than in the previous analyses, we opted to only analyze habituators. Thus, Table 10 presents an overview of the predictive effects in this subsample of habituated children. Total fixation time in the language-specific task had a significant effect on productive vocabulary, while the effects of the control variables were in general comparable to those in Table 4 and Table 5 in the main manuscript.

Table 10

Model to Predict Productive Vocabulary (Language-specific Task)

	Habituators (N=140)	
	β	SE B
Total fixation time (general task)	.01	0.41
Attention recovery (general task)	.13	14.51
Total fixation time (language-specific task)	.24**	0.37
Attention recovery (language-specific task)	.03	11.13

Children’s age	.24**	4.84	
Children’s gender (1=male; 2=female)	.15*	9.93	
Maternal education (years)	.10	2.49	
Equivalized household income	.16*	12.76	
Family language (0=German; 1=Not-German)	-.22**	18.66	
R^2			.32**

Note. N=140, *p<.05, **p<.01.

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Appendix C: Study 3

Numeracy skills in young children as predictors of mathematical competence

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ORIGINAL ARTICLE

Numeracy skills in young children as predictors of mathematical competence

Maximilian Seitz[1] | Sabine Weinert[2]

[1]Leibniz Institute for Educational Trajectories, Bamberg, Germany
[2]Department of Developmental Psychology, University of Bamberg, Germany

Correspondence
Maximilian Seitz, Leibniz Institute for Educational Trajectories, Wilhelmsplatz 3, 96049 Bamberg, Germany.
Email: maximilian.seitz@lifbi.de

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Abstract

As mathematical competence is linked to educational success, professional achievement, and even a country's economic growth, researchers have been interested in early predictors for quite some time. Although there have been numerous studies on domain-specific numerical abilities predicting later mathematical competence in preschool children, research in toddlers is scarce, especially regarding additional influential aspects, such as domain-general cognitive abilities and the children's social background. Using a large-scale dataset, the present study examined predictive effects of numeracy skills in 17-month-olds for later mathematical achievement. We found small, positive effects, even when controlling for child-related variables (i.e., age and sex) and the children's social background (i.e., maternal education and household language). Additionally, we compared results with a domain-general categorization task and found no distinct effect on mathematical competence. The present results are discussed with regard to the specificities of the dataset, as well as implications for future studies on predictors of mathematical competence.

KEYWORDS
cognitive development, mathematical competence, numeracy skills

BACKGROUND

Over the last few decades, research has provided ample evidence supporting a basic understanding of numerosity in children below 3 years of age (e.g., Cordes & Brannon, 2009; Starkey & Cooper, 1980; Wynn, 1992). A number of studies have shown that infants discriminate between various small number sets and pay attention to the number ratio of displayed objects (for a review, see Cantrell & Smith, 2013). Also, there is mounting evidence that Wynn's (1992) original findings on early arithmetic skills, namely that 5-month-old infants have basic addition and subtraction skills, are reliable (for a meta-analysis, see Christodoulou et al., 2017). Given that differences in basic numerical understanding appear to remain relatively stable during early childhood, it is therefore not surprising that researchers expect early numeracy skills to be predictive of later mathematical competence (Feigenson et al., 2013). However, meta-analyses reveal that most studies on the predictive effects of early numerical understanding on later mathematical competence focus on children aged 5 years and above (Chen & Li, 2014; Schneider et al., 2017, 2018). Existing studies that focus on younger children are still rare, limited in sample size (Ceulemans et al., 2015; Starr et al., 2013), and often lack important controls. Therefore, the present study uses a large-scale dataset to investigate the relationship between early numeracy skills – that is, early number perception and sensitivity to numerical changes in 17-month-old toddlers – and later mathematical competence, while controlling for the children's social background and early domain-general cognitive abilities.

Numeracy skills in early childhood

Mathematical competence is linked to educational success (Aubrey et al., 2006; Duncan et al., 2007), the solving of daily problems (Stacey, 2012), professional achievement (Organisation for Economic Co-operation & Development, 2005), and even to a country's economic growth (National Mathematics Advisory Panel, 2008; Organisation for Economic Co-operation & Development, 2010). Thus, it is not surprising that researchers want to identify how precursor abilities such as early numeracy skills development in young children. Numeracy skills are a central concept of early perception, processing, and reasoning about numbers (Feigenson et al., 2004). They are a widely researched concept and are also referred to as quantitative abilities, numerical reasoning, or numerical abilities (Antell & Keating, 1983; Bynner & Parsons, 1997; Geary, 2000; Starkey, 1992; Van de Rijt & Van Luit, 1999).

From a theoretical perspective, cognitive models of the development of numerical understanding in young children argue that infants perceive numerosity non-verbally and approximately, using basic perceptual cues (Mix et al., 2002). In particular, Clements et al. (2019) assume that infants start to quantify rigid objects with a general pre-attentive process that individuates discrete objects, while a specific number-related estimator simultaneously stores information about the quantity of the objects. Thus, two different cognitive systems are actively involved in the processing of numerical information: an analog magnitude system, which helps infants to discriminate between continuous number ratios of different sets of objects, and an object file system, which helps infants to represent an exact and discrete number of objects (Cordes & Brannon, 2008). With this theoretical approach, it can be reasoned that: (I) the understanding of numbers and quantities already starts in infancy; (II) numerical understanding is related to attentional processes, general perceptual skills, and more specific encoding processes of quantitative information; and (III) attention and attentional shifts to numerical stimuli comprising different numerical relations may indicate numerical understanding.

Attention to numerical stimuli is often examined using visual familiarization or habituation–dishabituation tasks. Such tasks are useful for investigating a broad range of cognitive skills in early childhood such as general visual or auditory discrimination and/or categorization skills (e.g., Arterberry & Bornstein, 2002). They present children with a series of either identical (i.e., information processing tasks) or similar (i.e., categorization tasks) stimuli. Observable behavioural responses such as looking behaviour, head turning (e.g., Lipton & Spelke, 2003), or the sucking rate (e.g., Antell & Keating,

Statement of contribution

What is already known on the subject?

- Numeracy skills in preschool children predict later mathematical competence.
- Predictive effects for children under 3 years have seldom been examined.
- Existing studies often have small samples and do not control for the children's social background.

What the present study adds?

- Large-scale data are used to analyse the predictive effects of early numeracy skills at 17 months on later mathematical competence.
- The study controls for the children's social background and early domain-general cognitive abilities.

1983) are recorded and used as a basis for calculating various measures of early information processing skills (for reviews, see Colombo & Mitchell, 2009; Kavšek, 2013). For the familiarization or habituation phase, measures of attentional decrement are used, which are interpreted as reflecting general information processing skills (e.g., Colombo et al., 2004). For the dishabituation phase, novelty measures are used. They are assumed to capture discriminatory memory performance or attention recovery (e.g., Friedman et al., 1970; Laucht et al., 1994). Habituation–dishabituation tasks are used for studying cognitive development (Rose et al., 2009) and the predictive effects of early cognitive measures for later competencies (Bornstein et al., 2013).

Domain-specific tasks are used to study a child's reaction in the dishabituation phase (novelty effect), showing how previous information is encoded, retrieved, and compared to the novel stimulus (e.g., Rose et al., 2012). Thus, domain-specific tasks assessing early numeracy skills usually habituate children to certain numerosity or ratio of quantities and investigate their reaction to novel quantitative information in the dishabituation phase (e.g., Antell & Keating, 1983; Ceulemans et al., 2015; Feigenson et al., 2013; Starr et al., 2013; Wynn, 1992). This reaction or novelty effect is generally interpreted as a basic form of numerical understanding, even though the effects are often confounded with space, contour shape, or density (Cantrell & Smith, 2013; Cordes & Brannon, 2008 for a critical discussion).

Early numeracy skills and mathematical competence

Mathematical competence is often conceptualized as a cognitive resource and as readiness to master challenges associated with the domain of mathematics (Niss & Højgaard, 2019). It involves, for example, the handling of operations with quantities, understanding of relationships between numbers, and geometrical or statistical understanding. Such definitions are compatible with the mathematical frameworks of the PISA and TIMSS studies (Lindquist et al., 2017; Organisation for Economic Co-Operation & Development, 2003). In these studies, mathematical competence, or mathematical literacy, also plays a fundamental role in preparing young people for everyday activities as well as for vocational challenges. Thus, mathematical competence enables a person to apply abstract mathematical operations in everyday contexts (Ojose, 2011), for example when describing, explaining, and predicting phenomena (Stacey, 2012).

Accumulated evidence suggests that there is a certain degree of continuity in mathematical development (for a review, see Siegler, 2016), as early interindividual differences are high (Duncan et al., 2007) and remain rather stable during the first years of schooling (Bailey et al., 2014; Jordan et al., 2009). Even earlier, namely at the age of 3–5, mathematical knowledge and numeracy skills – such as advanced counting skills, counting with cardinality, and subitizing (see below) – are strong predictors of later mathematics achievement (Nguyen et al., 2016; Watts et al., 2014). This highlights the notion that the association between numeracy skills and mathematical competence develops early on in life and remains rather stable. For example, some authors argue that subitizing – namely, the ability to immediately perceive a small number of objects without explicitly counting them – is related to the immediate and intuitive perception of numerosity or is simply a basic encoding mechanism before formal counting is acquired (Clements et al., 2019). According to the subitizing model of Clements et al. (2019), this ability is related to how children form number-related schemes by abstracting numbers and integrating this information into a counting-based verbal system. While several studies have investigated the associations between the numeracy skills of preschool children and their later mathematical competence in elementary school (e.g., Aunio & Niemivirta, 2010; Fuhs & McNeil, 2013; Krajewski & Schneider, 2009; Nguyen et al., 2016), studies of even younger children are relatively scarce.

Two notable studies investigated the predictive effects of very early numeracy skills and later mathematical competence but their findings were not as straightforward as the findings on numeracy in later childhood. Starr et al. (2013) studied the approximate number system in 6-month-old infants using a numerical change detection task (Libertus & Brannon, 2010). The authors presented the children with a sequence of slides with varying quantities of black dots. In one task, there was always the same amount of dots, whereas in the other task the numbers of dots switched between 10 and 20. Weber fraction scores were calculated to identify children with a higher number sense, that is, a higher discrimination skill for the numerical change. The scores predicted standardized mathematics test scores at 3.5 years of age ($r = .28$, $p < .05$). The standardized mathematics test featured tasks such as counting, number comparison, number knowledge, and basic calculation (Ginsburg & Baroody, 2003). The second study investigated number discrimination using a habituation task (Ceulemans et al., 2015). In this study, 8-month-old infants were shown sets of slides with different arrays of dots. In a test phase, the children were shown alternating slides of the familiar and novel stimuli. The difference in looking times was dichotomized, with children who looked at the novel stimulus for a longer time being categorized as having successfully discriminated between the presented magnitudes. However, the authors did not find an effect of number discrimination on the children's performance in a standardized cardinality test administered at 4 years of age. They only found a positive effect of number discrimination at 24 months on later cardinality scores and concluded that infancy might be too early for measures of number discrimination to predict later cardinality and, thus, that future research should focus more on toddlers.

Taken together, there is evidence for an association between early numeracy skills and later mathematical competence but the findings related to very young children are mixed and rare. The study by Starr et al. (2013) found a weak but significant correlation that was robust, even when general cognitive abilities were controlled for. The study by Ceulemans et al. (2015) did not identify effects in 8-month-old children but in 24-month-olds. Although the studies had well-controlled experimental designs, both drew on small samples, a fact Ceulemans et al. (2015) pointed out as a central shortcoming of previous research. Further, only Starr et al. (2013) included measures of early domain-general information processing which should be related to both early numeracy skills and later mathematical competence.

The present study

The present study investigates the predictive relationship between early numeracy skills and mathematical competence in young children. Hereby, we address several shortcomings of previous studies. First, only a few studies have investigated numeracy skills in children below 3 years of age and later mathematical competence. As early numeracy skills in preschool-age have been shown to be positively associated with later number knowledge, arithmetical knowledge, and complex mathematical problem solving (Aunio & Niemivirta, 2010; Chu et al., 2016), the present study extends this limited body of literature to toddlers.

Second, many studies on early numeracy skills use domain-specific tasks, for example, measures of numerical discrimination (e.g., Cordes & Brannon, 2009; Xu & Arriaga, 2007). However, they often do not include more domain-general tasks, unlike studies on preschool children (Chu et al., 2016; Passolunghi & Lanfranchi, 2012). The ability to abstract patterns (Amit & Neria, 2008) and form structural knowledge about numerical relations constitutes the basis for acquiring mathematical competence (Jonassen et al., 1993; Sfard, 1991). Thus, both domain-specific numeracy skills as well as more general cognitive abilities may contribute to task performance (Clements et al., 2019).

Lastly, research on whether numeracy skills in infancy predict later mathematical competence is typically conducted in small laboratory studies. It has been discussed whether a series of studies with small samples might lead to an overestimation of the actual effect at the population level (Maxwell, 2004; Oakes, 2017). Further, previous studies were conducted on rather homogenous samples and did not consider children's social background. Indeed, Fuhs and McNeil (2013) argue that the numeracy skills of preschool children (4–6 years of age) from low-income families could be more weakly associated with mathematical competence because these children might not have fully integrated numeracy skills in the larger context of mathematical competence. Their findings supported their initial expectation that social background is already an influencing factor for this age group. Furthermore, a longitudinal study on the effect of learning environments on the development of numeracy skills in preschool (i.e., counting, identification of numbers, knowledge of shapes, and understanding of early mathematical concepts, such as addition or subtraction) found household language and maternal education to be associated with the children's initial numeracy levels and their development of numeracy skills (Anders et al., 2012).

Therefore, the present study used a large-scale dataset to address these issues, controlling for central variables that have a meaningful impact on how young children develop mathematical competence. In particular, drawing on existing literature, we controlled for children's sex (Aunola et al., 2004) and age (Siegler & Braithwaite, 2017). Furthermore, we included the following social background characteristics: maternal education, as it influences a child's learning environment in formative years (Anders et al., 2012; Aunio & Niemivirta, 2010; Melhuish et al., 2008); household language, as the mathematical competence test was administered in German and mathematical achievement is usually correlated with language skills (Martiniello, 2009).

Research questions

Taken together, over the last few decades, research has been conducted to determine whether early numeracy skills are predictive of later mathematical competence, yet findings on early childhood are still limited. We used data from a large-scale study, which allowed us to additionally test and control for potential influences of the children's social background. In particular, our study had three main goals. First, we investigated whether early numeracy skills in 17-month-old children are predictive of mathematical competence at the age of 4 years. For that, we looked at the children's novelty effect in a numerical visual habituation–dishabituation task. We hypothesized that the novelty effect would be positively associated with later mathematical competence, even when controlling for general attention in the habituation phase. Second, we investigated whether important aspects of the children's social background influence this relationship. Many previous studies did not control for such aspects, but we suspected that the effect of numeracy skills on mathematical competence would be robust, as studies with older children confirm that domain-specific precursors are relevant for acquiring mathematical skills. Finally, we additionally used data of a domain-general categorization task with non-numerical stimuli to test whether the effect on mathematical competence is really due to domain-specific early numeracy skills.

METHOD

Sample

The Newborn Cohort of the National Educational Panel Study (NEPS SC1; Blossfeld et al., 2011) is a longitudinal dataset from a representatively drawn sample of N = 3481 infants born in Germany

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between February and July 2012 (Weinert et al., 2016). Each year, both the target children (observational tasks or competence tests) and their parents (parental interviews and questionnaires) take part in the survey. Over the course of the first years, about 80% of the target children were regularly assessed (Zinn et al., 2020). By design, only about half (N = 1893) of the original sample was asked to take part in the habituation–dishabituation tasks at the second measurement point (children aged on average 17 months); after dropout, N = 1510 parents participated in the study. Most of them (98.28%) gave informed consent for the habituation–dishabituation tasks and a total of N = 1315 children successfully finished the tasks, after child-related disturbances and technical errors were excluded. The mathematical competence test was administered at the fifth measurement point when children were on average 4 years old, which means there was a further longitudinal dropout. This study included all children who participated in the mathematical competence test from the subsample at the second measurement point and who also successfully participated in the habituation–dishabituation tasks (N = 871 children; 50.63% female).

Assessment of early numeracy skills

At the second measurement point, a visual habituation–dishabituation task with numerical stimuli was administered. The task was based on Cooper's (1983) method for assessing children's attention towards and discrimination of numerical changes, which have been suggested to be central precursor abilities for later mathematical competence (e.g., Feigenson et al., 2013). Cooper (1983) showed 10–12-month-old children two different arrays of dots. In the habituation phase, one array always featured more dots, while in the dishabituation phase the other array featured more dots. Thus, it was tested whether the children could process numerical changes. In the present study, all children were presented with the same stimulus material in the same sequence (fixed trial procedure); thus, surface area, perimeter, and density were not manipulated. All children were presented with a habituation phase, a subsequent dishabituation phase, and an attention control phase. The stimulus pictures (trials) in the habituation and dishabituation phases were presented for 10 s each, with an intertrial interval of 2 s. In the end, two additional and vastly different pictures were shown (attention control phase). We used these trials to check for outliers, possibly indicating that some children had fallen asleep or were not paying attention at all. As these control trials did not contain numerical stimuli, we did not include them in the present analyses. In the habituation phase, the stimulus sequence consisted of four pictures with varying amounts of identical cartoon sheep on the left side and identical bears on the right side were used. Instead of simple dots, this rather child-friendly stimulus material was chosen, as the household setting could have potentially distracted the children from boring pictures (the stimulus material was pretested; Freund, 2012). In Cooper's (1983) study, there were five familiar trials (i.e., the habituation phase), one (novel) reversed dishabituation trial and one trial with an equal ratio. Because the children in the original experiment were younger (10–12-month-olds), we expected the current number of habituation trials to be sufficient. The ratio of sheep and bears in the four trials of the habituation phase was always below the subitizing threshold, namely 3:2 (trial 1), 4:3 (trial 2), 3:1 (trial 3), and 4:2 (trial 4), respectively. As a fixed-trial procedure was used, this sequence was the same for all children, with no repetition of any trial. Thus, in the habituation phase, there were always more sheep than bears, while the first dishabituation picture reversed that ratio (2:4) and the second dishabituation picture had a balanced ratio (3:3). The total area and contour length varied between the trials. Each trial was accompanied by a short three-note auditory cue to attract children's attention. The task was administered by trained interviewers in the children's homes using a laptop (Weinert et al., 2017). The task lasted 94 s in total, not counting a pause interval of about 10 s between the numerical and the categorization task. The child's looking behaviour was recorded, and coding was performed offline using Mangold INTERACT software. For every single coding frame (30 frames per second), coders had to rate the children's looking behaviour (on/off target); the reliability was good, κ = .93. The present study used the accumulated sum of looking times for each trial, which ranged from 0 to 10 s. Looking times were not truncated, so there was no cut-off criterion for short looking times.

Children who discriminated between trials of the habituation and trials of the dishabituation phase were expected to look at the stimulus material for a longer time in the latter. In other words, they were expected to dishabituate to the novel stimulus which displayed a change in the number relation (Johnson & Zamuner, 2010). As the response to the novel stimulus reflected how the previous habituation phase was encoded (Kavšek, 2013), the novelty effect was defined as the difference in manifest looking times between the first dishabituation trial and the last habituation trial. We only used the first trial as this was the most discrepant to the habituation pictures (inverse number relation) and because using only the first novel stimulus had been shown to be the most robust (Kavšek, 2004). Higher values represent a strong reaction towards the dishabituation stimulus, indicating a large novelty response. In addition, we defined total time looking at the target during the habituation phase as another commonly used measure (e.g., Colombo et al., 1987). Hereby, we wanted to control for the children's general attention (Colombo et al., 2010).

Assessment of domain-general cognitive abilities

In addition to the numerical habituation–dishabituation task, a general habituation–dishabituation task with categorical stimuli was used. The task was also administered at the second measurement point, and the experimental setup, as well as the procedure, were similar to the numerical task – both tasks mirror the standard procedure of fixed-trial experiments in infant habituation. The only differences between both tasks were the number of trials in the habituation phase (i.e., nine pictures instead of four) and the stimulus material (i.e., categorical but not numerical). The higher number of trials in the habituation phase was deemed necessary for the children to form an adequate mental representation of the stimulus category. The original series of experiments from which this task was adapted had the same number of habituation trials – with the exception of the dishabituation phase having a novelty preference design (Zhang, 2007). The pictures presented in the habituation phase featured one round-shaped cartoon bug each which mainly differed with regard to highly specific details as well as the colour scheme; the pictures in the dishabituation phase featured rectangular-shaped cartoon bugs which differed with respect to many features from the habituation bugs. As in the numerical task, this sequence was the same for all children, with no repetition of any trial. We used the same approach to the data and the same measures as in the numerical task, namely the novelty effect and total looking time. The categorization task was always administered before the numerical task, and there was an additional dropout of $N = 64$ cases, mostly due to child-related reasons associated with the start of the tasks. The task lasted 154 s in total.

Assessment of mathematical competence

Children's mathematical competence was assessed at the fifth measurement point (children aged 4 years) with an adapted version of the Kieler Kindergartentest (Grüßing et al., 2013) developed specifically for implementation in the NEPS (Neumann et al., 2013). The test was administered on a tablet computer and consisted of 20 verbally administered questions that assess age-appropriate knowledge on the following content areas: sets, numbers, and operations (I), units and measuring (II), space and shape (III), change and relationships (IV), and data and chance (V; Jordan et al., 2015). The reliability of the test was acceptable (EAP/PV reliability = 0.70 and weighted likelihood estimators [WLE] reliability = 0.67). Due to the broad performance distribution, it was expected to accurately measure person abilities in high- and low-ability regions (Petersen & Gerken, 2018). The present analyses used WLE as an estimated score of individual competence (Warm, 1989).

Control variables

As child characteristics, we included sex (50.63% female) and age at the fifth measurement point; the children's social background was indicated by maternal education and household language. All control variables are reported for the final sample of $N = 871$ children.

For *maternal education*, we used the International Standard Classification of Education (ISCED), which classifies a broad range of institutional and professional qualifications in ascending levels, with higher scores representing higher educational degrees. This study uses an adapted version of ISCED 1997 (United Nations Educational Scientific & Cultural Organization, 2012) with a total of 10 categories, sorted in ascending order from no formal qualification to doctorate/habilitation.

For *household language*, we used a dichotomized variable. Children were grouped into primarily German (87.37%) and primarily non-German speaking households. If the parents reported at least once during the first five measurement points that the household language was primarily not German, the children were grouped into the latter category.

Statistical analyses

To examine associations between early measures of the numerical task and mathematical competence as well as between the control variables and mathematical competence, correlations were computed (Pearson correlation, point biserial correlation, and phi correlation, respectively). Furthermore, we conducted stepwise multiple linear regression analyses. We started with the novelty effect as the sole predictor of mathematical competence. The total looking time during the numerical task (habituation phase), individual child characteristics (i.e., sex and age), and the characteristics of the child's social background (i.e., maternal education and household language) were then added stepwise. In the last step, we calculated a similar multiple regression analysis, additionally including measures of the general categorization task, and then compared both final models with a Wald test. As preterm birth is generally associated with higher rates of mathematics learning disabilities (Simms et al., 2013; Taylor et al., 2009), we initially analysed children born preterm separately ($N = 46$) but found no effect on the association between their early numeracy skills and later mathematical competence. Thus, we report collapsed data for all children. There was a certain degree of missing values for the general categorization task (7.35%). However, as there was no correlation with the control variables, these values were regarded as missing at random, and full information maximum likelihood (FIML) was chosen to estimate the values. The calculations were performed in STATA© release 16 (StataCorp, 2019). The discussed findings are statistically significant at the $\alpha \leq .05$ level unless otherwise noted.

RESULTS

Table 1 displays descriptive information regarding the children's age, maternal education, mathematical competence (fifth measurement point), early numeracy skills, early categorization skills (i.e., novelty effects assessed at the second measurement point), and all control variables.

Because of the relatively high degree of dropout and the reduced sample at the second measurement point (by design), we conducted several analyses testing for potential bias in the data. First, we compared the children in our final sample ($N = 871$) with the rest of the initial sample of NEPS SC1 ($N = 2610$) regarding their social background. A Welch's t-test revealed a significant difference between the final sample ($M = 7.01$, $SD = 2.46$) and the rest of the cohort ($M = 5.85$, $SD = 2.93$; $t(1753.22) = -11.53$, $p < .001$) regarding maternal education. A proportion test also revealed a significant difference between the final sample ($M = 0.13$, SE = 0.01) and the rest of the cohort ($M = 0.24$, SE = 0.01; $z = 7.09$, $p < .001$) regarding household language, indicating that children in the final sample were less likely to come from primarily non-German speaking households. Next, we investigated differences in individual

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TABLE 1 Descriptive overview of mathematical competence, early numeracy skills, and control variables

	N	Mean	Median	*SD*	Min	Max
Mathematical competence	871	0.07	0.03	1.02	−2.85	3.19
Numeracy skills	871	0.04	0	2.89	−9.27	9.63
Numerical task: total looking time (seconds)	871	30.36	31.97	7.30	1.80	40.16
General categorization task: Novelty effect	807	0.07	0	2.43	−7.60	9.93
General categorization task: Total looking time (seconds)	807	70.40	72.65	12.24	12.60	90.27
Child age (months; second measurement point)	871	17.02	17.02	0.59	15.77	18.95
Child age (months; fifth measurement point)	871	50.06	50.10	1.57	45.74	53.67
Maternal education	871	7.12	8	2.42	0	10

Note: Variables mathematical competence and maternal education refer to the fifth measurement point; numeracy skills, categorization skills, and total looking times of the children were assessed at the second measurement point.

child characteristics. As expected, there was an age difference between the final sample and the rest of the cohort, which was due to the habituation–dishabituation tasks being assessed several weeks after the parental interview at the second measurement point. There were no differences regarding the children's sex, $X^2(1, N = 3481) = 1.22, p = .27$. Importantly, the effects were also found when children in the final sample were compared only to the children who were selected by design to participate at the second measurement point.

Table 2 shows the correlations between mathematical competence at the age of 4, numeracy skills and categorization skills at 17 months, as well as all control variables. In line with our expectation, there was a positive correlation between early numeracy skills, as measured by numerical habituation–dishabituation task at 17-months of age, and the mathematical competence test at 4 years ($r = .07$, $p = .03$). In addition, there were significant correlations between mathematical competence and age ($r = .19, p < .001$), sex ($r = .08, p = .01$), maternal education ($r = .17, p < .001$), and household language ($r = -.15, p < .001$). The association between mathematical competence and total looking time was marginally significant for the numerical habituation task. There were no significant correlations between early numeracy skills and the control variables.

We conducted multiple linear regression analyses (Table 3) to predict mathematical competence based on early numeracy skills (Model 1.1). Total looking time for the numerical task (Model 1.2), individual child characteristics, and indicators of the child's social background (Model 1.3) were added stepwise. The exclusion of all children born preterm ($N = 46$) resulted in virtually identical effects and the model fits with the effect of numeracy skills in Model 1.1 being only marginally significant. Thus, collapsed results are reported.

In all models, early numeracy skills were a stable, significant predictor of later mathematical competence. Total looking time in the numerical task also predicted mathematical competence. For the control variables, standardized coefficients show that the children's age, maternal education, and household language each had a stronger predictive effect on mathematical competence than early numeracy skills. The overall explained variance was 10%.

To analyse the degree to which domain-general cognitive abilities might account for the effect of the numerical task, again multiple linear regression analyses were conducted (Table 4). Model 2.1 included early numeracy skills and total looking time for the numerical task as well as the novelty effect and total looking time for the general categorization task at 17 months to predict mathematical competence at the age of 4. In Model 2.2, individual child characteristics and indicators of the child's social background were added. The exclusion of all children born preterm ($N = 46$) resulted in virtually identical effects and model fits; only numeracy skills in Model 2.1 and total looking time for the numerical task in Model 2.2 were marginally significant. Thus, collapsed results are reported.

In both models, the measures of the general categorization task had no significant effect, while the effects of the numerical task remained significant. Based on Model 2.2, a Wald test was calculated to

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TABLE 2 Correlations between early numeracy skills (age 17 months), mathematical competence (age 4 years), and all control variables ($N = 871$)

	Mathematical competence	Numeracy skills	Numerical task: total looking time	General categorization task: novelty effect[1]	General categorization task: total looking time[a]	Child age	Child sex	Maternal education
Numeracy skills	**.07***							
Numerical task: total looking time	.07	**−.19****						
General categorization task: novelty effect[a]	.04	.03	.03					
General categorization task: total looking time[a]	.06	−.005	**.31****	−.05				
Child age	**.19****	−.04	−.04	−.05	−.01			
Child sex	**.08***	−.05	.02	.06	−.002	.03		
Maternal education	**.17****	−.01	.06	**.08***	.06	−.01	.05	
Household language	**−.15****	−.05	−.01	−.02	.02	.05	−.02	**−.27****

Note: $*p < .05$; $**p < .01$. Child sex (1 = male and 2 = female); household language (0 = primarily German and 1 = primarily another language).
[a]$N = 807$.

TABLE 3 Summary of multiple linear regression analyses for variables predicting mathematical competence ($N = 871$)

	Model 1.1			Model 1.2			Model 1.3		
	B	SE *B*	β	*B*	SE *B*	β	*B*	SE *B*	β
Numeracy skills	.03	.01	.07*	.03	.01	.09*	.03	.01	.10**
Numerical task: total looking time				.01	.005	.08*	.01	.005	.08*
Child sex							.15	.07	.07*
Child age							.13	.02	.20**
Maternal education							.06	.01	.14**
Household language							−.34	.10	−.11**
R^2			.015			.01			.10
ΔR^2						.007			.09
F for change in R^2						5.79*			20.40**

Note: $^*p < .05$, $^{**}p < .01$; $N = 871$ for all models. Child sex (1 = male and 2 = female); household language (0 = primarily German and 1 = primarily another language).

TABLE 4 Summary of multiple linear regression analyses for variables predicting mathematical competence ($N = 871$)

	Model 2.1			Model 2.2		
	B	SE *B*	β	*B*	SE *B*	β
Numeracy skills	.03	.01	.09*	.03	.01	.09**
Numerical task: total looking time	.01	.01	.07	.01	.005	.07*
General categorization task: novelty effect	.01	.01	.03	.01	.01	.02
General categorization task: total looking time	.003	.003	.04	.003	.03	.03
Child sex				.14	.07	.07*
Child age				.13	.02	.20**
Maternal education				.06	.01	.13**
Household language				−.35	.10	−.11**
R^2			.01*			.10**

Note: $^*p < .05$, $^{**}p < .01$; $N = 871$ for all models; FIML was used for $N = 64$ missing values in the general categorization task. Child sex (1 = male and 2 = female); household language (0 = primarily German and 1 = primarily another language).

further investigate the effect of both measures. The null hypothesis could not be rejected when the novelty effect and total looking time for the general categorization task were simultaneously set equal to zero ($\chi^2 = 1.42$, $p = .50$). This indicated that the inclusion of these variables did not significantly improve model fit. Further, a robustness check was conducted without including the $N = 64$ children with missing values in the general categorization task. There were negligible differences in effect size and no differences in significance for all variables. Thus, only results with estimated missing values are reported in Table 4.

DISCUSSION

Previous studies on numeracy skills have seldom investigated the predictive effects of numeracy skills in toddlers for later mathematical competence; those that did failed to control for the children's social background and/or more domain-general cognitive abilities (Ceulemans et al., 2015; Starr et al., 2013). Thus, the aim of the present study was to investigate whether early numeracy skills in 17-month-old children are predictive of later mathematical competence at the age of 4 years. A visual habituation–dishabituation task with numerical stimuli was used, and we defined the novelty effect (i.e., attention to numerical changes) as a measure of numeracy skills and total looking time as a measure of general attention. We expected numeracy skills to be positively associated with later mathematical competence. Indeed, we found a significant predictive effect of early numeracy skills on later mathematical competence, even when controlling for general attention, individual child characteristics (i.e., sex and age), and indicators of the child's social background (i.e., maternal education and household language). The effect of the domain-specific precursor was small but comparable to the effects previously found (Ceulemans et al., 2015; Starr et al., 2013). Overall this effect was robust but smaller than the effect of age, maternal education, or household language. Altogether, the explained variance indicated that other, possibly more influential mechanisms still need to be explored. In particular, we compared the results with a model that also considered a general categorization task with a similar experimental design and procedure to the numerical task. Measures of this task were not predictive of mathematical competence, and numeracy skills remained significant when these measures were controlled for.

Researchers investigating children's numeracy skills typically habituate children to a specific ratio (e.g., Ceulemans et al., 2015; Xu & Arriaga, 2007) or to objects in an arithmetic relation (e.g., Wynn, 1992). Thus, the numerical habituation–dishabituation task in NEPS SC1 deviates from more common methods with an approach that has not been frequently used since Cooper's (1983) original study. The numerical habituation–dishabituation task habituated the children to a series of different ratios, favoring one of two presented stimulus types (i.e., sheep), while the dishabituation phase-shifted the numerical relation in favor of the other stimulus type (i.e., bears). Cooper (1983) argues that in the first year of life infants learn the concept of 'more' by combining numerosity and basic arithmetic operations, which he sees as the start of number development and of more complex mathematical operations. Likewise, the present study showed a predictive effect of numeracy skills on later mathematical competence. Thus, we argue that this approach is useful for examining the longitudinal effects of early numeracy skills on educational achievement.

Our study draws on a comparably large sample, which is why we were able to control for the children's social background. As aspects of the children's social background have been shown to be related to the early development of mathematical competence (e.g., Fuhs & McNeil, 2013), we included maternal education and household language as control variables. Overall, both variables had a stronger effect on mathematical competence than children's early numeracy skills in toddlerhood. Previous research on social disparities documents robust effects of children's social background (e.g., parental education and household income) on the early quantitative knowledge of children in preschool age (Aunio & Niemivirta, 2010; Halle et al., 2009), so these findings were expected. Interestingly, both variables were not correlated with early numeracy skills in toddlerhood. However, we do not rule out associations, as the focus of the present study was not to investigate social disparities in early numeracy skills, especially given that sample attrition was associated with the children's social background. It is possible that the numerical habituation–dishabituation task assessed children's more basic attention towards numerical changes, which already develop within the first year of life (Clements et al., 2019). This basic attentional measure might not be influenced by their social background as much as more formal mathematical knowledge such as counting and number knowledge (Jordan & Levine, 2009). Still, future research should investigate this topic more thoroughly, as at least one previous study already found social disparities in early quantitative knowledge at the age of 24 months (Halle et al., 2009).

Studies examining early numeracy skills in infants and toddlers with habituation–dishabituation tasks have been criticized for overinterpreting their findings (Cordes & Brannon, 2008; Quinn, 2008). Therefore, a careful interpretation of the present findings seems reasonable, especially because the effects – as in previous studies – were small. Further, the sequence of stimulus pictures was not randomized, and the total area or contour shape was not controlled for. As the stimulus material of the categorization task which we used as a measure of general cognitive ability did not differ with regard to space, contour shape, or density, we cannot rule out these confounding factors. In addition, as the children in the sample were aged 17 months on average, they were relatively old compared to other studies using habituation–dishabituation tasks. Furthermore, due to the test design of NEPS SC1, we cannot rule out sequence effects, as the numerical task and the general categorization task were always administered in the same order.

Lastly, the household setting could be a reason why the effects were small and why our findings might not be completely comparable to controlled settings in baby laboratories. Even though great attention was paid to the training of interviewers and the experimental setup was strictly specified and controlled with a computer, the observational setting could have differed depending on the characteristics of the household. For instance, there could have been different room lighting or the task could have been administered at different times of the day, possibly influencing the children's attention. Also, the living situation might have differed with regard to room space and traffic noise. Note, however, that this applies to both habituation tasks and that both the interviewers and the video raters reported few such cases. Nevertheless, for habituation–dishabituation tasks, there have been extremely few comparison studies; one short report found that looking time and habituation decrement were comparable between household and laboratory settings (Bornstein & Ludemann, 1989). Still, we believe that observing children in their homes can increase the ecological validity of such tasks. However, given the myriad of possible influences in children's homes, future research should compare different observational settings more thoroughly.

A central problem is that the numerical and general categorization tasks were not directly comparable, as both had a different number of stimulus pictures in the habituation phase (4 vs. 9 trials). Thus, the numerical tasks may have not included enough trials for children to habituate properly. In addition, as already mentioned, the tasks were administered in a fixed order, with the numerical task always coming after the general categorization task. This was deemed necessary because NEPS SC1 focuses on inter-individual group differences. We consequently cannot control for sequence effects, especially regarding children's general attention. Indeed, although initial looking times for both tasks were comparable, looking times for the numerical task tended to decrease more strongly and faster, but this could also be due to the stimulus material.

Owing to the considerable longitudinal dropout, we tested for potential bias in the final sample. We found that the mothers of children who successfully participated in the habituation–dishabituation tasks and for whom mathematical competence test scores were available had higher education levels on average and that their household language was more likely to be German. Thus, considering these variables, the final sample is not representative of the initial NEPS SC1 sample (for more information on sample attrition, see Zinn et al., 2020). Consequently, although the present sample is still larger (and probably more heterogeneous) than those of typical laboratory studies, results should not readily be generalized to the whole population. Given the ongoing debate about replicability and biased sampling in developmental studies (e.g., Fernald, 2010), future research should draw on more diverse samples and/or investigate the causes of sample attrition and participation as a function of children's social background.

Lastly, we only included a broad, dichotomous indicator of the children's household language, focusing on the comparison of children raised in primarily German-speaking households with children raised in households where another language was primarily spoken. The mathematical competence test was administered in German, which is why children from German-speaking households could have had an advantage. Thus, the validity of the measure could vary depending on children's language proficiency, although care was taken to use simple instructional language and to reduce the verbal demands as far as possible. Indeed, a previous study on German children in elementary school showed that German language skills had an effect on mathematical competence development over and above socioeconomic background and basic cognitive abilities (Paetsch et al., 2016). Still, because we used WLE scores, as provided by the NEPS, which showed negligible differential item functioning between children with and without migration background and, thus, acceptable test fairness (Petersen & Gerken, 2018), we do not consider this limitation critical for the main findings of our analyses. Of course, other studies focus on the role of language in the development of mathematical competence; however, this was not the aim of the present study.

The current study focused on whether the numeracy skills of 17-month-old children predict their mathematical competence at the age of 4 years. A robust relationship between toddlers' early numeracy

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skills and mathematical competence was found, even when controlling for sex, age, maternal education, and household language. The effect was generally small, and most control variables had larger effects on mathematical competence. Nevertheless, the inclusion of an attentional measure and a categorization task ruled out potential alternative explanations regarding domain-general cognitive abilities. We conclude that the adapted approach presented here should be compared to other numeracy tasks in studies investigating the development of mathematical competence. In addition, future studies should investigate possible associations between a child's social background and his or her developing numeracy skills more thoroughly.

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CONFLICTS OF INTEREST

All authors declare no conflict of interest.

AUTHOR CONTRIBUTION

Maximilian Seitz: Conceptualization; Formal analysis; Writing – original draft. **Sabine Weinert:** Conceptualization; Funding acquisition; Project administration; Supervision; Writing – review & editing.

DATA AVAILABILITY STATEMENT

This paper uses data from the National Educational Panel Study (NEPS): Starting Cohort Newborns, https://doi.org/10.5157/NEPS:SC1:6.0.0. From 2008 to 2013, NEPS data were collected as part of the Framework Program for the Promotion of Empirical Educational Research funded by the German Federal Ministry of Education and Research (BMBF). As of 2014, NEPS has been carried out by the Leibniz Institute for Educational Trajectories (LIfBi, Bamberg) in cooperation with a nationwide network. Data of the numerical habituation–dishabituation task was also collected by the NEPS but coded by the project ViVA and will be added to the NEPS scientific use files. The data are available on reasonable request to the authors.

ORCID

Maximilian Seitz https://orcid.org/0000-0002-8589-6701
Sabine Weinert https://orcid.org/0000-0002-8341-9821

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Appendix D: Study 4

Visual habituation-dishabituation tasks in NEPS Starting Cohort 1: Approaches to interpreting the data

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NEPS *SURVEY PAPERS*

Maximilian Seitz, Manja Attig,
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VISUAL HABITUATION - DISHABITUATION TASKS IN NEPS STARTING COHORT 1: APPROACHES TO INTERPRETING THE DATA

NEPS *Survey Paper* No. 102
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Visual Habituation-Dishabituation Tasks in NEPS Starting Cohort 1: Approaches to Interpreting the Data

Maximilian Seitz[1], Manja Attig[1], Dave Möwisch[1], Sabine Weinert[2]

[1]Leibniz Institute for Educational Trajectories (LIfBi)
[2]University of Bamberg

E-mail address of lead author:

maximilian.seitz@lifbi.de

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Visual Habituation-Dishabituation Tasks in NEPS Starting Cohort 1: Approaches to Interpreting the Data

Abstract

Research suggests a certain degree of interindividual stability and continuity in cognitive development. Studying basic cognitive abilities in young children is crucial for understanding the development of later abilities, skills, and competencies. One central behavioral method for studying early cognition are habituation-dishabituation tasks. In habituation-dishabituation tasks, children's visual attention towards different stimuli are examined. Typically, a sequence of identical or similar stimuli are presented in a habituation phase, whereas the subsequent dishabituation phase features a novel and divergent stimulus. A broad consensus is that such behavioral measures reflect early cognitive abilities, namely stimulus encoding, remembering, and discrimination. As one of few large-scale studies, the Newborn Cohort of the German National Educational Panel Study (NEPS SC1) used habituation-dishabituation tasks to assess early cognitive abilities in the first two survey waves, namely when the children were on average 7 months and 17 months. This survey paper provides an overview on the theoretical and empirical backgrounds of these tasks. Further, a detailed technical report on the stimulus material and testing procedure is given. In addition, there is an overview on what kind of information is available for the scientific community in the Scientific Use File. In the main section, several approaches to the data are presented as a means to estimate children's habituation and dishabituation and, consequently, generate indicators of early cognitive abilities. This includes a number of discrete index measures that are typically used in the literature as well as examples of a data reduction procedure that has seen less coverage in infant research. The index measures are contrasted and their usage with regard to NEPS SC1 is discussed. Finally, we provide information on, among others, task disturbances, missing data, and child characteristics that are useful for data selection and interpretation.

Keywords

Habituation, infants, cognitive development

Table of contents

1. Introduction and theoretical background

From a lifespan perspective, it is necessary to study the development of cognitive abilities from infancy. To understand the origins of later competencies and achievements in educational settings, young children's cognitive functioning needs to be examined, especially in the context of other interindividual differences regarding structural and environmental factors (e.g., socioeconomic background, parenting behavior, and educational institutions). Fantz' (1964) seminal study on infant visual habituation marked the beginning of modern investigations on the cognitive development of young children and highlighted that even with preverbal infants, habituation-dishabituation tasks can give insight into cognitive functioning at an early age (Colombo & Mitchell, 2009). The central observation was that by presenting children with a series of visual stimuli, their behavioral response, for example fixation or looking time, could be measured. The underlying concept is that children distribute attention to the stimulus material, which is associated with distinct behavioral patterns. Habituation and the conceptually related process of familiarization (Aslin, 2007) refer to the phenomenon of decreasing attention throughout a sequence of either identical or similar stimuli, while dishabituation covers the subsequent mechanism of attention recovery when a novel stimulus is shown. Habituation and dishabituation are generally thought to reflect aspects of basic cognition such as attention, categorization, or information processing (Colombo & Mitchell, 2009). Since the 1960s, research has used this basic paradigm in numerous variations by manipulating the stimulus material, presentation time, or the presentation mode (Thompson, 2009). Often, habituation-dishabituation tasks are used to study early precursor abilities of later cognitive skills or competencies (Colombo & Mitchell, 2009).

This section provides an introduction to the theoretical background of habituation-dishabituation tasks (**1.1 Theoretical background on infant habituation**) as well as basic information on how habituation-dishabituation tasks are used to predict later skills and competencies (**1.2 Predicting cognitive abilities with habituation-dishabituation tasks**). Finally, the use of habituation-dishabituation tasks in large-scale studies is discussed, which is linked with the question why they are a relevant method for studying early cognition abilities (**1.3 Uses in large-scale studies**).

1.1 Theoretical background on infant habituation

Historically, there have been several approaches to explaining the phenomena of habituation and dishabituation. Early theories essentially hold habituation as a sign of fatigue and dishabituation as perceptual sensitization. Such models theorized that habituation is either predominately a physiological process of local retinal adaptation (Bronson, 1974) or a process of selective cortical adaptation (Dannemiller & Banks, 1982). However, because processes of habituation and dishabituation occur independent of the eye (Slater et al., 1983) and in tasks with delayed stimulus presentation (Slater & Morison, 1985), purely perceptual frameworks cannot explain the phenomena adequately.

In contrast, cognitive theories hold habituation and dishabituation as indicators of information processing in infants. The most popular cognitive model is Sokolov's (1990) comparator model, in which habituation reflects the formation of a neuronal representation of the stimulus (i.e., stimulus encoding), whereas dishabituation reflects stimulus discrimination (Kavšek, 2013). The decrement in looking times during the habituation phase is, hereby, the result of an activated inhibitory system in the hippocampus that increasingly suppresses the orientation response. In accordance, dishabituation is a renewed orientation response to a novel stimulus due to a lack of inhibition because the novel stimulus does not match the previously formed mental representation. Sokolov's conceptualization remains one of the most relevant theoretical frameworks to understand the processes of habituation and dishabituation in infancy (Kavšek, 2013; Sicard-Cras et al., 2022). Still, it should be noted that while attention decrement is generally interpreted as an indicator of information processing (Colombo & Mitchell, 2009), many internal and external factors may contribute to any observable behavior in young children (e.g., familiarization or fatigue; Houston-Price & Nakai, 2004; Slaughter & Suddendorf, 2007).

Although many studies on infant cognition use habituation-dishabituation tasks, there are essential differences in stimulus material, presentation time, and presentation mode. Generally, there are infant-controlled and fixed-trial designs. In the former, the transition from the habituation to the dishabituation phase is administered adaptively if the child showed a pre-defined decrement in looking time; in the latter, the presentation time for all stimuli as well as for the intertrial interval is the same (Oakes, 2010). Stimulus material in the dishabituation phase may be presented alone or paired with a distracting stimulus, depending on the research design. In fixed-trial designs, children's reaction indicates attention recovery, in infant-controlled designs, novelty preference is assessed (Colombo & Mitchell, 2009). For most task types, stimulus material can be manipulated in a number of ways (e.g., identical stimuli vs. categorical stimuli) and modes (e.g., visual, auditory, tactile). Overall, there have been numerous approaches at operationalizing attention decrement and attention recovery, depending on the research question and data availability, and the present report only presents selected measures (**4. Approaches to interpreting the data**).

1.2 Assessing early cognitive abilities with habituation-dishabituation tasks

Empirically, visual habituation-dishabituation tasks are used, among others, to study children's perception (Arterberry & Kellman, 2016), categorization skills (Quinn & Eimas, 1996), memory capacity (McCall & Carriger, 1993), understanding of physical (Baillargeon, 2008) and mathematical processes (Cantrell & Smith, 2013), statistical learning (Bulf et al., 2011), and theory of mind (Onishi & Baillargeon, 2005). They are not only used for testing theoretical assumptions of early cognition but also to study typical and atypical cognitive development and early predictors of later cognitive skills and competencies. Because of a certain degree of continuity and stability in information processing in childhood (Bornstein, 1985; Jensen, 1993; Kail, 1991), habituation and dishabituation measures can be used as early predictors of interindividual cognitive differences (e.g., Davis & Anderson, 2010). In this context, continuity refers to the assumption that individual sources of variation in early abilities and skills explain variation at later time points, whereas stability refers to children's relative rank order in their performance on cognitive tasks over time when compared to others (Bjorklund & Causey, 2018).

Habituation efficiency and attention recovery, indicating fast stimulus encoding and good discrimination abilities, are seen as a foundation of general cognitive development (Bornstein et al., 2006; McCall & Carriger, 1993). Habituation measures are reasoned to be associated with speed of information processing or fluid intelligence, while dishabituation measures are associated with recognition memory or memory capacity (Rose et al., 2004; Rose et al., 2012). Because children need to compare each stimulus with the previous ones, processes of repeated memory updating are activated that are essential for working memory (Ropeter & Pauen, 2013). Thus, habituation and dishabituation measures have been used to predict later general cognitive functioning (McCall & Carriger, 1993), receptive and productive language skills (Tamis-LeMonda & Bornstein, 1989; Dixon & Smith, 2008), and school achievement (Bornstein et al., 2013; Colombo et al., 2004). The predictive effects were found to be robust, even after controlling for the children's family background, like maternal education or socio-economic status (Bornstein et al., 2006). Meta-analyses (Kavšek, 2004b; McCall, 1994) have shown medium-sized predictive effects of early information processing as measured with habituation-dishabituation tasks for later intellectual functioning (habituation measures: r=.45; dishabituation measures: r=.39; see also Domsch et al., 2009).

Regarding the predictive effects of habituation and dishabituation measures for various aspects of cognition, studies showed that attention decrement (i.e., stimulus encoding) and attention recovery (i.e., stimulus discrimination) are positively associated with early cognitive abilities (Bornstein & Sigman, 1986; McCall & Carriger, 1993; Rose et al., 2012). More specifically, habituation in three-month old children positively predicts IQ scores (e.g., Griffiths Mental Development Scales; Griffiths, 1984) four years later (Bornstein et al., 2006; Laucht et al., 1994), although effects are small (coefficients of up to r=.21). Still, arguing for developmental cascades, Bornstein and colleagues (2013) found that habituation efficiency had a distinct positive, albeit indirect, effect on school achievement ten years later (r=.06). Several authors argue that habituation-dishabituation tasks are more useful than standard developmental tests for assessing early cognitive abilities in infants and predicting later skills and competencies (McCall, 1994; Teubert et al., 2011), especially in longitudinal designs.

When studying such predictive effects, habituation-dishabituation tasks may tap into either domain-general or domain-specific precursor abilities. While there is considerable debate about the nature and relation of underlying domain-general and domain-specific mechanisms of cognition (for a discussion, see Rakison & Yermolayeva, 2011), many researchers agree that children's developmental learning process necessarily involves domain-general and domain-specific abilities (Bjorklund & Causey, 2018). Habituation-dishabituation tasks indicate early learning, which contributes to how children acquire new content knowledge and develop competencies. In this sense, habituation-dishabituation can be used to assess cognitive precursor abilities of later skills and competencies in various domains of knowledge, such as mathematics or language (National Research Council, 2015).

1.3 Uses in large-scale studies

Cognitive abilities at an early age are frequently assessed in large-scale studies drawing on newborn cohorts (Hachul et al., 2019). When opting for behavioral observations, most studies use the Bayley Scales of Infant Development (Bayley, 2006) or the extended Infant Scales of the Griffiths Mental Developmental Scales (Griffiths, 1970; Luiz et al., 2001) (see Hachul et al., 2019). However, in large-scale assessments, the administration of such standardized developmental tests can be relatively error-prone. In addition, such tests in the first two years of life have poor predictive validity for later cognitive functioning (Aylward, 2013; Krogh & Væver, 2019), probably due to the focus on potentially unstable sensorimotor measures (Dunst & Rheingrover, 1981). Thus, in the Newborn Cohort of the German National Educational Panel Study (NEPS SC1) habituation-dishabituation tasks were implemented for assessing basic cognitive abilities in addition to a short measure of sensorimotor development

(Weinert et al., 2016). For studying cognitive development in children, large-scale studies are important because they are typically more heterogeneous than laboratory studies (Oakes, 2017). Moreover, small laboratory studies might lead to an overestimation of actual effects at the population level (Maxwell, 2004), which is why large-scale studies need to replicate and verify existing findings (Oakes, 2017).

Small laboratory studies often have homogeneous samples because of convenience sampling, resulting in an unwanted focus on infants from a middle-class socioeconomic background (Fernald, 2010). Relying on such samples could potentially lead to biased findings on infant cognitive development (Henrich et al., 2010) because socioeconomic background is associated with interindividual differences in cognitive stimulation from early on (Attig & Weinert, 2018). Likewise, Bronfenbrenner's bioecological model of human development (Bronfenbrenner & Morris, 2006) stresses the importance of the family on the microsystem level, especially the effect of the social class (e.g., parental income and education). Empirically, it could be shown that social disparities in the cognitive development of infants can be found as early as 9 months (Halle et al., 2009). Few studies have investigated effects of socioeconomic background on early cognitive abilities using habituation-dishabituation tasks, probably because of the selective samples that usually participate in laboratory studies (Oakes, 2017). To conclude, there are associations of young children's socioeconomic backgrounds and their cognitive development, which is why large-scale studies with heterogeneous samples are important.

To the knowledge of the authors, apart from NEPS SC1, there have been only two previous large-scale studies in which habituation-dishabituation tasks were used: The Mannheim Study of Children at Risk (MARS) and the Avon Longitudinal Study of Parents and Children (ALSPAC). MARS was a German prospective longitudinal study of psychosocial risk factors on child development that started data collection in 1986 (Esser & Schmidt, 2017; Laucht et al., 1994; Laucht et al., 2000). ALSPAC was a British population-based study that started data collection in 1991. In ALSPAC, the tasks were administered in an infant-controlled design at 4 months in the Child in Focus subsample (about 10% of the cohort; The ALSPAC Study Team, 2019). Measures of visual attention and visual recognition memory were included as predictors of later cognitive development, as an outcome measure of prenatal maternal behavior, and as a control variable for general child development (Moulton et al., 2020). Methodologically, analyses of the large-scale data have shown that non-completion of the habituation task, namely because the children were too restless, tired or distressed, was not at random, highlighting the potential bias in existing data and warning against generalizations of the findings (Bell et al., 1998; Bell et al., 2002). With regard to the validity of the measures as indicators of early cognitive functioning, only few analyses have included the tasks (Bornstein et al., 2006; Bornstein et al., 2013).

The aim of the present survey paper was to provide an overview of all habituation-dishabituation tasks used in NEPS SC1. In the next sections, information on the stimulus material, testing procedure, coding procedure (**2. Stimulus material and task procedure**), and sample are given (**3. Information on available data**). We selected two general approaches to interpreting the children's habituation and dishabituation (**4. Approaches to interpreting the data**): Index measures for interindividual comparisons and more advanced data reduction techniques. As we were interested in interindividual differences, we also examined age-related differences. In addition, information on data selection is given and methodological caveats when using NEPS SC1 are discussed (**5. Data selection**). Finally, we summarized central findings from our calculations (**6. Summary and conclusion**). The stimulus material can be found in the appendix (**8. Appendix**).

2. Stimulus material and task procedure

This section provides a technical report and overview of the habituation-dishabituation tasks used in NEPS SC1. The aim of this survey paper is to inform users of approaches to the available data and highlight potential ways to analyze them. As habituation-dishabituation tasks tap into early cognitive abilities, the data may be used to investigate the development of cognition, examine the predictive validity of measures drawn from the tasks for later skills and competencies, or control for early interindividual differences in cognition (Weinert et al., 2016).

At Wave 1 (children on average 7 months) and Wave 2 (children on average 17 months), domain-general and domain-specific habituation-dishabituation tasks were conducted to assess children's early cognitive abilities. In the context of NEPS, the terms domain-general and domain-specific refer to precursor abilities for later skills development. Similarly, cognitive abilities refer to a global capacity of applying various aspects of mental processes for learning and knowledge acquisition (VanLehn, 1996). Thus, the habituation-dishabituation tasks in NEPS SC1 were conceptualized to assess early learning in more general and more specific domains of cognition (e.g., mathematics and language).

Overall, there were four different tasks: Two domain-general categorization tasks (Wave 1: Task A and Task B; Wave 2: Task C; Task B and Task C used the same stimulus material); a numerical task (Wave 2: Task D); and a word-learning task with categorical stimulus material (Wave 2: Task E). The domain-general categorization tasks featured categorical stimulus material during the habituation phase with an out-of-category exemplar during the dishabituation phase. The level of complexity differed between the tasks and the more complex task was also administered at Wave 2 for comparing the children's habituation and dishabituation over time. The numerical task featured varying proportions of magnitude that were reversed in the dishabituation phase. Finally, the word-learning task featured categorical stimulus material during the habituation phase that was presented with a pseudoword.

For all tasks, a fixed-control procedure without task or stimulus randomization was chosen because a reliable on-line coding of the children's looking behavior with trained interviewers in the children's households with a limited experimental setup was not possible. As suggested by Werner and Perlmutter (1979), fixed-trial designs can be useful for samples with a broad age range because they accommodate individual differences in encoding time. The focus in NEPS SC1 was on interpreting interindividual differences, which fixed-trial designs typically allow for (Slater et al., 1984; Thomas & Gilmore, 2004). In addition, an attention control phase with completely different pictures was included for all tasks to control for possible effects of fatigue or distractions in the children's homes.

It is theoretically expected that habituation-dishabituation tasks assess information processing or early learning, which is indicated by attention decrement (familiarity effect) during the habituation phase and attention recovery (novelty effect) during the dishabituation phase (Figure 1). Thus, the domain-general tasks were expected to assess early categorical information processing, which should be predictive of later general intellectual functioning.

The numerical task was hypothesized to tap into children's early numerical understanding or quantitative abilities, which should be a precursor of later mathematical skills. Finally, the word-learning task tested children's early word learning, which should be an important precursor of later vocabulary development.

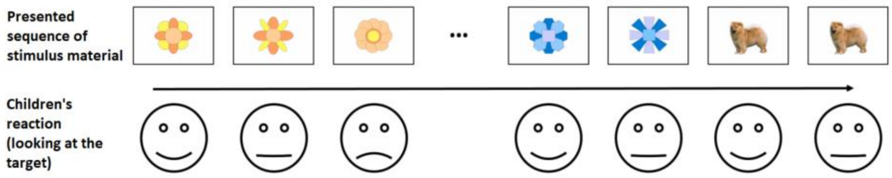

Figure 1. Schematic illustration of the procedure of the habituation-dishabituation tasks.

2.1 Experimental setup

NEPS SC1 (NEPS Network, 2021)[1] collected data nation-wide between August 2012 and March 2013 (Wave 1) and between July 2013 and December 2013 (Wave 2). Both the parental interviews (Wave 1) and the child observations were conducted in the households (direct behavioral measures). On average, a home visit lasted about 95 minutes in Wave 1 (i.e., interview and observation of the child) and 60 minutes in Wave 2 (i.e., a preliminary telephone interview of the full sample and child observation of half of the sample at a later point) (Weinert et al., 2016). Visual habituation-dishabituation tasks as direct behavioral measures were administered at both waves. Interviewers who had a professional background in large-scale interviews were trained regarding psychological testing to administer the tasks. To ensure a standardized procedure in the households of the participating families, the experimental setup and task sequence were clearly defined, and extensive training courses for the interviewers were provided.

The children sat on the lap of their parent, which was in the most cases the biological mother (Wave 1: 98.19%; Wave 2: 99.02%). The experimental setup, consisting of a notebook (model: Lenovo T60) for presenting the stimulus material and a video camera (model: AIPTEK AHD Z700) for recording the children's behavior, was arranged on a nearby table (height: 65-85 cm). The interviewers should clear away any distracting objects and arrange the whole setup so as no light reflections would impair the children's sight.

The stimulus material was presented as a video sequence on the notebook, with the volume set to maximum. The notebook was on a cardboard box and both the setup and the screen were adjusted to the infants' ideal field of vision. The cardboard box was 10 cm from the edge of the table, with the screen being 1 m away from the infant's ear. One foldable visual cover was placed over the notebook's keyboard, while another was used to mask the camera and

[1] This paper uses data from the National Educational Panel Study (NEPS; see Blossfeld & Roßbach, 2019). The NEPS is carried out by the Leibniz Institute for Educational Trajectories (LIfBi, Germany) in cooperation with a nationwide network.

the area behind the notebook. The camera lens protruded the visual cover to record the children's behavior from a central angle (Figure 2).

The parent was instructed to sit as quietly as possible and not distract the child in any way (e.g., verbal or non-verbal reactions to the stimulus material). However, the parent was not blindfolded. During the task, the interviewer stood behind the parent, away from the child's field of vision. Other people (e.g., partners) or pets were not allowed in the same room, with the only exceptions being young siblings in cases where they could not be taken care of in another room.

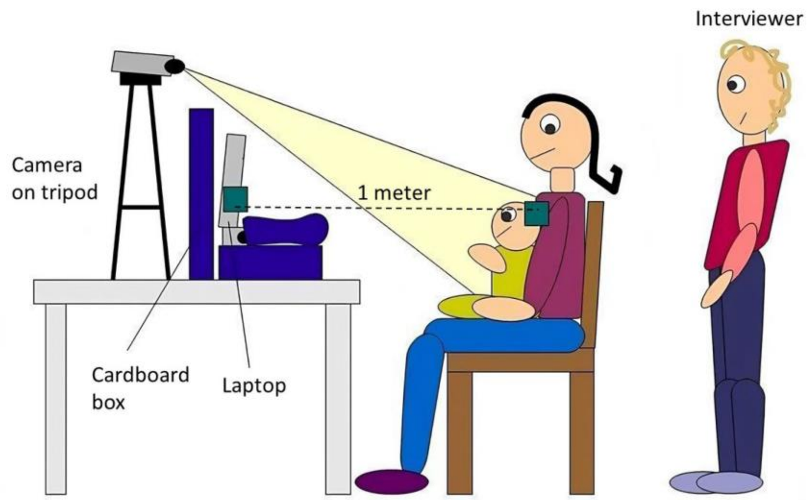

Figure 2. Schematic illustration of the task administration.

2.2 Task administration

As the habituation-dishabituation tasks were administered by interviewers who typically had no professional background in conducting experiments, a high degree of standardization and off-line coding were necessary, which is why a fixed-trial design was chosen. The interviewers were instructed to choose when to administer the habituation-dishabituation task during the parental interview. This way, fatigue effects could be avoided and the tasks could be assessed when the child was deemed alert, calm, and cooperative.

During the experimental setup, a blue dummy screen was shown. All tasks started the same way, with a countdown (i.e., numbers 3-1) and a subsequent eye-catcher (i.e., an animated penguin accompanied by a short three-note jingle). When the interviewer started the experiment, descending black numbers from 3-1 were shown on the blue screen (count in) (**8. Appendix: Stimulus material**). After that, the habituation phase started immediately.

2.3 Procedure at Wave 1

At Wave 1 (infants aged on average 7 months), all infants of the sample were asked to participate in a fixed sequence of two visual, domain-general habituation-dishabituation tasks testing categorization skills (Task A; Task B). Regarding the sequence of the stimulus material and the presentation time, the procedure was the same for all infants. In both tasks, the habituation phase was followed by a dishabituation phase and a subsequent attention control phase, respectively (**8. Appendix: Stimulus material**). The habituation phases featured a number of individually presented categorical stimuli. The dishabituation and attention control phases deviated to different extents from the respective habituation phase. The dishabituation phase featured images comparable to the previous habituation phase but deviant in form and color (i.e., out-of-category exemplars). Thus, this phase tested children's attention recovery and categorization. The attention control phase featured completely different pictures to check for effects of fatigue. All habituation trials were presented for 10 seconds and were accompanied by an audio cue (i.e., a three-note jingle) to attract the children's attention. The dishabituation and attention control trials were presented for 15 seconds, also accompanied by the audio cue; for reasons of comparability, only 10 seconds were coded and made publically available. Intertrial interval duration was 2 seconds, or 1 second between two trials of the dishabituation and attention control phases, respectively. There was a pause interval of 5 seconds between the tasks. The habituation phases featured nine trials, meaning nine individual pictures. Overall, administering both tasks lasted for about 6.5 minutes.

2.4 Procedure at Wave 2

At Wave 2 (toddlers aged on average 17 months), half of the original sample[2] participated in a fixed sequence of visual habituation-dishabituation tasks: A domain-general task testing categorization skills (Task C), a domain-specific task testing numerical abilities (Task D), and a domain-specific task testing word learning (Task E). Regarding the sequence of the stimulus material and the presentation time, the procedure was the same for all children. In all tasks, the habituation phase was followed by a dishabituation phase and a subsequent attention control phase, respectively (8. Appendix: Stimulus material). The habituation phases featured a number of individually presented categorical stimuli. The dishabituation and attention control phases deviated to different extents from the respective habituation phase. The dishabituation phase featured images comparable to the previous habituation phase but deviant in form and color (i.e., out-of-category exemplars; Task C; Task E) or with a reversed proportion, respectively (Task D). Thus, this phase tested children's attention recovery and categorization (Task C), numerical abilities (Task D), or word learning (Task E). The attention control phase featured completely different pictures to check for effects of fatigue. All trials were presented for 10 seconds and were accompanied by an audio cue (i.e., a short three-note jingle) to attract the children's attention, except for Task E. Intertrial interval duration was always 2 seconds. There was a pause interval of 5 seconds between the tasks. The habituation phases featured nine trials (Task C; Task E), or four trials (Task D), respectively. Overall, administering all tasks lasted for about 7.5 minutes.

2.5 Stimulus material

Task A: The first task at Wave 1 featured categorical stimuli to test children's domain-general categorization skills. All trials were introduced by a short three-note jingle played once (400-300-500 Hz; 1.14 seconds). The habituation phase featured various curvilinear cartoon flowers

[2] By design, only half of the sample (random selection) was visited at home to participate in the habituation-dishabituation tasks. Beforehand, all families participated in a telephone interview when the children were on average 14 months old.

with an orange and yellow color scheme, while the dishabituation phase featured two different rectangular cartoon flowers with a blue color scheme. The attention control phase featured two identical photos of a dog. The stimulus material was adapted from previous validation studies (Pahnke, 2007)[3].

Task B: The second task at Wave 1 featured categorical stimuli to test children's domain-general categorization skills. All trials were introduced by a short three-note jingle played once (500-500-400 Hz; 1.14 seconds). The habituation phase featured various curvilinear cartoon bugs with symmetrical antennae, while the dishabituation phase featured two different rectangular cartoon bugs with asymmetrical antennae and a blue color scheme. The attention control phase featured two identical photos of a pineapple. The stimulus material was used and tested in previous studies at the chair of developmental psychology at the University of Bamberg, Germany (Zhang, 2007).

Task C: The first task at Wave 2 was nearly identical with Task B. The only difference to Task B was that in Task C the presentation time of the dishabituation trials was shorter (i.e., 10 seconds instead of 15 seconds). Administrating the same task at Wave 2 was deemed useful for analyzing the development of habituation and dishabituation.

Task D: The second task at Wave 2 featured number-related stimuli to test children's domain-specific understanding of non-symbolic magnitudes, which is also called numerical ability (Geary, 2000) or numeracy (Bynner & Parsons, 1997). All trials were introduced by a short three-note jingle played once (400-300-500 Hz; 1.14 seconds). An adapted version of Cooper's (1984) stimulus material was tested at the chair of developmental psychology at the University of Bamberg, Germany (Freund, 2012). A sequence of four pictures was presented in the habituation phase; cartoon sheep were always on the left side, whereas cartoon bears were always on the right side. In each presented habituation picture, the number of sheep outmatched the number of bears (≤ 4 per category). The first dishabituation stimulus reversed the ratio in favor of the bears and the second dishabituation picture had a balanced ratio. The attention control phase featured two identical photos of a flower. Thus, the task tested whether children would be surprised by the shift in magnitude at the transition to the dishabituation phase, and consequently show more attention to the novel stimulus.

Task E: The third task at Wave 2 featured categorical stimuli in combination with a pseudoword (Zhang, 2007). In the habituation phase, the visual stimuli were imaginary cartoon creatures that were made of a varying number of circular shapes. All had the same facial features (i.e., eyes, nose, and mouth). In the two trials of the dishabituation phase, the creatures consisted of rectangular shapes and dim colors. Because of the rectangular design, the facial features were markedly different from the previous trials. The attention control phase featured two identical pictures of a tree. With each visual stimulus, a pseudoword was played as a language-related stimulus. The pseudoword was played once per picture and was accompanied by an object identifier (i.e., "Ein Jalos"; 1.93 seconds). "Ein" is a German indefinite article and "Jalos" is a pseudoword referring to the creature (Waxman & Kosowski, 1990). The auditory stimulus was produced by an adult woman and did not vary, as variation is often thought to be distracting (Parmentier et al., 2011). Thus, the task can be considered a

[3] We would like to thank Prof. Dr. S. Pauen for her advice on the implementation of the paradigm.

word-learning task, as the pseudoword was presented in combination all stimuli (e.g., Stekmachowicz et al., 2004).

2.6 Coding procedure

The tasks were recorded in the households of the families on a video camera in 30 frames per second, at a resolution of 1280×720 pixel. The children's looking behavior was coded offline by trained independent raters blind to the stimulus material. For each frame, the children's looking behavior was categorized in "towards the target" or "away from the target". Blinking (i.e., events ≤ 8 frames) was coded as a continuous target fixation, if the child looked at the target stimulus before and after having blinked. In this manner, looking times were accumulated for each trial. While visual attention research uses more fine-grained definitions of fixation time (Hendry et al., 2019), in the context of NEPS SC1, the term refers to the global looking time on target. The coding software was Interact 9.6.1.170 (Mangold International, 2011; see Attig & Weinert, 2018; Weinert et al., 2017). Interrater reliability was tested on a subsample of 10% of all videos at each wave. Two independent raters coded randomly drawn videos and the collapsed rating agreement at Wave 1 (unadjusted level of agreement: 95%; κ=.92) and Wave 2 (unadjusted level of agreement: 96%; κ=.92) was high.

2.7 Household setting

As findings and field reports from comparable large-scale studies were limited and household settings in habituation research had seldom been compared to laboratory settings (Bornstein & Ludeman, 1989), prior to NEPS SC1, run-up tests were conducted to identify issues that could be a threat to standardization. Several aspects were identified that were also addressed in the training course of the interviewers, even if certain aspects could not be standardized.

Lighting: Uneven or unbalanced illumination in the room of observation could distract children and lead to unreliable video coding. The interviewers were trained in creating comparable lighting for each observation, but given the heterogeneity of the households, this aspect could not be completely standardized.

Furnishing: Tables and chairs of varying sizes and heights were expected in the households. Therefore, certain necessary features were defined (i.e., table height), while others were prohibited (e.g., the use of swivel chairs). It was expected that such basic furniture should not be a problem in most households.

Laptop setup: The tilt angle of the screen had to be adjusted by the interviewers in order that the children could see the stimulus presentation without any distractions (e.g., screen glare). Therefore, the interviewers should check the children's field of vision before starting the tasks.

Camera position: The interviewers were instructed to position the camera for recording the children's looking behavior at a preset height directly behind the laptop setup. Thus, the position was centered and the height of the camera was fixed, regardless of the differences in interior design of the households.

3. Information on available data

The following section provides information on all available data in the public Scientific Use File[4] (NEPS Network, 2021). Due to data curation other data releases might differ from the data set used for the present calculations, although no fundamental changes regarding the data of the habituation-dishabituation tasks are expected. In the following sections, the general sample is described, as not for all children valid looking times are available even though most parents gave consent in participating in the habituation-dishabituation tasks (**3.1 Data base information**). In addition, descriptive information on children's accumulated fixation times on target is provided (**3.2 Describing the data**). These fixation times provide the basis for the calculations in the latter section of this report.

3.1 Data base information

Overall, NEPS SC1 started with a sample size of N=3481 children at Wave 1. However, due to a lack of parental consent, sample attrition, study design, child-related reasons, and extraneous disturbances, the habituation-dishabituation tasks were not assessed or could not be correctly coded in all cases. Table 1 reports information on parental consent in participating in the habituation-dishabituation tasks, which was administered during the parental interview (Wave 1) or on a separate date after the parental telephone interview (Wave 2). At both waves, parental consent was high. At Wave 2, all parents were asked to participate in a telephone interview; however, only half of the sample was by design asked to participate in the habituation-dishabituation tasks (N=1510). Due to the large-scale sampling, children's age was broadly distributed: Wave 1 (M=7.00 months, SD=0.76, Min=5.15, Max=11.93), Wave 2 (M=17.05 months, SD=0.61, Min=15.77, Max=20.36).

Table 1

Parental Consent in Participating in the Habituation-Dishabituation Tasks

	Wave 1 **(full sample)**	**Wave 2** **(half sample per design)**
Informed consent	3129 (89.89%)	1484 (98.28%)
No consent	352 (10.11%)	26 (1.72%)

Note. Percentages refer to the total sample at Wave 1 (N=3481) and to the sample for which observational measures were planned at Wave 2 (N=1510), respectively.

Not all cases in which parents consented in participating in the habituation-dishabituation tasks could be realized. This dropout was due to child-related reasons, namely that the child was unfit to participate at the moment, or due to external reasons. At Wave 1, there were video recordings of N=2945 (94.12%) children, whereas at Wave 2, there were video recordings of N=1315 (88.61%). However, not all of these video recordings could be validly coded, for example, due to multiple and/or severe disturbances during the observation.

[4] The current version of the Scientific Use File (Release 9.1.0) only includes data on the first habituation-dishabituation task at Wave 1 (Task A) and Wave 2 (Task C), respectively. Data of all other tasks were coded and processed under another grant (Project ViVA at the University of Bamberg) and will be added in future data releases. "ViVA: Video-based Validity Analyses of Measures of Early Childhood Competencies and Home Learning Environment" – project funded by the German Research Foundation (DFG) within the priority programme 1646 (grant to Sabine Weinert; WE 1478/7-1; WE 1478/7-2). We thank Jan-David Freund for his contribution to the project and the coding.

Disturbances that occurred while the tasks were administered were typically not child-related (see also Table 22), but rather due to external factors (e.g., lighting condition, distracting noises, parental interference, interviewer error). Table 2 reports an overview of the codability of the videos; looking time data for cases with multiple and/or severe disturbances were not released in the Scientific Use File. In most tasks, a large percentage of the children participated with no external disturbances or distractions. Given the household setting with limited standardization, this was deemed adequate. Detailed information on the types of disturbances is reported in Table 22.

Table 2

Video Codability Rating of the Habituation-Dishabituation Tasks

	Not evaluable (multiple/severe disturbances)	**At least one problem**	**No disturbances or distractions**	**No information available**
Task A	467 (14.92%)	365 (11.67%)	2195 (70.15%)	102 (3.26%)
Task B	504 (16.00%)	309 (9.88%)	2178 (69.61%)	138 (4.41%)
Task C	231 (15.57%)	399 (26.88%)	820 (55.26%)	34 (2.29%)
Task D	231 (15.57%)	269 (18.12%)	946 (63.75%)	38 (2.56%)
Task E	328 (22.10%)	280 (18.87%)	838 (56.47%)	38 (2.56%)

Note. Percentages refer to the samples with informed consent at Wave 1 (N=3129) and at Wave 2 (N=1484), respectively. The category "no information available" refers to videos that could not be coded although no specific details regarding potential disturbances were reported; for these cases, no looking time data is available. The categories "not evaluable" and "multiple/severe disturbances" were collapsed because both ratings resulted in the data not being released. Task A – Task B were administered at Wave 1; Task C – Task E were administered at Wave 2. Task B and Task C featured the same stimulus material.

3.2 Describing the data

For each trial or presented stimulus picture, a number of variables was coded that are available in the public Scientific Use File: Maximum, minimum, mean, total fixation time, and number of fixations on target, as well as off target. This section gives a descriptive overview of total fixation times on target for all habituation-dishabituation tasks, as these have been found to be most stable and reliable (Kavšek, 2004a). Each table reports data for all cases without missing values in the respective task. An explanation of the naming conventions for the reported items in the public Scientific Use File can be found in Figure 3.

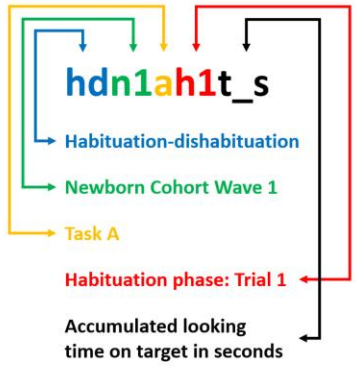

Figure 3. Naming conventions of the reported items on the children's accumulated looking times on target illustrated for the first trial of Task A (Wave 1).

The following descriptive overview features common measures of statistical dispersion to gain insight into the overall distribution of children's total fixation times in all tasks. Skewness indicates whether a distribution is symmetrical and kurtosis is the degree of tail extremity. Values of skewness between 0.5-1 are considered moderately skewed, while values above as substantially skewed (Hair et al., 2014). Values of kurtosis represent either a mesokurtic distribution (=0), a platykurtic distribution (<0) or a leptokurtic distribution (>0). However, as skewness and kurtosis depend heavily on the sample size (Westfall, 2014), these measures are reported as additional information only and not further interpreted.

Table 3 – Table 7 report details on total fixation times, namely the accumulated sum of looking time on target for all trials in each task. Distributions for all trials revealed that longer looking times were more frequent. This is also reflected by the median and the mode. However, comparably many children did not look at the target stimulus at all. The differences in maximum value between 10.03 seconds and 10.07 seconds reflect technical aspects of the coding procedure.

Table 3

Task A: Descriptive Information on Looking Times in all Trials

Variable	M	SD	Median	Mode	Min	Max	Skewness	Kurtosis
hdn1ah1t_s	6.68	2.34	7.00	10.03	0	10.03	-0.65	2.91
hdn1ah2t_s	6.09	2.60	6.41	10.03	0	10.03	-0.45	2.45
hdn1ah3t_s	6.20	2.60	6.60	10.03	0	10.03	-0.53	2.49
hdn1ah4t_s	6.10	2.60	6.44	10.03	0	10.03	-0.46	2.45
hdn1ah5t_s	5.98	2.67	6.30	10.03	0	10.03	-0.40	2.32
hdn1ah6t_s	5.91	2.73	6.23	10.03	0	10.03	-0.39	2.27
hdn1ah7t_s	5.86	2.66	6.07	10.03	0	10.03	-0.34	2.28
hdn1ah8t_s	6.05	2.69	6.40	10.03	0	10.03	-0.45	2.31
hdn1ah9t_s	5.70	2.68	5.97	10.03	0	10.03	-0.32	2.24
hdn1a11t_s	6.18	2.55	6.57	10.03	0	10.03	-0.61	2.74
hdn1a12t_s	5.43	2.57	5.60	0	0	10.03	-0.24	2.30
hdn1a21t_s	5.92	2.54	6.23	0	0	10.03	-0.46	2.48
hdn1a22t_s	5.11	2.56	5.17	0	0	10.03	-0.10	2.27

Note. N=2506; in seconds. Task A refers to the first domain-general habituation-dishabituation task at Wave 1. The variable names correspond to the official data release in the Scientific Use File.

Table 4

Task B: Descriptive Information on Looking Times in all Trials

Variable[5]	M	SD	Median	Mode	Min	Max	Skewness	Kurtosis
hdn1bh1t_s	7.68	2.21	8.23	10.03	0	10.03	-1.07	3.75
hdn1bh2t_s	7.33	2.37	7.83	10.03	0	10.03	-1.04	3.67
hdn1bh3t_s	6.73	2.52	7.10	10.03	0	10.03	-0.66	2.76
hdn1bh4t_s	6.79	2.63	7.27	10.03	0	10.03	-0.76	2.85
hdn1bh5t_s	6.54	2.62	6.90	10.03	0	10.03	-0.59	2.60
hdn1bh6t_s	6.28	2.67	6.53	10.03	0	10.03	-0.51	2.52
hdn1bh7t_s	6.21	2.75	6.53	10.03	0	10.03	-0.49	2.37
hdn1bh8t_s	6.23	2.69	6.60	10.03	0	10.03	-0.51	2.45
hdn1bh9t_s	6.20	2.69	6.50	10.03	0	10.03	-0.51	2.47
hdn1b11t_s	5.79	2.73	6.00	10.03	0	10.03	-0.29	2.19
hdn1b12t_s	5.41	2.69	5.50	10.03	0	10.03	-0.16	2.22
hdn1b21t_s	5.35	2.67	5.53	0	0	10.03	-0.27	2.29
hdn1b22t_s	4.40	2.51	4.30	0	0	10.03	0.16	2.35

Note. N=2478; in seconds. Task B refers to the second domain-general habituation-dishabituation task at Wave 1. The variable names are preliminary.

[5] The current version of the public Scientific Use File (Release 9.1.0) does not include data of Task B, Task D, and Task E. Data of these tasks was processed under a different grant and will be added in future versions of the data set. The variable names reported in Table 4, Table 6, and Table 7 are therefore preliminary.

Table 5

Task C: Descriptive Information on Looking Times in all Trials

Variable	M	SD	Median	Mode	Min	Max	Skewness	Kurtosis
hdn2ch1t_s	8.23	1.85	8.63	10.03	0	10.03	-1.23	4.49
hdn2ch2t_s	8.12	1.86	8.63	10.03	0	10.03	-1.32	4.89
hdn2ch3t_s	7.99	1.99	8.50	10.03	0	10.03	-1.21	4.21
hdn2ch4t_s	8.04	2.02	8.53	10.03	0	10.03	-1.35	4.76
hdn2ch5t_s	7.68	2.15	8.13	10.03	0	10.03	-1.05	3.76
hdn2ch6t_s	7.56	2.23	8.03	10.03	0	10.03	-1.08	4.02
hdn2ch7t_s	7.48	2.27	7.93	10.03	0	10.03	-0.98	3.59
hdn2ch8t_s	7.46	2.30	7.97	10.03	0	10.03	-0.94	3.36
hdn2ch9t_s	7.48	2.32	7.97	10.03	0	10.03	-0.98	3.48
hdn2c11t_s	7.58	2.23	8.03	10.03	0	10.03	-1.02	3.79
hdn2c12t_s	6.87	2.43	7.20	10.07	0	10.07	-0.62	2.65
hdn2c21t_s	7.24	2.26	7.70	10.03	0	10.03	-0.79	3.13
hdn2c22t_s	6.00	2.50	6.13	10.07	0	10.07	-0.18	2.20

Note. N=1131; in seconds. Task D refers to the first domain-general habituation-dishabituation task at Wave 2. The variable names correspond to the official data release in the Scientific Use File.

Table 6

Task D: Descriptive Information on Looking Times in all Trials

Variable[4]	M	SD	Median	Mode	Min	Max	Skewness	Kurtosis
hdn2dh1t_s	8.53	2.14	9.47	10.03	0	10.03	-1.76	5.80
hdn2dh2t_s	7.64	2.35	8.30	10.03	0	10.03	-0.98	3.24
hdn2dh3t_s	7.39	2.46	8.10	10.03	0	10.03	-0.93	3.08
hdn2dh4t_s	6.91	2.61	7.43	10.03	0	10.03	-0.64	2.47
hdn2d11t_s	6.92	2.77	7.60	10.03	0	10.03	-0.65	2.33
hdn2d12t_s	6.29	2.79	6.60	10.03	0	10.03	-0.42	2.21
hdn2d21t_s	7.18	2.40	7.67	10.03	0	10.03	-0.90	3.31
hdn2d22t_s	5.92	2.65	5.93	10.07	0	10.07	-0.19	2.21

Note. N=1167; in seconds. Task D refers to the domain-specific numerical habituation-dishabituation task at Wave 2.The variable names are preliminary.

Table 7

Task E: Descriptive Information on Looking Times in all Trials

Variable[4]	M	SD	Median	Mode	Min	Max	Skewness	Kurtosis
hdn2eh1t_s	8.67	1.60	9.15	10.07	0	10.07	-1.39	5.25
hdn2eh2t_s	7.99	1.99	8.47	10.03	0	10.03	-1.18	4.26
hdn2eh3t_s	7.80	2.14	8.30	10.03	0	10.03	-1.01	3.39
hdn2eh4t_s	7.23	2.26	7.57	10.03	0	10.03	-0.80	3.13
hdn2eh5t_s	7.25	2.33	7.63	10.03	0	10.03	-0.71	2.87
hdn2eh6t_s	7.36	2.34	7.89	10.03	0	10.03	-0.91	3.28
hdn2eh7t_s	6.92	2.58	7.37	10.03	0	10.03	-0.72	2.73
hdn2eh8t_s	6.56	2.61	6.87	10.03	0	10.03	-0.54	2.44
hdn2eh9t_s	6.46	2.63	6.63	10.03	0	10.03	-0.48	2.36
hdn2e11t_s	6.83	2.60	7.27	10.03	0	10.03	-0.73	2.80
hdn2e12t_s	6.18	2.76	6.37	10.03	0	10.03	-0.37	2.22
hdn2e21t_s	6.99	2.56	7.45	10.07	0	10.07	-0.74	2.87
hdn2e22t_s	6.01	2.67	6.17	10.00	0	10.00	-0.29	2.22

Note. N=1112; in seconds. Task E refers to the domain-specific word-learning habituation-dishabituation task at Wave 2. The variable names are preliminary.

4. Approaches to interpreting the data

In this section, frequently used approaches and measures to interpreting fixation times are discussed and applied to the data from the habituation-dishabituation tasks administered in NEPS SC1. There are two general approaches to interpreting interindividual performance differences in habituation-dishabituation tasks: (I) Calculating index measures of habituation and dishabituation and (II) grouping infants with comparable looking time patterns (data reduction). Most studies use the former approach and there is a number of useful established measures (Colombo et al., 1987; Kavšek, 2004a). The latter approach reduces data by creating groups or profiles based on comparable looking time patterns (McCall, 1979). For the following results, data for all children with no missing values for the respective task was used. The calculations used accumulated looking times, namely the sum of individual fixation times at each trial, with no cut-off criteria applied.

Regarding index measures of habituation and dishabituation, the approaches will be documented in the following way: (I) We provide a general descriptive overview of each measure; (II) we report correlative associations of the measure between all tasks as well as with the children's age; (III) we discuss advantages and disadvantages of the approach in the context of NEPS SC1. Regarding looking time patterns (data reduction), we first discuss cluster analysis and latent profile analysis before illustrating the latter method with NEPS SC1 data, and finally we discuss advantages and disadvantages of the approach.

For testing associations between continuous variables, we chose Pearson correlation. For comparing measures between dichotomous groups, unequal variance t-tests or Welch tests were chosen, as such tests have been shown to be more robust than classic t-tests (Delacre et al., 2017; Ruxton, 2006). Regarding habituation slope, we used growth curve modeling (Duncan & Duncan, 2004). Finally, for findings groups of children with comparable looking time patterns, we used latent profile analysis (Nylund-Gibson & Choi, 2018). Calculations were done in STATA© release 16 (StataCorp, 2019).

4.1 Measures of habituation and dishabituation

Regarding habituation, Kavšek (2004a) provides an overview of commonly used measures for interpreting children's looking times during the habituation phase. Due to the experimental design, stimulus material, and available data, we selected the following measures for the present report: Total fixation time (TFT) and habituation strength (STR) (Colombo et al., 1987). In addition, we selected a dichotomous criterion that indicates whether the child showed a typically expected attention decrement during the habituation phase, namely 50% during the course of habituation trials compared to the initial looking times (HAB) (Fennell, 2012). Finally, habituation slope modeling is introduced as a means to estimate children's attention decrement independent of their overall attention level.

Kavšek (2004a) also provides various measures of dishabituation. However, as NEPS SC1 used a fixed-trial design, only attention recovery (ATR) can be used. The measure indicates the difference in looking times at the transition to the dishabituation phase and uses the last habituation and the first dishabituation trial. Comparable measures sometimes use more than one habituation trial to gain a more robust measure (Oakes, 2010). As we expected relatively high looking times due to the categorical stimulus material and because using only the first dishabituation trial was shown to be the most robust (Kavšek, 2004a), we opted for the present approach.

Habituation: Total fixation time (TFT)

TFT is a measure of accumulated looking time on target during all trials (stimulus pictures) of the habituation phase. Prolonged looking is typically associated with a small attention decrement, which is why higher values are usually interpreted as poor information processing. For the descriptive analysis, we included all cases with no missing values in the respective task. As the total number of habituation trials in Task D was lower than in the other Tasks, TFT is also lower. Table 8 shows that for all tasks, TFT was generally high, as all distributions are left-skewed. Correlations show that TFT of tasks in the same wave tended to have higher coefficients than between the two waves (Table 9). This was expected, as the age range was relatively high at both waves (**3.1 Data base information**).

Although the literature generally focuses on the decrement in looking times during the habituation phase, in the present data, there are many children with long fixation times (see Table 3 – Table 7). Consequently, children with such looking time patterns deviate from typical habituation responses, which also influences other measures such as STR or HAB. In addition, the present sample had the longest looking times for the stimulus material at Wave 2 and TFT only correlated positively with children's age in Task A (Table 9). This was not expected, as older children typically show shorter TFT when compared to younger children (Colombo et al., 2004). However, as laboratory studies usually focus on infants during the first year of life, there are limited findings regarding the development of looking time patterns in the second year of life. Thus, it could be that interindividual age-related differences are substantially smaller in toddlers. It is therefore reasonable to examine children's TFT during the habituation phase in more detail, as it could reflect children's general or sustained attention (Dixon & Smith, 2008).

As an indicator of cognitive functioning, TFT is a convenient measure that can be easily calculated. Previous studies have often used this measure and, compared to other measures, it was found to be robust (Kavšek, 2004a), as it is not as much influenced by local maxima or missing values. In addition, TFT can be interpreted as the amount of overall attention to the stimuli (Ruff, 1986). However, the interpretation of summed up looking times is complex (Oakes et al., 1991). The tasks in NEPS SC1 differed in stimulus material, method, and duration, which is why one cannot expect all tasks to be uniformly related to each other, as well as with later skills or competencies.

Table 8

Descriptive Overview of Total Fixation Time (TFT) in All Tasks.

Variable	N	M	SD	Min	Max	Skewness	Kurtosis
TFT_A	2506	54.59	18.61	1.80	90.27	-0.47	2.65
TFT_B	2474	59.97	16.88	3.40	90.27	-0.63	2.97
TFT_C	1131	70.04	12.66	12.60	90.27	-1.07	4.41
TFT_D	1166	30.46	7.29	1.80	40.16	-1.00	3.59
TFT_E	1112	66.24	13.72	13.03	90.31	-0.65	3.17

Note. Only cases with no missing data in the respective task reported; in seconds. TFT refers to the total fixation time during the habituation phase of the respective tasks at Wave 1 (Task A – Task B) and Wave 2 (Task C – Task E). Task B and Task C featured the same stimulus material.

Table 9

Pearson Correlations of Total Fixation Time (TFT) and Children's Age in All Tasks

	TFT_A	TFT_B	TFT_C	TFT_D	TFT_E
TFT_B	.39**				
TFT_C	.09**	.10**			
TFT_D	.01	.04	.29**		
TFT_E	.03	.05	.32**	.51**	
Children's age	.17**	-.02	-.05	.03	.02

Note. ** p<.01. TFT refers to the total fixation time during the habituation phase of the respective tasks at Wave 1 (Task A – Task B) and Wave 2 (Task C – Task E). Task B and Task C featured the same stimulus material.

Habituation: Habituation strength (STR)

STR is a measure of difference between a defined number of trials at the beginning (i.e., fixation baseline) and at the end of the habituation phase (e.g., Domsch et al., 2009; Pahnke, 2007). Positive values indicate that fixation times at the beginning were longer than at the end of the habituation phase, suggesting a typical pattern of looking time decrement. Conversely, negative values indicate that fixation times at the end were longer than at the beginning of the habituation phase, suggesting an atypical looking time pattern. Consequently, positive values should point to efficient stimulus encoding and, thus, good information processing.

Typically, two or three trials are combined to generate robust measures, namely to minimize measurement error (Oakes, 2010). However, there are several reasons why we only used the first and last trial for the present report. For one, the children's looking times at the categorical stimulus material were generally high, which limits variance of STR. In addition, the fixed-trial design resulted in the longest looking times at the first trial of the habituation phase and the shortest looking times at the last trial of the habituation phase. Thus, interindividual differences in looking times should be the most pronounced when considering only these trials. Finally, including more trials would have resulted in limited comparability of Task D with the other tasks, as it featured considerably less trials.

Table 10 shows that for all tasks mean values were sharply peaked. Thus, most values were centered on the empirical mean, which limits variance and, thus, discriminatory ability of the measure between the children. This was probably because many children consistently showed long fixation times during the habituation phase (see Table 3 – Table 7). STR was mostly correlated within each wave, although correlation coefficients were generally small (Table 11). In addition, there were no significant correlations between children's age and STR. Although this was not expected, it can probably be reasoned that the measure does not accompany age differences as well as for example TFT, as it only indicates the relation of fixation times. Thus, any decremental pattern may result in positive values, regardless of the overall visual attention.

Overall, STR is a convenient measure that can be easily calculated and has been used in several previous studies (Attig & Weinert, 2018; Lavoie & Desrochers, 2002; Mayes & Kessen, 1989; Domsch et al., 2009). Still, although there are certain caveats when applying the measure to the data of NEPS SC1. There is no consensus on how many trials to consider when calculating habituation strength. If several trials are considered, variance can decrease and if too few trials are considered, local maxima or minima can bias the results, especially because the tasks in NEPS SC1 used categorical stimuli, which might elicit spontaneous dishabituation. In addition, the present results highlight that intercorrelations were low, which means that task comparability is limited when using STR.

Table 10

Descriptive Overview of Habituation Strength (STR) in All Tasks

Variable	N	M	SD	Min	Max	Skewness	Kurtosis
STR_A	2506	0.11	0.31	-1.00	1.00	0.25	4.99
STR_B	2476	0.14	0.30	-1.00	1.00	0.46	5.60
STR_C	1131	0.06	0.22	-1.00	1.00	0.88	7.46
STR_D	1167	0.12	0.25	-1.00	1.00	0.20	6.57
STR_E	1112	0.18	0.25	-1.00	1.00	0.79	4.91

Note. Only cases with no missing data in the respective task reported. STR refers to the habituation strength during the habituation phase of the respective tasks at Wave 1 (Task A – Task B) and Wave 2 (Task C – Task E). Task B and Task C featured the same stimulus material.

Table 11

Pearson Correlations of Habituation Strength (STR) and Children's Age in All Tasks

	STR_A	STR_B	STR_C	STR_D	STR_E
STR_B	.13**				
STR_C	.09*	.05			
STR_D	.08*	-.03	.09*		
STR_E	.01	.05	.11**	.17**	
Children's age	-.02	.01	-02	-.01	-.05

Note. * p<.05, ** p<.01. STR refers to the habituation strength during the habituation phase of the respective tasks at Wave 1 (Task A – Task B) and Wave 2 (Task C – Task E). Task B and Task C featured the same stimulus material.

Habituation: Habituation criterion (HAB)

For habituation-dishabituation tasks, the decrement during the habituation phase is often measured in a categorical way, namely whether the child reached a pre-defined decrement (e.g., a 50% decrease during the habituation phase, when compared to the initial looking time). Usually, a dichotomous indicator is used for either comparing habituators and non-habituators (e.g., Baillargeon, 1987; McCall, 1979) or the number of trials to reach the criterion (e.g., Dixon & Smith, 2008; Monroy et al., 2019). Conceptually, this measure is used to approximate whether the child habituated during the habituation phase, namely whether the child formed a mental representation of the stimulus material. Consequently, habituators compared to non-habituators are expected to process information faster (particularly in fixed-trial designs), and the measure was shown to predict cognitive skills later in development (Kavšek, 2013). It should be noted that habituation criteria are typically only dichotomous approximations of the looking time decrement during the habituation phase and cognitive theories suggest that the decrement indicates the formation of a mental representation (**Habituation: Habituation slope modelling**).

For the present analysis of NEPS SC1, a cut-off criterion of 50% was used (Cohen, 2004; Fennell, 2012), which means that only children who had a decrement of at least 50% fixation time during the habituation phase in comparison to the initial looking time were seen as successful habituators. Because of the categorical stimulus material, we expected a high amount of non-habituators (Fennell, 2012; Siddle & Glenn, 1974; Slater et al., 1984).

Overall, between 27.59% and 48.29% of all children habituated in the tasks (Table 12). This is at the lower range of typical findings, as usually at least half of the sample habituate in comparable tasks (e.g., McCall, 1979). In addition, it is held that the habituation rate decreases with increasing age of the child, for example, due to maturational changes (Clifton & Nelson, 1976) or increasing experience. Thus, the findings regarding Task B and Task C seem counterintuitive, as both use the same stimulus material. Moreover, HAB was only significantly associated with children's age at Wave 1 (Table 13) – note that the reported results do not control for preterm birth status (**5.3 Child characteristics**). However, HAB is seldom reported in toddlers during the second year of life. It could be that the longer fixation time – and consequently smaller decrements – at Wave 2 were due to qualitative changes in attentional processes. Thus, the comparison between habituators and non-habituators should only be drawn for Wave 1. Still, this does not account for the negative association between children's age and having habituated in Task B. Here, the task could have been too complex for this age group, which is why HAB might primarily indicate effects of fatigue in younger children. Regarding the low number of habituators in Task D, it could be reasoned that the short habituation phase (i.e., four trials) resulted in familiarization (Aslin, 2007), namely only a weak decrease in looking times.

HAB is an often-used measure of decrement in fixation times during the habituation phase (Cohen, 2004; Fennell, 2012; Oakes, 2010). As both the beginning and the end of the habituation phase are included, the measure also indicates interindividual differences in habituation patterns, although fixed-trial designs might underestimate slow habituating children (DeLoache, 1976). Some authors also suggest that only habituators should be considered in further calculations (Cohen, 2004; Oakes, 2010), even though this might exclude a large number of children and probably bias the sample. In addition, while a 50% decrement is generally regarded sufficient, other cut-off values are also used (Fennell, 2012). Thus, it depends on the research question whether to focus on this measure, although it should usually be calculated for means of comparison. In the context of NEPS SC1, subgroups of interest should be checked before formal analyses due to the age range of the children and the categorical stimulus material.

Table 12

Descriptive Overview of Habituated Children in All Tasks

	Total Sample	Habituators
Task A	2506	1131 (45.13%)
Task B	2476	1193 (48.18%)
Task C	1131	341 (30.15%)
Task D	1167	322 (27.59%)
Task E	1112	537 (48.29%)

Note. Only cases with no missing data in the respective task reported. Task A – Task B were administered at Wave 1; Task C – Task E were administered at Wave 2. Task B and Task C featured the same stimulus material.

Table 13

Children's Age in the Groups of Habituators and Non-Habituators

	Habituators		Non-Habituators				
	M	SD	M	SD	df	t	d
Task A: Children's age	6.89	0.71	7.02	0.71	2422.09	4.45**	0.18
Task B: Children's age	7.00	0.75	6.93	0.66	2393.17	-2.48*	0.10
Task C: Children's age	17.10	0.59	17.02	0.62	663.67	-1.95	0.12
Task D: Children's age	17.03	0.64	17.05	0.59	537.71	0.47	0.03
Task E: Children's age	17.07	0.61	17.04	0.60	1089.87	-0.59	0.04

Note. Children's age reported in months; **p<.01, *p<.05. Task A and Task B were administered at Wave 1; Task C – Task E were administered at Wave 2. Task B and Task C featured the same stimulus material.

Habituation: Habituation slope modeling

Another method to gain insight into children's habituation is to use modeling techniques to estimate a habituation slope. Because cognitive theories hold that the decrement in looking times during the habituation phase indicates the formation of a mental representation of the stimulus material (Colombo & Mitchell, 2009; Kavšek, 2013), habituation slopes should indicate the speed of information processing more directly than other measures. While linear regression models have been used in previous studies (e.g., Ashmead & Davis, 1996), growth curve modeling is a more elaborated way to estimate "interindividual variability in intra-individual patterns of change" (Curran et al., 2010, p. 2). More specifically regarding infant visual habituation-dishabituation tasks, growth curve modeling can be used to estimate differences between the children in intraindividual change across trials. Due to the distinction between fixed (i.e., overall trajectory mean of the sample) and random effects (i.e., individual variance around the overall mean), the intercept and slope can be estimated both for the whole sample, as well as for the individual. Intercept and slope are treated as latent variables that are predicted by the manifest looking times for each trial. For the intercept, fixed factor loadings can be used, while for the slope, the factor loadings can parallel the sequence of stimulus presentation. One example is Monroy and colleagues' (2019) study on visual habituation in deaf children. The authors used growth curve modeling for calculating the growth slope during the first four trials of the habituation phase to examine differences in early language skills between deaf and hearing infants. The slopes were found to be linear for hearing infants, whereas those of deaf infants were fluctuating.

To illustrate this approach with NEPS SC1 data, we calculated unconditional growth models for both tasks at Wave 1 (Table 14). NEPS SC1 has the advantage that due to the fixed-trial design, the children can be compared directly using habituation slope modeling. For Task A and Task B, we included looking times for all nine trials of the habituation phase and calculated models with random intercepts and random slopes (with linear and quadratic growth). In all models, intercept and slope were allowed to correlate with each other as initial looking and looking decrement are typically associated with each other (e.g., Colombo & Mitchell, 2009). Indeed, we found significant correlations between the intercept and slope in most models (Task A Model 1: $r=-.26$, $p<.01$; Task A Model 2: $r=-.17$, $p<.01$; Task B Model 1: $r=-.13$, $p<.01$; Task B Model 2: $r=-.07$, $p=.07$). Estimating a linear and quadratic slope simultaneously resulted in the model not reaching convergence in both tasks. Comparing the models using standard goodness of fit statistics tentatively reveals that for both tasks, a linear growth model fits the data best, although these calculations should not be interpreted as comprehensive because no other variables were controlled for. When applying growth curve modeling to habituation data, individual child characteristics as well as characteristics of the stimulus material should be checked.

One advantage of this approach is that missing data in growth curve modeling can be dealt with by multiple imputation (Duncan et al., 1998) or a Full Information Maximum Likelihood approach (FIML; Acock, 2005; Enders, 2001). In addition to comparing model goodness of fit statistics for linear and polynomial models, factor loadings can be customized to parallel the experimental design. In addition, growth curves can be used to study group differences (e.g., Monroy et al., 2019). Studies on non-linear modeling or polynomial modeling (e.g., Lavoie & Desrochers, 2002) of habituation found that model-based approaches that analyze the intercept and slope of children's looking times separately tend to perform better than the typical habituation criterion. This approach allows for a more fine-grained categorization of whether infants show a systematic decrease during the habituation phase, as well as an increased sensitivity for detecting an increase in the dishabituation phase (Dahlin, 2004; Thomas & Gilmore, 2004). In other words, growth curve modeling allows for estimating the habituation slope, which may be analyzed independent from the overall looking time (i.e., intercept).

However, growth curve modeling is still not frequently used in visual habituation research, probably because it needs a large sample size. Depending on the research design, Curran and colleagues (2010) recommend at least 100 cases (and more for increasingly complex designs). It should be noted, however, that with mixed effects models that effectively also represent estimates of latent growth, sample sizes need not be large (McNeish & Matta, 2018). In addition, estimations are difficult to compare when children's looking time trajectories differ (e.g., linear vs. quadratic) and nearly impossible when the sequence of trials differs, like in many infant-controlled designs. Including many trials in a model also increases complexity, which is why Monroy and colleagues (2019) only used the first four trials because those were the only trials in the infant-controlled design for which all children had valid looking time data.

However, one possible solution is using random-effects pattern-mixture modeling (Hogan & Laird, 1997), which allows for varying lengths in longitudinal data (Young & Hunter, 2015).

Table 14

Exemplary Comparison of Latent Growth Models (Wave 1)

Model	Change function	χ2	df	CFI	SRMR	RMSEA	AIC / BIC
Task A Model 1	Linear	418.65**	33	.97	.07	.07	95942.58 / 96065.37
Task A Model 2	Quadratic	537.39**	33	.97	.08	.08	96061.33 / 96184.12
Task B Model 1	Linear	330.54**	33	.97	.06	.06	96543.30 / 96665.47
Task B Model 2	Quadratic	407.87**	33	.96	.08	.07	96620.63 / 96742.80

Note. CFI = comparative fit index; SRMR = standardized root mean square residual; RMSEA = root mean square error of approximation; AIC = Akaike information criterion; BIC = Bayesian information criterion; * p<0.05. ** p<.01. Task A and Task B refer to the domain-general categorization tasks at Wave 1.

Dishabituation: Attention recovery (ATR)

In NEPS SC1, the stimulus material only featured one picture in the dishabituation phase. Therefore, the orientation response of the children refers to the concept of ATR (Kavšek & Bornstein, 2010). ATR is usually defined as the difference between the fixation times at the first dishabituation and the last habituation trial. Theoretically, the children should show ATR if they perceive the stimulus picture as novel or out of category. Positive values indicate that fixation time at the dishabituation trial was higher than at the last habituation trial, suggesting a typical pattern of renewed attention towards the novel stimulus. Conversely, negative values indicate that fixation times at the last habituation trial were higher than at the dishabituation trial, suggesting that the children perceived the dishabituation trial as familiar. Consequently, positive values should point to good discriminatory abilities and, thus, good attention recovery.

Table 15 shows that for all tasks, mean values of ATR were centered and evenly distributed (overall sample). Still, the high variance suggests that while some children perceived the dishabituation trial as novel and showed positive ATR (novelty effect), others perceived the dishabituation trial as familiar and showed negative ATR (familiarity effect). Thus, for the overall sample, the measure might not be informative, as these two subgroups are collapsed. This is supported by the low intercorrelations of the measure in all tasks (Table 16), although it should be noted that previous studies also found no consistent reliability in dishabituation measures (Colombo et al., 1987; Kavšek, 2004a). In addition, we also tested whether ATR was associated with children's age. Against our expectations, there were no significant correlations between ATR and children's age.

Because it is held that habituated children show attention recovery (novelty effect) while non-habituated children show attention decrement (familiarity effect), we used HAB to differentiate between habituators and non-habituators (Table 17). Thus, we used the measure to analyze the looking times for the last habituation trial and the first dishabituation trial between these two groups. T-tests yielded consistent results: In most tasks, habituators showed significantly longer looking times at the novel stimulus (novelty effect), whereas non-habituators had stable or significantly shorter looking times (familiarity effect). These results suggest that habituators and non-habituators show generally typical looking time patterns, which is relevant when working with ATR.

ATR is an informative measure of the children's dishabituation reaction in tasks with a dishabituation phase consisting of individually presented out-of-category exemplars. It allows for assessing the children's behavioral response to a change in stimulus material (Kavšek, 2013; Rose et al., 2004). Even if only one dishabituation trial is considered, as in the case of NEPS SC1, the measure should adequately model interindividual differences in fixation time (Kavšek, 2004a). Still, children's response to the dishabituation phase critically depends on the previous habituation phase as was shown in the present analyses. Still, it should be critically noted that dishabituation measures were generally shown to have no consistent reliability (Colombo et al., 1987; Kavšek, 2004a) and associations between the habituation phase and the dishabituation reaction are probably more complex than often assumed (Jerome et al., 1979). Overall, it depends on the research question and relevant sample (e.g., Kavšek & Bornstein, 2010) whether to focus on ATR when analyzing NEPS SC1 and the measure should always also consider children's habituation.

Table 15

Descriptive Overview of Attention Recovery (ATR) in All Tasks

	N	M	SD	Min	Max	Skewness	Kurtosis
Task A	2506	0.48	2.35	-10.03	10.03	0.03	3.89
Task B	2476	-0.41	2.62	-10.03	10.03	0.07	3.58
Task C	1131	0.10	2.48	-8.57	9.93	0.31	4.37
Task D	1167	0.01	2.93	-9.27	9.63	-0.12	3.16
Task E	1112	0.36	2.57	-9.80	9.10	0.10	3.60

Note. Only cases with no missing data in the respective task reported. ATR refers to the attention recovery during the dishabituation phase of the respective tasks at Wave 1 (Task A – Task B) and Wave 2 (Task C – Task E). Task B and Task C featured the same stimulus material.

Table 16

Pearson Correlations of Attention Recovery (ATR) in All Tasks

	ATR_A	ATR_B	ATR_C	ATR_D	ATR_E
ATR_B	-0.04				
ATR_C	-0.04	.00			
ATR_D	0.01	-0.01	0.00		
ATR_E	-0.01	0.08*	0.08*	0.02	
Children's age	.03	-.01	.01	.01	-.02

Note. * p<.05. ATR refers to the attention recovery during the dishabituation phase of the respective tasks at Wave 1 (Task A – Task B) and Wave 2 (Task C – Task E). Task B and Task C featured the same stimulus material.

Table 17

Looking Times in Habituators and Non-habituators

		Trial 9		Trial 10				
		M	SD	M	SD	df	t	d
Task A	Habituators	4.10	2.57	5.13	2.70	1391	-13.49**	0.39
	Non-habituators	6.98	2.00	7.01	2.08	1163	-0.60	0.02
Task B	Habituators	4.85	2.75	4.73	2.68	1193	1.46	0.04
	Non-habituators	7.45	1.9	6.77	2.39	1288	10.60**	0.31
Task C	Habituators	5.87	2.81	6.45	2.68	380	-3.51**	0.21
	Non-habituators	8.07	1.76	7.89	2.00	837	2.42*	0.09
Task D	Habituators	4.46	2.57	5.48	2.95	339	-5.51**	0.37
	Non-habituators	7.81	1.94	7.40	2.54	875	4.65**	0.18
Task E	Habituators	5.09	2.70	5.79	2.73	539	-5.57**	0.25
	Non-habituators	7.73	1.81	7.80	2.03	574	-0.71	0.03

Note. Children's looking times reported in seconds; ** p<.01, * p<.05. Task A and Task B were administered at Wave 1; Task C – Task E were administered at Wave 2. Task B and Task C featured the same stimulus material. Trial 9 was the last trial of the habituation phase, whereas Trial 10 was the first dishabituation trial.

4.2 Data reduction methods

Apart from using index measures that are calculated by using the looking times of each respective trial to interpret individual task performance, there are several studies that use data reduction methods to create groups that can be compared regarding differential developmental patterns (Bronson, 1991; Richards & Cameron, 1989). In previous research, McCall (1979) found age-related differences in the habituation phase when using cluster analysis as a data reduction method. Infants at 5 months were clustered into three groups (i.e., monotonically decrease; decrease-increase; increase) and infants at 10 months were clustered into five groups, that were generally flatter and more mixed. Another use of cluster analysis can be found in Baillargeon (1987), who found three groups in a sample of 3-4 month-old-infants (i.e., fast habituators; slow habituators; mixed group).

Cluster analysis as a data-led method might reveal coherent interindividual looking time patterns, which can be compared to theoretically expected ones. The groups are usually interpreted in a straightforward manner, as the individual looking time at the stimulus material does not have to be analyzed in detail. However, cluster analysis based on observable visual behavior also has drawbacks. It could be shown that the clusters might represent statistical artifacts when the underlying habituation function includes an additive random error. This has a detrimental effect on the estimated expected number of clusters when the patterns between the groups are similar (Gilmore & Thomas, 2002). Additionally, cluster analyses cannot statistically verify the number of groups and therefore assign group number only categorically (Dolnicar, 2002). Some studies, for example, create a group of children with a mixed profile, without explaining what the benefit of such a heterogeneous group is (e.g., Baillargeon, 1987; McCall, 1979). Longitudinally, it is also difficult to find stability, as children's looking time patterns often change – something, that cluster analyses do not automatically reflect (Kavšek, 2004a; McCall, 1979). In addition, for large sample sizes the patterns are much more difficult to interpret because cluster assignment is influenced by group size (Siddiqui, 2013). Finally, although clusters can empirically be found, they may represent statistical artifacts because they underlie the same basic habituation function (Gilmore & Thomas, 2002).

As a possibility to deal with two main statistical issues of cluster analysis, namely that the number of groups cannot be statistically determined and the impact of statistical artifacts on how group membership is assigned, latent profile analysis can be used. Although to the knowledge of the authors, there have been no studies so far that implemented latent profiles in infant habituation research, it should allow for a probabilistic way to assign children to specific groups of looking time patterns and even statistically compare models with different group sizes.

Probabilistic clustering methods are useful for classifying individuals into groups of profiles based on conditional probabilities. With continuous variables (i.e., fixation times) and categorical outcomes (i.e., group membership), probabilistic clustering is often referred to as latent class analysis (Fairley et al., 2014) or latent profile analysis (Dean & Raftery, 2010; Vermunt & Magidson, 2002). Latent profile analysis assumes a statistical model for the population of the current sample and estimates the similarity of the individuals from their observed scores on a set of indicators that share the same probabilistic distributions. Group membership is therefore estimated by the probability of being a member of a latent class and the class-specific normal density (Tein et al., 2013; Vermunt & Magidson, 2002). The posterior group membership assigns the classes to those with the highest similarity of the observed scores and the class-specific normal density (Vermunt & Magidson, 2002). In addition, latent profile analysis allows for incorporating missing data by applying multiple imputation (Duncan et al., 1998) or Full Information Maximum Likelihood (FIML; Acock, 2005; Enders, 2001) (see Fairley et al., 2014). Finally, group sizes can be compared via standard goodness of fit measures (Vermunt & Magidson, 2002), such as AIC, CAIC, BIC/SIC, and sample size adjusted BIC (Nylund et al., 2007). In short, the sequence of habituation or dishabituation trials can be used as manifest variables to estimate latent looking time profiles, based on the looking times of all children in the sample.

To illustrate this approach with NEPS SC1 data, we calculated latent profile analysis for all trials in the habituation phase of Task A. To avoid solutions based on local maxima and to increase robustness of the findings, 100 random sets of starting values were defined. Typically, AIC, BIC, and entropy are used to assess the quality of the respective profile solutions (Celeux & Soromenho, 1996). When comparing the present profile solutions (Table 18), entropy started to fall with the 4-profile solution and with a growing number of classes, profile size also decreases, limiting the interpretation of the results (Tein et al., 2013), so we chose the 3-profile solution, which also matches the number of clusters McCall (1979) found.

Table 18

Selected Solutions of Latent Profile Analysis (Task A)

	AIC	**BIC**	**Entropy**
2 Profiles	98120.09	98283.23	.97
3 Profiles	95356.42	95577.82	.97
4 Profiles	94474.98	94754.65	.96

Note. AIC = Akaike information criterion; BIC = Bayesian information criterion. Task A refers to the first domain-general categorization task at Wave 1.

Table 19 reports descriptive data on children's mean looking times in Task A. For all profiles, fixation times tended to decrease during the habituation phase, although the decrement was smaller than what is typically expected (e.g., Colombo et al., 2004). However, the profiles were markedly different in the initial looking times (i.e., the first trial) as well as in the overall level of looking times (Figure 4). Thus, the profiles do not differ with regard to the decrement in looking times but rather with regard to the overall looking time at the target.

Table 19

Descriptive Overview of Mean Fixation Times in Latent Profiles (Task A)

	Profile 1: M (SD)	**Profile 2: M (SD)**	**Profile 3: M (SD)**
hdn1ah1t_s	3.83 (2.08)	6.30 (1.91)	8.02 (1.71)
hdn1ah2t_s	2.56 (1.87)	5.54 (1.95)	7.82 (1.74)
hdn1ah3t_s	2.53 (1.87)	5.57 (1.91)	8.04 (1.56)
hdn1ah4t_s	2.39 (1.72)	5.43 (1.88)	8.00 (1.53)
hdn1ah5t_s	2.37 (1.81)	5.09 (1.90)	8.05 (1.51)
hdn1ah6t_s	2.23 (1.80)	5.03 (1.96)	8.01 (1.58)
hdn1ah7t_s	2.30 (1.82)	5.03 (1.91)	7.86 (1.60)
hdn1ah8t_s	2.51 (2.03)	5.30 (2.07)	7.97 (1.59)
hdn1ah9t_s	2.28 (2.00)	4.98 (2.04)	7.56 (1.78)

Note. Profile 1 (N=378); Profile 2 (N=1027); Profile 3 (N=1101); fixation times in seconds. Task A refers to the first domain-general categorization task at Wave 1.

Next, we examined differences in children's age between the three profiles. Descriptively, children in Profile 1 were youngest (M=6.75, SD=0.65), while children in Profile 3 were oldest (M=7.08, SD=0.73), and Profile 2 was in-between (M=6.91, SD=0.69). Regression analysis and post-hoc tests showed that the level differences between all three classes were significant; Profile 1 and Profile 2: $F(1, 2499)=15.12$, $p<.01$; Profile 1 and Profile 3: $F(1, 2499)=61.10$, $p<.01$; Profile 2 and Profile 3: $F(1, 2499)=28.65$, $p<.01$. The results suggest that younger children spent less time looking at the stimulus material, while older children show prolonged looking times, which is counterintuitive given the typically decreasing looking times in habituation-dishabituation tasks with increasing age (e.g., Colombo et al., 2004). As the overall slope of looking times during the habituation phase was comparable between the profiles, we reason that the youngest children (Profile 1) were maybe more uncomfortable with the observational setting and, therefore, focused less on the stimulus material.

Thus, using data reduction methods, the pattern of results for Task A is not similar to findings from the literature. In 5-month-old infants, McCall (1979) reported two clusters with fluctuating patterns, while a third cluster showed a typical decrement during the habituation phase. As the present findings suggest rather stable interindividual looking times across trials, this can probably be attributed to the categorical stimulus material, which was shown to result in prolonged looking behavior and greater engagement in the task, especially in older children (Courage et al., 2006; Fennell, 2012). In addition, prolonged looking behavior might be a result of the familiar setting in the children's home compared to standard laboratories, which activated the children more during task administration (Wass & Leong, 2016). As the three profiles mainly reflect level differences, this might indicate that the task discriminated between overall visual attention instead of information processing. Thus, when applying data reduction methods, the patterns need to be contrasted to theoretical assumptions about looking time patterns in general (Colombo & Mitchell, 2009) as well as specific empirical findings reported in the relevant age range (Colombo et al., 2004).

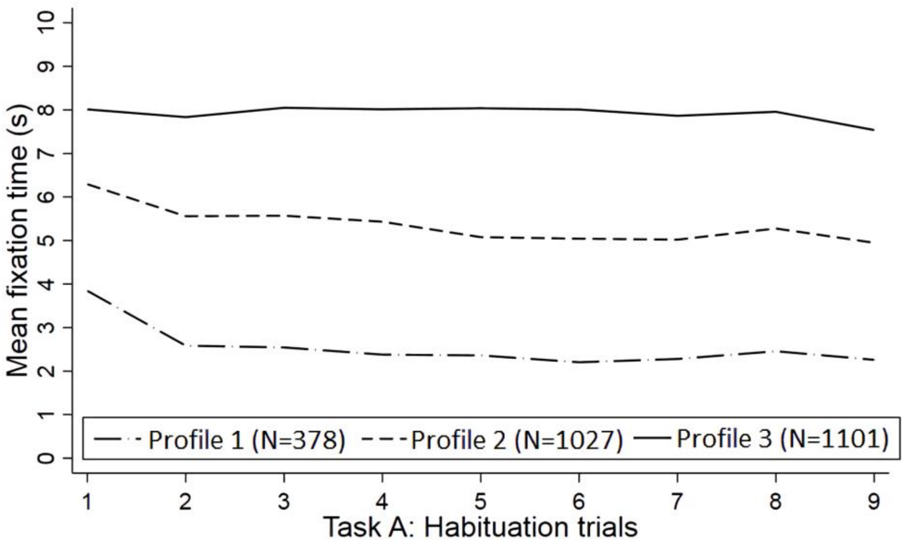

Figure 4. Fixation time patterns during the habituation phase of Task A for all three profiles. Task A refers to the first domain-general categorization habituation-dishabituation task at Wave 1.

5. Data selection

As data selection criteria have a great influence on calculating and interpreting fixation times (Fennell, 2012; Kavšek, 2004a; Oakes, 2010), this chapter presents further information on how the children's looking times can be approached from a methodological standpoint. Specifically, short looking times, relevant child characteristics, and disturbances during the observation are discussed. Finally, we provide information on possible forms of data transformation.

5.1 Handling short looking times

To make sure that the children's looking times can be interpreted as a valid indicator for having processed the presented stimuli adequately, cut-off criteria for short fixation times (i.e., short episodes of looking at the target) are often used (Oakes, 2010). However, as Colombo and Mitchell (2009) note, there is no consensus in the literature on what cut-off criterion to use. Some authors suggest that within a range of 0.5-1 seconds, cutting off values does not result in systematically different results (Colombo & Mitchell, 1990), while others argue that single looking time events should not be smaller than 400 milliseconds (Kavšek, 2013). In experiments on sustained attention in infants, it could be shown, that through a change in heart rate, a minimum of about 1 second is required, following stimulus onset. This has been interpreted as a stimulus orienting response of the infants, which likely reflects attentional processing (Richards & Casey, 1992). In studies on sustained deceleration (Colombo et al., 2004) and in studies with more complicated stimulus material (Cohen et al., 1975), even higher cut-off values have been discussed. Thus, many authors argue that cut-off criteria can reduce local maxima, which influences measures of habituation and dishabituation.

However, cut-off values are often arbitrary and differ vastly among studies (Colombo & Mitchell, 2009). A certain amount of data will be defined as invalid, when in reality the looking time event might have contributed to how the infant processed the stimulus. For reaction time tasks, it was shown that truncated looking times can bias results and distort linear relationships because valid events of stimulus processing are excluded (Ulrich & Miller, 1994). Moreover, cut-off criteria usually lead to an increase in missing values and dropout of cases. Finally, most studies with cut-off criteria have infant-controlled designs. In such studies, the elimination of small looking times events is directly related to reaching the habituation criterion and, thus, how long the stimulus material is presented (e.g., Bornstein & Suess, 2000; Brooks & Meltzoff, 2008; Colombo et al., 2004; Mayes & Kessen, 1989). To the knowledge of the authors, there have been no methodological studies on whether short looking time events have a comparable impact in fixed-trial designs.

In the context of NEPS SC1, an extreme example of short looking times are cases with zero looking times (i.e., the child did not look at the target during the 10 second interval). Handling such cases becomes relevant when one decides against using cut-off criteria. These cases do not represent missing values in a traditional sense (e.g., Graham, 2009). Rather, such zero looking times indicate that external or internal factors resulted in the child having looked away from the target in the respective interval. Overall, children showed no looking time on target for a number of trials (Wave 1: Table 20; Wave 2: Table 21). In Wave 1 (Task A: N=414; Task B: N=517), the number of cases with zero looking times was generally higher than in Wave 2 (Task C: N=61; Task D: N=85; Task E: N=117).

Table 20

Number of Trials with Zero Looking Time on Target (Wave 1)

	Task A	**Task B**
No zero looking times	2092 (83.48%)	1959 (79.12%)
1	224 (8.94%)	281 (11.35%)
2	90 (3.59%)	106 (4.28%)
3	36 (1.44%)	57 (2.30%)
4	22 (0.88%)	36 (1.45%)
5	7 (0.28%)	20 (0.81%)
6	11 (0.44%)	8 (0.32%)
7	12 (0.48%)	6 (0.24%)
8	4 (0.16%)	2 (0.08%)
9	1 (0.04%)	0
10	5 (0.20%)	1 (0.04%)
11	2 (0.08%)	0
12	0	0
13	0	0

Note. All cases considered with video recordings and available looking time data (without missing values); all respective trials considered. Task A – Task B refer to the domain-general categorization habituation-dishabituation tasks at Wave 1.

Thus, although most of the children do not show zero looking times, the issue should be addressed when working with the data of NEPS SC1. The descriptive overviews also suggest that the number of cases with no looking time towards the target tends to increase during the sequence of tasks at each wave (Table 20; Table 21). As fixed-trial designs are used to study interindividual differences, trials with zero looking time on target should not be critical when they are randomly distributed, for example, due to unsystematic internal or external factors. However, they are potentially problematic when there is a systematic influence. When zero looking times indicate task systematic interruptions or distractions such as external (e.g., distractions of other people or loud noises) or internal events (e.g., sleepiness/fussiness of the child), such cases should be excluded (Jones, 2019).

Table 21

Number of Trials with Zero Looking Time on Target (Wave 2)

	Task C	**Task D**	**Task E**
No zero looking times	1070 (94.61%)	1082 (92.72%)	995 (89.48%)
1	40 (3.54%)	66 (5.66%)	78 (7.01%)
2	14 (1.24%)	13 (1.11%)	27 (2.43%)
3	3 (0.27%)	5 (0.43%)	6 (0.54%)
4	1 (0.09%)	1 (0.09%)	3 (0.27%)
5	1 (0.09%)	0	2 (0.18%)
6	1 (0.09%)	0	1 (0.09%)
7	0	0	0
8	1 (0.09%)	0	0
9	0	-	0
10	0	-	0
11	0	-	0
12	0	-	0
13	0	-	0

Note. All cases considered with video recordings and available looking time data (without missing values); all respective trials considered in each task. Task C – E refer to the habituation-dishabituation tasks at Wave 2.

Overall, handling short looking times depends on the research question. When using the habituation-dishabituation tasks in NEPS SC1 to investigate early predictors of later cognitive abilities, most cut-off criteria are not likely to influence the overall pattern of results and may be regarded as measurement error – even though the error should not be completely at random (Gilmore & Thomas, 2002). When investigating the available looking time data from a methodological standpoint, however, short looking time events should be analyzed more thoroughly and different cut-off criteria should be considered and possibly compared. Still, it should be noted that looking time data in current data releases of NEPS SC1 does not allow for investigating different underlying processes of visual attention in detail (i.e., orienting attention and selective engagement; Reynolds, 2015) because only accumulated looking times are available. When cut-off criteria are not considered, zero looking times need to be addressed. Although cases with a substantial amount of zero looking times were rare, they should be excluded from the analysis, as it can be reasoned that the stimulus material was not sufficiently processed. Still, some authors argue that including zero looking times does not generally bias results and leads to an increased sample size (Colombo & Mitchell, 1990), which is why robustness checks should be done after applying a cut-off criterion. At least when examining specific trials (e.g., for calculating certain measures or when focusing on the dishabituation phase), cases with zero looking times should not be included without robustness checks.

5.2 Disturbances

In infant studies, child-related disturbances are frequently reported such as fussiness (see Slaughter & Suddendorf, 2007), drowsiness, crying, excessive movements, irritability, and restlessness or falling asleep. These cases are usually excluded because such disturbances influence if and how the child participates during the task and how the stimulus material is processed. At the first two waves, the coders of the video recordings protocolled child-related disturbances for each task. Table 22 shows that reported child-related disturbances were marginal in the overall sample with informed consent, especially when compared to studies conducted in a laboratory setting (Slaughter & Suddendorf, 2007). It should be noted, however, that cases in which video recordings could not be started or finished due to child-related disturbances, could not be covered this way.

Table 22

Descriptive Overview of Child-Related Disturbances in the Habituation-Dishabituation Tasks

	No child-related disturbance	**Child-related disturbances**	**No information available**
Task A	2985 (95.40%)	24 (0.77%)	120 (3.83%)
Task B	2915 (93.16%)	68 (2.17%)	146 (4.67%)
Task C	1366 (92.05%)	25 (1.68%)	93 (6.27%)
Task D	1228 (82.75%)	35 (2.36%)	221 (1.89%)
Task E	1215 (81.87%)	69 (4.65%)	200 (13.48%)

Note. All cases considered with informed consent at Wave 1 (N=3129) and at Wave 2 (N=1484), respectively. Task A – Task B refer to the habituation-dishabituation tasks at Wave 1; Task C – Task E refer to the habituation-dishabituation tasks at Wave 2.

Such extremely low numbers of child-related disturbances were unexpected but probably a result of the familiar environment. Thus, most children can be regarded cooperative during the habituation-dishabituation tasks in both waves. The household setting could have been responsible for the children's level of participation and sustained attention. However, NEPS SC1 has limited information on the immediate environment of the children, namely qualities of the household. Examples are stressful and chaotic features of the immediate environment. Household chaos refers to aspects that may confuse young children, such as disorganized structures and hurriedness in the home, especially if these disturbances happen severely and chronically (for an overview, see Emond, 2020). Such stressful contexts were already shown to be associated with reduced information processing in 5-month-old infants (Tomalski et al., 2017) and may result in the detrimental development of school-related skills and competencies (Martin et al., 2012). This might also increase measurement error during habituation-dishabituation tasks, as well as influencing children's attention selectively, although given the present number of disturbances such cases in the data of NEPS SC1 should generally be rare.

5.3 Child characteristics

Child characteristics relevant for interpreting habituation and dishabituation include preterm birth (i.e., <37 weeks of gestation; Kavšek & Bornstein, 2010), low birthweight (i.e., <2000g; Hack et al., 1995), post-term birth (i.e., >42 weeks of gestation; Bornstein et al., 2013), visual/hearing impairment (Kavšek & Bornstein, 2010) depending on the stimulus presentation, and later reported developmental disability (Brian et al., 2003). Usually, these cases should be controlled for or excluded because they often indicate prematurity, which is problematic when examining interindividual differences (Kavšek & Bornstein, 2010; Ohgi et al., 2003; Ortiz-Mantilla et al., 2008). In addition, preterm low birthweight infants were found to have a higher variance in their looking time patterns than full-term infants (Thomas et al., 1998), which could result in statistical artifacts. Children born preterm are often excluded, especially if habituation and dishabituation are used for predicting later abilities and competencies. In NEPS SC1, there was only a small subsample of children born preterm and children born post-term were the exception (Table 23).

Table 23

Birth Status of NEPS SC1 Children

	Full-term	Preterm	Post-term
Task A	2349 (93.74%)	143 (5.71%)	14 (0.55%)
Task B	2317 (93.58%)	146 (5.90%)	13 (0.52%)
Task C	1062 (93.90%)	62 (5.48%)	7 (0.62%)
Task D	1094 (93.74%)	66 (5.67%)	7 (0.59%)
Task E	1048 (94.24%)	57 (5.13%)	7 (0.63%)

Note. All cases considered with available looking time data (without missing values). Task A – Task B refer to the habituation-dishabituation tasks at Wave 1; Task C – Task E refer to the habituation-dishabituation tasks at Wave 2.

Regarding children's health, it should be noted that there is no exact information on nutritional status at both waves, although information of the routine medical examinations is included (i.e., information from the child health record books). At least for malnourished 12-month-old infants, it was shown that habituation to auditory signals was substantially associated with belated or absent orientation response and a lack of dishabituation (Lester, 1975) – although differences only showed in severely malnourished infants (Lester et al., 1975). Using a visual preference study, Lasky and Klein (1980) also supported the notion that malnourished children compared to well-nourished children respond to a lesser extent to novel stimuli. However, for the German population, such cases should be extremely rare (McCarthy et al., 2019). Regarding more unstable child characteristics such as mild illness, research is scarce. However, one previous study found no systematic effect on habituation patterns, except for a higher rate of fatigue (Haskins et al., 1978).

Finally, child temperament (e.g., effortful control and surgency) has been suggested to be associated with children's visual attention (Papageorgiou et al., 2015) and, thus, with their performance in habituation-dishabituation tasks. It was found, for example, that infants with an agitated temperament were less likely to complete a habituation task at 4 months (Bell et al., 1998; Bell et al., 2002; similarly Treiber, 1982) – see Mink and colleagues (2013) for contrasting findings regarding dropout rates. This effect could be associated with the child's gender (Wachs & Smitherman, 1985). In previous analyses of NEPS SC1, child temperament (i.e., negative affectivity) was positively associated with total fixation time during the habituation phase in Task A (Weinert et al., 2017) but not in Task C (Attig & Weinert, 2018). Similarly, in categorical habituation tasks, fearful (Rieser-Danner, 2003) and distressed children (Vonderlin et al., 2008) were less likely to show a typical looking time pattern (i.e., familiarity with the test administrator and testing environment).

5.4 Multiple family languages

In cognitive research, it has been suggested that children growing up with multiple languages at home, namely crib bilinguals (e.g., Kovács, 2016), may have several advantages. Typically, researchers point out specific developmental differences between monolinguals and bilinguals regarding gray matter density in the left parietal cortex (García-Pentón et al., 2014) and higher executive functions, covering inhibitory control, monitoring, and attention switching (Diamond, 2013). Overall, results are still inconsistent regarding the domain-specificity of such a bilingual advantage (Bialystok, 1999; Kovács & Mehler, 2009; but see Paap & Greenberg, 2013; Samuel et al., 2018). Theoretically, it is reasonable that domain-general cognitive processes are impacted by the exposure to more than one language during infancy. Indeed, Singh and colleagues (2015) found that 6-month-old bilingual infants showed faster information processing and better recognition memory than monolinguals. They used an infant-controlled habituation-dishabituation task with identical stimulus material and found significant advantages in bilinguals for several measures (i.e., attention decrement, habituation slope, and novelty preference). The authors, thus, argue for a domain-general advantage of bilinguals over monolinguals that comprises basic visual information processing and emerges in the first months of life.

Still, it should be noted that regarding bilingual language exposure, data in NEPS SC1 is limited and often confounded with other variables of interest. Thus, not all challenges of bilingualism research can be met with the dataset (e.g., context of exposure or language dominance; Werker & Byers-Heinlein, 2008).It should be carefully considered if and how family language can be controlled for, when using habituation-dishabituation tasks for indicating early cognitive abilities. Although previous studies found a domain-general effect in a sample of 6-month-old infants (Singh et al., 2015) and possibly differences in the novelty effect of bilingual and monolingual infants (Singh, 2021), there have been very few comparable studies.

5.5 Data transformation

As other reaction time based experimental designs, looking time data in habituation-dishabituation tasks are usually left-skewed (e.g., Farroni et al., 2005; Leslie & Chen, 2007). If the data is heavily skewed (i.e., not normally distributed and/or without homogeneous standard deviations), traditional parametric statistical approaches (e.g., t-test or regression analysis), will not produce reliable results (Chin & Lee, 2008), resulting in biased estimators and confidence intervals that cannot be adequately interpreted (Ernst & Albers, 2017; Williams et al., 2013). To generate normally distributed data, there are several approaches. One approach is to identify and eliminate outliers (e.g., Beier & Spelke, 2012; Jones, 2019;

Wagner & Carey, 2005). However, excluding certain values is often arbitrary in disregarding data and inefficient when the data structure is complex. Another approach is to use non-parametric tests (Havron et al., 2020) that make fewer assumptions about the data distribution (i.e., normally distributed residuals; Rasmussen & Dunlap, 1991) but are also generally less powerful than parametric tests (Chin & Lee, 2008). Lastly, in infant habituation research, logarithmic data transformation has sometimes been used to produce log-normal distributions (e.g., Bornstein et al., 2013; Dunn & Bremner, 2016; Mayes & Kessen, 1989; Woodward, 1998). However, other types of transformations have also been used, for example arcsine/angular (Barten & Ronch, 1971; Imafuku et al., 2019) or square-root transformation (Colombo et al., 1987; Millar & Weir, 1995). In comparing looking time data to general reaction time data (see Whelan, 2008), Csibra and colleagues (2016) noted that due to the non-arbitrary zero point, the continuously positive types of measurement, and the possibility to interpret accumulated fixation times proportionally to each other, looking time data might follow a log-normal distribution. At least when using proportions of looking times for sequential stimuli, the authors recommend transforming the data logarithmically. Regarding NEPS SC1, most previous analyses transformed the data logarithmically due to the characteristics of the distribution (Attig & Weinert, 2018; Hondralis & Kleinert, 2021).

6. Summary and Conclusion

In NEPS SC1, visual habituation-dishabituation tasks were administered in the first two waves, namely when the children were on average 7 and 17 months. Domain-general categorization and domain-specific tasks tapping early quantitative abilities and word learning were administered in the children's home by trained interviewers. Compared to typical infant studies, NEPS SC1 provides rich data on the children's socioeconomic background and the sample is relatively heterogeneous, which is especially important for analyzing structural and environmental factors. For the habituation-dishabituation tasks, the Scientific Use File provides a range of information on children's looking times on and off target. This technical report presented selected insights into how the data may be approached, although not all aspects could be elaborated in detail. As examples of often-used measures, we included total fixation time (TFT), habituation strength (STR), habituation criterion (HAB), habituation slope, and attention recovery (ATR) (Colombo et al. , 1987; Kavšek, 2004a). In addition, the possibility of analyzing children's looking time patterns with data reduction methods was discussed. Overall, it depends on the research question what approach to use.

The familiar setting in the children's home probably resulted in atypical looking time patterns in the habituation and dishabituation phases of most tasks. Although one previous study found no systematic difference in looking times between household and laboratory setting (Bornstein & Ludeman, 1989), we suspect that the familiar environment facilitated children's attention. In other words, the habituation-dishabituation tasks in NEPS SC1 could have higher ecological validity when compared to standardized laboratory environment. We found that looking times at the target were generally high and only subgroups of children showed a decrease in fixation times in the habituation phase. Still, NEPS SC1 only provides a limited amount of information regarding potential effects of the children's immediate environment (e.g., interruptions by parents or siblings, lighting, traffic noise). However, while there could be numerous reasons why a household setting might influence the children's attention negatively, overall the opposite seems to be the case as a large amount of children participated in the tasks without any interruptions or disturbances, which is a central strength of the data.

Regarding interindividual differences in habituation and dishabituation, we found only few significant correlations between children's age and fixation time on target. Previous studies suggest that, because fixation times indicate processing speed, they should decline with age (Ropeter & Pauen, 2013). Because older children process visual information more quickly, they should also habituate more efficiently (Colombo et al., 1988; Kavšek, 2004a). However, as other authors have already suggested, the relationship between looking times as a quantitative measure and the quality of information processing is not fully understood because looking times may indicate processing of local and/or global features (Freeseman et al., 1993). In addition, typically only the first year of life is investigated in the literature; thus, interindividual differences regarding the children's age could be substantially smaller in the second year of life, due to maturational changes.

Overall, our findings suggest that total fixation time in NEPS SC1 indicates a form of sustained attention (Ruff, 1986), while in laboratory studies children with consistently high looking times would be categorized as non-habituators or slow habituators (e.g., McCall, 1979). It is generally held that children with long fixation times have poorer processing speed than children with a typical decrement in the habituation phase (e.g., Ropeter & Pauen, 2013; Sigman et al., 1997). Thus, showing prolonged looking time during the habituation phase or not reaching the habituation criterion was frequently shown to be associated with poorer cognitive outcomes (e.g., McCall & Carriger, 1993; Teubert et al., 2011). However, there is also evidence suggesting that the effect of attention decrement during the habituation phase on language skills might be moderated by attentional focus (Dixon & Smith, 2008). Here, the authors found that for children with high attention focus, processing speed was positively related to productive vocabulary at 20 months – so, children with longer fixation times and consequently a weaker habituation decrement had higher language skills if they also had high attentional focus. The authors conclude that volitional attention is probably an underlying mechanism, which is why slow habituation should not generally be regarded as poor performance. The present data also indicates that long looking times, and consequently slower habituation, should be examined more carefully (see Colombo et al., 2004).

One limitation of the experimental design of the habituation-dishabituation tasks in NEPS SC1 was the lack of a randomized task order. At both waves, the sequence of the tasks was fixed, which makes it impossible to disentangle effects of categorization, attentional processes, and task sequence, which is why direct comparisons between the tasks is not possible, even if Task B and Task C effectively used the same stimulus material. However, the fixed sequence also makes large-scale group comparisons easier, which was the focus of NEPS SC1. Additionally, only tasks with a fixed-trial design were administered which are often criticized as outdated because many children might not habituate properly (Bornstein & Sigman, 1986; but see Haaf et al., 1983). As a result, some children might not identify the dishabituation stimulus as novel, while others might have already habituated early on. This is why some authors prefer the term familiarization for such designs instead of habituation (Aslin, 2007; Oakes, 2010). Still, in the large-scale context of NEPS SC1, the fixed-trial design was deemed useful, as it allowed for a high degree of standardization and certain elements of infant-controlled tasks were seen as problematic (i.e., interviewer experience and online coding). In addition, analyzing the looking time behavior in habituators and non-habituators revealed consistent patterns that matched our previous expectations. Thus, NEPS SC1 is useful for identifying interindividual differences in early cognitive functioning on a group level (Colombo & Mitchell, 2009).

One important benefit of NEPS SC1 is that habituation-dishabituation tasks were administered to a large and heterogeneous sample in a household setting. Thus, there is rich data on the children's socioeconomic background, family, home learning environment, social capital or other cultural resources, regional information (Weinert et al., 2016), as well as longitudinal competence data (Artelt et al., 2013; Weinert et al., 2019). As habituation-dishabituation tasks may be used to examine early cognitive abilities as well as the effects of such precursors on later skills and competencies, the data offers numerous possibilities for extending, replicating, and verifying existing results as well as gaining knowledge about how children's immediate environment influences their cognitive development (e.g., Bronfenbrenner & Morris, 2006).

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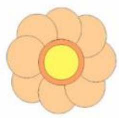
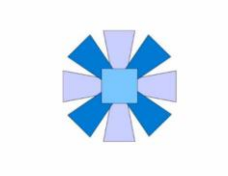
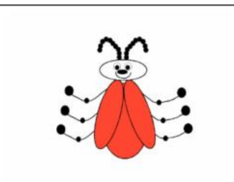
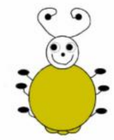
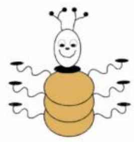
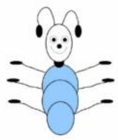
8. Appendix: Stimulus material

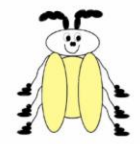
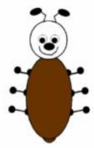
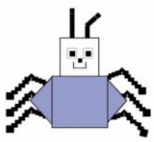
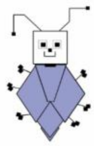
Wave 1: Presentation sequence of the stimulus material

Trial	Task	Presentation time *(seconds)*	Stimulus
--	Attention getter	3	
1	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
2	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
3	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
4	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*

Trial	Task	Presentation time *(seconds)*	Stimulus
5	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
6	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
7	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
8	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
9	Task A Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*

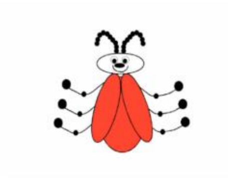
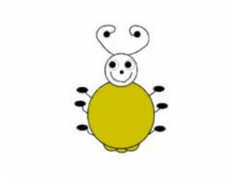
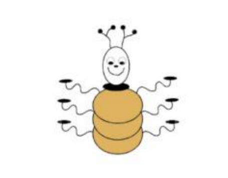
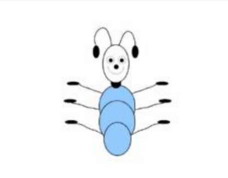
Trial	Task	Presentation time *(seconds)*	Stimulus
10	Task A Dishabituation phase	15	
--		1	-- *white screen (intertrial interval)* --
11	Task A Dishabituation phase	15	
--		2	-- *white screen (intertrial interval)* --
12	Task A Attention control	15	
--		1	-- *white screen (intertrial interval)* --
13	Task A Attention control	15	
--		5	-- *white screen (pause interval)* --
--	Attention getter	3	
14	Task B Habituation phase	10	

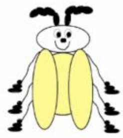
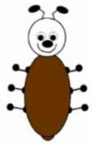
Trial	Task	Presentation time *(seconds)*	Stimulus
--		2	-- *white screen (intertrial interval)* --
15	Task B Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
16	Task B Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
17	Task B Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
18	Task B Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
19	Task B Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --

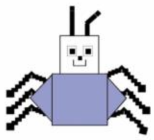
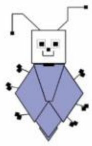
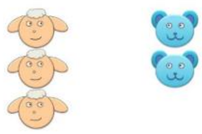
Trial	Task	Presentation time *(seconds)*	Stimulus
20	Task B Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
21	Task B Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
22	Task B Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
23	Task B Dishabituation phase	15	
--		2	-- *white screen (intertrial interval)* --
24	Task B Dishabituation phase	15	
--		2	-- *white screen (intertrial interval)* --

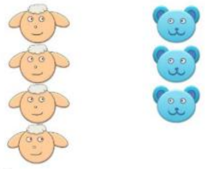
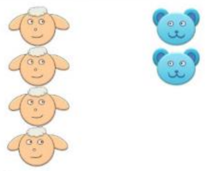
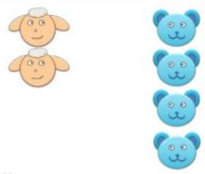
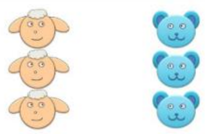
Trial	Task	Presentation time *(seconds)*	Stimulus
25	Task B Attention control	15	
--		2	*-- white screen (intertrial interval) --*
26	Task B Attention control	15	
		End of habituation-dishabituation tasks	

Wave 2: Presentation sequence of the stimulus material

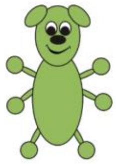
Trial	**Task**	**Presentation time** *(seconds)*	**Stimulus**
--	Attention getter	3	
1	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
2	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
3	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
4	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*

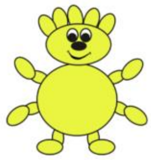
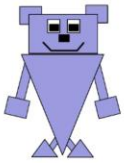
Trial	Task	Presentation time *(seconds)*	Stimulus
5	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
6	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
7	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
8	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
9	Task C Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*

Trial	Task	Presentation time *(seconds)*	Stimulus
10	Task C Dishabituation phase	10	
--		2	-- *white screen (intertrial interval)* --
11	Task C Dishabituation phase	10	
--		2	-- *white screen (intertrial interval)* --
12	Task C Attention control	10	
--		2	-- *white screen (intertrial interval)* --
13	Task C Attention control	10	
--		5	-- *white screen (pause interval)* --
--	Attention getter	3	
14	Task D Habituation phase	10	

Trial	Task	Presentation time *(seconds)*	Stimulus
--		2	-- *white screen (intertrial interval)* --
15	Task D Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
16	Task D Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
17	Task D Habituation phase	10	
--		2	-- *white screen (intertrial interval)* --
18	Task D Dishabituation phase	10	
--		2	-- *white screen (intertrial interval)* --
19	Task D Dishabituation phase	10	
--		2	-- *white screen (intertrial interval)* --

Trial	Task	Presentation time *(seconds)*	Stimulus
20	Task D Attention control	10	
--		2	*-- white screen (intertrial interval) --*
21	Task D Attention control	10	
--		5	*-- white screen (pause interval) --*
--	Attention getter	3	
22	Task E Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
23	Task E Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
24	Task E Habituation phase	10	

Trial	Task	Presentation time *(seconds)*	Stimulus
--		2	*-- white screen (intertrial interval) --*
25	Task E Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
26	Task E Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
27	Task E Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
28	Task E Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
29	Task E Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*

Trial	Task	Presentation time *(seconds)*	Stimulus
30	Task E Habituation phase	10	
--		2	*-- white screen (intertrial interval) --*
31	Task E Dishabituation phase	10	
--		2	*-- white screen (intertrial interval) --*
32	Task E Dishabituation phase	10	
--		2	*-- white screen (intertrial interval) --*
33	Task E Attention control	10	
--		2	*-- white screen (intertrial interval) --*
34	Task E Attention control	10	
End of habituation-dishabituation tasks			

Documentation of the modifications as of April 2023

Date	Page	Modification
April 2023	Page 12	Inserting the footnote