T i t e l

Face representation – on the content, structure and flexibility of face space

Inaugural-Dissertation
in der Fakultät Humanwissenschaften
der Otto-Friedrich-Universität Bamberg

vorgelegt von

Ronja Müller
aus
Langenhagen

Bamberg, den 10.09.2021

Bamberg, 2022

Tag der mündlichen Prüfung:	18.01.2022

Dekan/Dekanin:	Universitätsprofessor Dr. Jörg Wolstein
Betreuer:	Universitätsprofessor Dr. Claus-Christian Carbon
Weiterer Gutachter:	Professor Dr. Tilo Strobach

Dieses Werk ist als freie Onlineversion über das Forschungsinformationssystem (FIS; https://fis.uni-bamberg.de) der Universität Bamberg erreichbar. Das Werk steht unter der CC-Lizenz CC-BY-NC-ND.

Lizenzvertrag: Creative Commons Namensnennung 4.0
http://creativecommons.org/licenses/by/4.0.

URN: urn:nbn:de:bvb:473-irb-547286
DOI: https://doi.org/10.20378/irb-54728

Acknowledgments

Such a great challenge as a dissertation project can never be mastered alone. Many people made this journey possible and enjoyable by supporting and motivating me throughout my research. Here I would like to thank them.

First and foremost, I wish to thank my supervisors Prof. Dr. Tilo Strobach and Prof. Dr. Claus-Christian Carbon who supported me greatly by always encouraging me in my research process and by forming the project with their knowledge and intellect. My special thanks go to Professor Strobach for giving me the opportunity to work on the project "Face adaptation", for his guidance during my research, and for always being available when help was needed. I also have to thank Professor Carbon greatly, for the many inspiring and enriching discussions, for always offering his time and expertise and for his readiness to help when questions and difficulties came up. Tilo and Claus, I am very much looking forward to continuing to work with both of you.

Furthermore, I want to thank my colleague and friend Sandra Utz, for always supporting me morally and for bringing so much fun into our work. I am grateful that the project has brought us together as friends.

I also want to thank my colleague and friend Charlotte Wittgens for providing encouragement, conversation and wisdom. It is a great pleasure to share an office with such an intelligent scientist and thoughtful woman.

Thank you, Alice, for the lovely company at lunch and coffee breaks. I am glad that you became part of our team – you are truly an asset!

Moreover, I have had the opportunity to work with incredibly talented research assistants without whom this research would have not been possible. Thank you, Kim Sievers and Mustafa Barie-Azizi.

I further want to thank my family, for their love, support and for nurturing intellectual curiosity. They have given me so many opportunities throughout my life and have laid the foundation for who I am today.

Finally, I want to thank my partner Nils, for his endless support and love. His encouragement and faith in me have kept me going and his positivity and zest for life have made everything so much easier.

Abstract

When identifying faces, the incoming face information is matched against mental face representations stored in memory. Accordingly, there must be a large number of representations in memory to account for the variety of familiar faces that one has encountered in life. The face space model of Valentine (1991) represents an abstract framework intended to explain and illustrate the retention of face representations in memory. This model describes a multidimensional space, in which face representations are located and organized on various face dimensions that reflect the specific characteristics of a face. This model, however, is defined just as incompletely as the general understanding of face identification. By focusing on the phenomena priming and adaptation, the present work aims to gain a better understanding of face processing and retention and thus the face space. A literature review on both phenomena provides important information about the structure and flexibility of the face space and the face representations contained therein. The results of two experimental studies on face adaptation further reveal information about the face characteristics that constitute the face representations. These studies are the first to systematically investigate the role of non-configural face information (i.e., information that is not related to any spatial aspects of a face) in mental face representation. The study results support the assumption of a high flexibility and hierarchical structure of face representation in face space. However, in contrast to previous assumptions, face representations and categories probably cannot be clearly distinguished from each other but should be considered in a more dimensional way. Moreover, the empirical studies in this work suggest that different face information is most likely represented in face space with a different valence. This valence of face information is presumably closely related to the relevance of the information for face recognition. Together, these findings indicate that the current model of face space might need to be modified to account for the complex processes of face recognition.

Keywords: face representation; face space; adaptation; priming

Zusammenfassung

Bei der Identifizierung von Gesichtern werden wahrgenommene Gesichtsinformationen, mit im Gedächtnis gespeicherten mentalen Repräsentationen dieser Gesichter, abgeglichen. Berücksichtigt man die Vielfalt der Gesichter, denen man im Leben begegnet ist, muss eine große Anzahl von Gesichtsrepräsentationen im Gedächtnis gespeichert sein. Das Face-Space Modell von Valentine (1991) stellt ein abstraktes Konzept dar, welches die Speicherung von Gesichtsrepräsentationen im Gedächtnis erklärt und veranschaulicht. Dieses Modell beschreibt einen mehrdimensionalen Raum, in dem Gesichtsrepräsentationen auf verschiedenen Dimensionen, die die spezifischen Gesichtsmerkmale widerspiegeln, lokalisiert und organisiert sind. Dieses Modell ist allerdings ebenso unvollständig definiert wie die generellen Prozesse der Gesichtsidentifikation. Unter Betrachtung der Phänomene *Priming* und *Adaptation*, zielt die vorliegende Arbeit daher darauf ab, ein besseres Verständnis der Gesichtsverarbeitung und -speicherung und damit des Face Space‘ zu gewinnen. Eine Literaturübersicht zu beiden Phänomenen liefert wichtige Informationen über die Struktur und Flexibilität des Face Space‘ und der darin enthaltenen Gesichtsrepräsentationen. Die Ergebnisse zweier experimenteller Studien geben darüber hinaus Aufschluss über die Gesichtsmerkmale, aus denen die Gesichtsrepräsentationen bestehen. In diesen Studien wird erstmalig die Rolle nicht-konfiguraler Gesichtsinformationen (d.h. Informationen, die nicht die relationalen oder räumlichen Aspekte des Gesichts betreffen), in der Repräsentation von Gesichtern systematisch untersucht. Die Studienergebnisse stützen die Annahme, dass die Gesichtsrepräsentation im Face Space sehr flexibel und hierarchisch strukturiert ist. Entgegen früherer Annahmen, lassen sich Gesichtsrepräsentationen und –kategorien jedoch wahrscheinlich nicht klar voneinander abgrenzen, sondern sollten in einer viel dimensionaleren Weise betrachtet werden. Darüber hinaus deuten die empirischen Untersuchungen in dieser Arbeit darauf hin, dass unterschiedliche Gesichtsinformationen höchstwahrscheinlich mit einer unterschiedlichen Wertigkeit im Face Space repräsentiert werden. Diese Wertigkeit von Gesichtsinformationen steht vermutlich in engem Zusammenhang mit der Relevanz der Informationen für die Gesichtserkennung. Zusammengenommen deuten diese Ergebnisse darauf hin, dass das derzeitige Modell des Face Space‘ möglicherweise modifiziert werden muss, um den komplexen Prozessen der Gesichtserkennung Rechnung zu tragen.

Schlüsselwörter: Gesichtsrepräsentation, Face Space, Adaptation, Priming

Table of content

List of Figures

I SYNOPSIS

1 Introduction

1.1 Face representation in the context of the face space

Face identification is considered to be a process where familiar faces are matched against mental face representations stored in long-term memory (e.g., Bruce & Valentine, 1986). These mental representations must contain a variety of different face information in order to distinguish the many different faces one has encountered over a lifespan. The "face space" model proposed by Valentine (1991) seeks to account for this variety of face information and representations. It describes an abstract concept that defines the mental face memory as a multidimensional space, where face representations are located according to their characteristics on different dimensions. Each dimension reflects specific face information, such as the distance between the eyes or the shape of the head (Valentine et al., 2016). Although the model does not define the concrete facial information that is represented in face space, the number of existing information dimensions was estimated by computer modeling to be about 15 to 22 (Lewis, 2004; other authors, however, assume a higher number; see Meytlis & Sirovich, 2007). Each face representation is defined by its specific value on these face dimensions and thus is located in the face space according to its similarity to other faces. Similar faces are located near each other in face space since they have similar values on these dimensions. Very unique face representations, however, are located apart from other representations as they have unique characteristics on these dimensions. Each mental face representation is considered to be the conglomerate of all encounters one has had with the face. Thus, new encounters and alterations of a face (e.g., due to aging processes) are continuously integrated into the face representation (Valentine, 1991; Valentine et al., 2016).

Over the years, numerous researchers have proposed different models of the face space, differing mainly in how the face dimensions and representations are structured in space (e.g., Byatt & Rhodes, 1998; Lewis, 2004; Lewis & Johnston, 1998, 1999; Valentine, 1991; Valentine & Bruce, 1986). The norm-based and the exemplar-based model are the two most well-known versions. The norm-based face space model suggests a structure where face representations are located around a central norm that reflects a generic prototype for faces in general. The face representations stored in memory are located around this prototype depending on their similarity with it. The deviation from the prototype (and thus the distinctiveness of a face representation) is expressed by the values on multiple face dimensions, defining the representation's position in face space (see Figure 1A). The exemplar-based face space model, however, assumes an arrangement of representations in space without any relations to a prototype or a face norm. According to this approach, the distribution of representations in space and their distances to each other reflect the distinctiveness of these representations. Very unique faces are located in an area with a low representation density. An accumulation of face representations in space, however, would reflect a high similarity between these representations (see Figure 1B; Lewis, 2004; Valentine, 1991; Valentine et al., 2016).

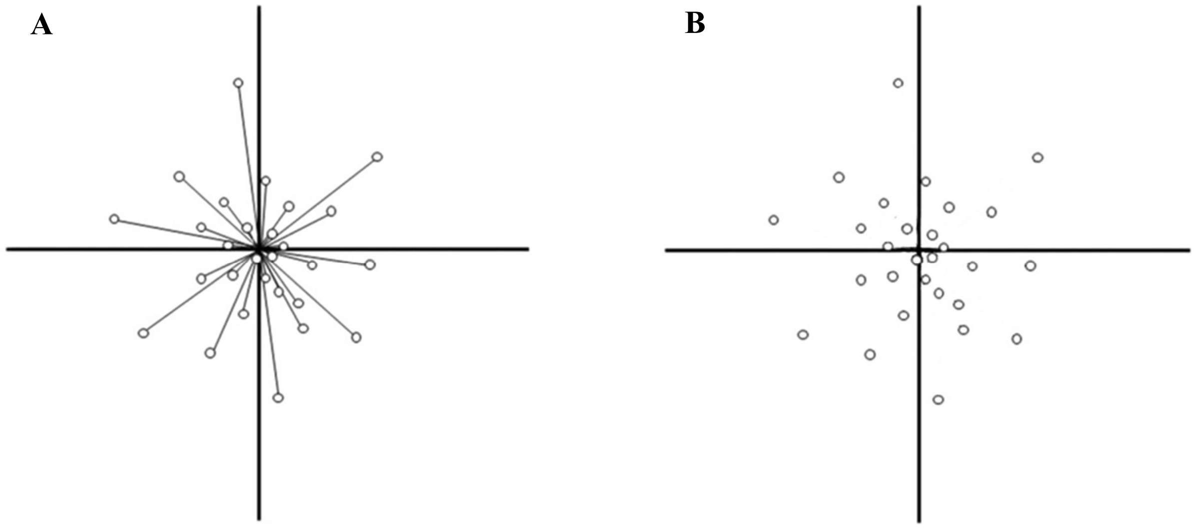

Figure 1. **A two-dimensional illustration of the mental face representation in face space according to the norm-based (A) and exemplar-based model (B). The two-dimensionality is applied for illustrative purposes only. Both models actually assume a multidimensional structure of the face space. The dots reflect the mental face representations distributed in face space whereas the bold lines illustrate the face dimensions on which the representations vary. The distribution of representations is the same in both models. However, according to the norm-based model representations are located in relation to a face prototype centered in the middle of the face space (illustrated by the thin lines in image A). The exemplar-based model considers faces to be mentally represented as discrete points in face space. The figure is based on the face space model illustrated in Valentine (1991) and Byatt and Rhodes (1998). The permission and figure licenses have been granted by the copyright holders [© SAGE Publications, Elsevier].**

1.2 Face priming and face adaptation

The face space seems to be a useful model to visualize the processes of face identification and retention. However, an investigation and validation of these processes in face space is only possible by using experimental paradigms. Previous studies investigating face identification and representation mainly relied on two experimental methods: face priming and face adaptation. Face priming describes a phenomenon where recently perceived faces subsequently facilitate the identification of similar or identical faces. Usually this effect is quantified by faster or more accurate identifications (e.g., Ellis et al., 1987; Walther et al., 2013). Several priming paradigms exist that differ in the mental concept they address. Repetition priming, for example, describes a paradigm where a face stimulus (prime) that is initially presented improves the identification process of the identical face stimulus in a subsequent test phase (compared to trials showing different prime and test face stimuli; e.g., Schweinberger et al., 1995). Activation of the mental representation of the displayed identity is considered to be the source of this priming effect. Hence, activating a mental face representation somehow results in a facilitated identification of the respective identity (Ellis et al., 1993; Schweinberger et al., 1995). Semantic priming (also called associative priming) is another version of the priming paradigm. It is characterized by a procedure where a face image (prime) is presented initially and a face stimulus that is not identical but semantically related to the prime is displayed afterwards. Usually the identification of semantically related test faces is significantly improved compared to semantically unrelated faces (e.g., Bruce & Valentine, 1986; Young et al., 1994). This priming effect is supposed to be based on activation of not only a specific face representation but a semantic network between different face representations. Thus, activation of a face representation would automatically result in an activation of semantically related face representations (e.g., the activation of the representation of "Michelle Obama" would lead to an activation of the representation of "Barack Obama"; McNamara, 2005; Schweinberger et al., 1995).

Face adaptation is another tool frequently used when investigating face identification and retention. It is usually assessed by presenting a strongly manipulated face stimulus (adaptor, e.g., the distortion of the concavity of a face, see Figure 2) in an initial adaptation phase and faces either nonmanipulated or slightly manipulated in the subsequent test phase (test stimuli). The participants typically tend to select a test face slightly manipulated in the direction of the adaptor when being asked to select the nonmanipulated face image out of the different face versions in the test phase (see, e.g., Carbon et al., 2007; Strobach et al., 2011). This bias is supposed to be based on altering the corresponding face representation. When being exposed to an obviously strongly manipulated adaptor (e.g., a strongly convex face, see Figure 2), the corresponding face representation integrates this new face information. This is probably done by averaging the new face information with the face information the representation already contains. This way the representation would be altered slightly toward the adaptor (e.g., slightly convex face).[1] Nonmanipulated face images then no longer correspond to the updated mental face representation stored in face space. Instead they somehow seem to be altered in the opposite direction of the adaptor (e.g., the face seems to be slightly concave). Face images slightly manipulated in the direction of the adaptor, however, then seem to be “normal” or “nonmanipulated” since they match with the updated face representation. When asking to select the nonmanipulated image in the test phase, participants therefore choose images slightly manipulated in the direction of the adaptor as the nonmanipulated face version (e.g., slightly convex face versions; see e.g., Strobach & Carbon, 2013; Valentine, 1991; Valentine et al., 2016).

[1] Previous adaptation studies show that participants select only a slightly manipulated face version in the test phase to be the veridical image, when being exposed to a series of different face versions that also include the strongly manipulated face adaptor (see e.g., Carbon et al., 2007). Accordingly, the new information (i.e., the strong manipulation) of the adaptor does not seem to be completely adopted by the mental face representation (otherwise the adaptor image would have been selected as the veridical image). The information is rather integrated into the representation and averaged with the information already contained in it, leading to the selection of only a slight manipulation.

Figure 2. **The figure illustrates the adaptation process in face space. The image of Angela Merkel is used as an illustrative example here. The line represents a face dimension in face space, on which faces can vary (in this case the concavity of a face). The two manipulated face versions at the end of the dimension represent extreme versions of the specific face dimension. Initially, the mental representation is probably located centrally on this dimension (since this would be the average of all encounters one had with Angela Merkel). After adaptation to the strongly manipulated adaptor (right pole of the dimension), the representation integrates the new face information by averaging the information contained in the representation with the new face information. This way the representation is slightly altered in the direction of the previously seen adaptor (new representation). After this process nonmanipulated images (such as the initial norm) are perceived as being manipulated in the direction opposite to the adaptor (i.e., in the direction of the counter adaptor), since they do not correspond to the new representation. Images similar to the new representation, however, are perceived as being "normal". Adapted from Mueller et al. (2021b). Permissions and image licenses have been obtained from the copyright holders [Source: © Drop of Light/Shutterstock.com].**

Face adaptation alters the face representations stored in memory, whereas priming seems to somehow activate them, making them more accessible for face processing. While in a priming paradigm probably the entire representation is activated, adaptation usually addresses only specific face information (e.g., the shape of the head; see e.g., Mohr et al., 2018; Schweinberger et al., 1995; Strobach & Carbon, 2013). This way, both phenomena lead to opposite effects: While priming usually enhances the identification of primed faces, the identification of (nonmanipulated) faces becomes more complicated through adaptation (e.g., Walther et al., 2013). Thus, both face priming and face adaptation seem to differ tremendously from each other. Nevertheless, in one way or another, they both address mental face representations and also alter the subsequent perception of faces. Consequently, face adaptation as well as face priming should potentially be good tools for investigating the structure and the functioning of the face space.

1.3 Characteristics of the priming and adaptation paradigm

When applying adaptation and priming paradigms, specific parameters are often systematically modified in order to examine the effects on face retention and thus on the structure and functioning of face representations. According to Strobach and Carbon (2013), these parameters can be divided into three different categories: (1) the timing conditions of the paradigm; (2) the transferability of the priming or adaptation effects onto different stimulus material; and (3) the specific face information that is focused on.

1.3.1 Timing

In the category *timing*, three different temporal characteristics can be distinguished (see Strobach & Carbon, 2013). The *prime/adaptor duration* describes the presentation duration of the priming or adaptation stimulus. A systematic modification of this duration can reveal the length of the presentation time that is needed to evoke a priming or adaptation effect. Through this, the ideal length of time for a face exposure can be identified, to either activate (priming) or alter (adaptation) the mental representation stored in memory. The second temporal characteristic is the *test duration*. It focuses on the presentation duration of the test stimuli. A modification of this duration can reveal the length of presentation time, after which a priming or adaptation effect (and thus either activation or alteration of the representation) still occurs. The third temporal characteristic is the *delay*. This describes the time interval between the prime or adaptor and the test stimuli. Here two different designs are usually applied: either a trial-wise or a block-wise procedure. When implementing the trial-wise procedure, the prime or adaptor and the test stimuli are presented within one trial, separated by a (usually very short) break. In a block-wise procedure, the prime or adaptor stimuli are presented in one block and the test stimuli are presented in another block. Both blocks are separated by a (usually longer) break (see e.g., Carbon & Ditye, 2011; Leopold et al., 2001). By varying the delay between the prime or adaptor and the test stimuli, essential information about the robustness of priming or adaptation effects can be revealed. More robust (i.e., more long-lasting) effects indicate a processing not only on a sensory basis but on a cognitively higher level, such as the memory. Moreover, a systematic evaluation of the delay can also reveal possible recalibration mechanisms (i.e., a reset back to the initial state) of the visual system and of face representations (Strobach & Carbon, 2013).

1.3.2 Transfer

The category *transfer* describes the transferability of priming or adaptation effects. Here, two approaches can be distinguished: (1) the transfer of priming or adaptation effects across differences of specific image dimensions (e.g., the size or the orientation of the image); and (2) the transfer between different images displaying the same or other identities (Strobach & Carbon, 2013). The first approach is applied by initially presenting a prime or adaptor and subsequently testing stimuli altered in a specific image dimension (e.g., the size of the image). Thus, in an adaptation paradigm, for example, the test images would also differ from the adaptor in other image dimensions (e.g., size), next to the alterations of the face information that is primarily focused on (e.g., distortions). This procedure is used to exclude retinal effects and therefore allows the analysis of the valence of the adaptation effect (Zhao & Chubb, 2001). For instance, the occurrence of an adaptation effect (e.g., on distortions) despite the transfer across different image dimensions (e.g., size) indicates that the effect is not just image-specific but somehow affects other concepts (such as the face representation). However, a reduced adaptation effect (in the transfer condition compared to a condition where no image dimension was altered), indicates at least involvement of image-specific aspects (Yamashita et al., 2005).

The second approach reflects a method where the transfer of priming or adaptation effects across different face images or even different identities is analyzed. To do so, three transfer levels can be distinguished (see Strobach & Carbon, 2013; and Figure 3 for an illustration): the first transfer level *pictorial* describes a procedure, where identical face images are presented in the priming/adaptation and test phase (in an adaptation paradigm this means that the adaptation and test stimuli do not differ from each other except for the altered adaptation information). The second transfer level *structural* reflects a procedure where the priming/adaptation and test phase present different images that still display the same identity. The third transfer level *cross-identity* is characterized by a presentation of images displaying even different identities in the priming/adaptation and test phase. The implementation of these different transfer levels enables an analysis of the identity specificity of priming or adaptation effects. Effects that only occur on the pictorial transfer level, for example, would indicate an image-specificity of the effects, while effects on a structural transfer level would suggest an involvement of identity-specific face representations that probably contain three-dimensional face information (e.g., Carbon et al., 2007; Jiang et al., 2009). Thus, through priming or adaptation, these three-dimensional representations would be addressed (either activated or altered) and would lead to a facilitated or altered perception of images that differ from the prime or adaptor but still show the same identity. Effects on a cross-identity transfer level, however, would indicate a hierarchical structure in the processing of faces. Thus, face priming or face adaptation would not only affect a specific face representation but also superordinate face concepts, such as a generic face norm or a face category like a specific gender, ethnicity or age. By activating or altering a particular face representation through priming or adaptation, a superordinate concept would be activated or altered as well, leading to a priming or adaptation effect in identities other than the identity presented in the priming or adaptation phase (e.g., Carbon & Ditye, 2011; Carbon et al., 2007; Strobach & Carbon, 2013).

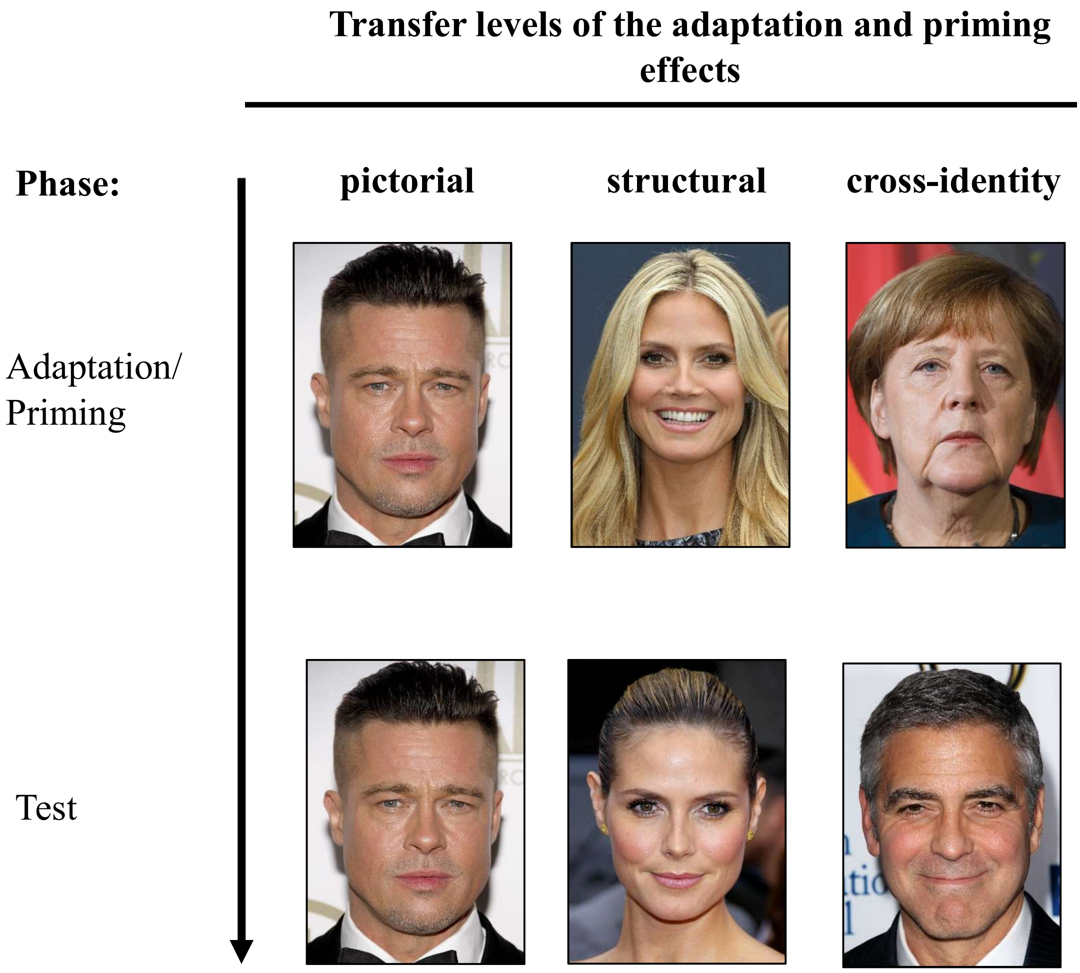

Figure 3. **The figure illustrates the different transfer levels of priming and adaptation paradigms. Each column reflects one trial where a different transfer level (pictorial, structural or cross-identity) is applied. The images are used as an example only. The figure is based on Carbon et al. (2007) and Mueller et al. (2020). Permissions and image licenses have been obtained from the copyright holders [Sources: © Drop of Light/Shutterstock.com, Tinseltown/Shutterstock.com, s_bukley/Shutterstock.com].**

1.3.3 Face information

The third category of parameters that are usually modified in priming or adaptation paradigms describes the specific facial information that is focused on (see Strobach & Carbon, 2013). In the context of adaptation, it is quite easy to address specific facial information by simply altering the facial information of interest (e.g., the shape of the head). The corresponding mental face representation is then altered toward this specific modification, which can be observed in the resulting bias of selecting a stimulus similar to the adaptor when being asked to select the veridical face image in the test phase (e.g., Carbon et al., 2007). In a priming paradigm, however, addressing specific face information is quite difficult. When presenting a face prime, the entire mental face representation would be activated instead of isolated face characteristics (e.g., Mohr et al., 2018). Likewise, the test phase of a priming paradigm is not designed to address specific face information. In, for example, an identification or familiarity task, a specific face characteristic of the mental representation would not be addressed but the representation as an entity (e.g., Boehm et al., 2006). Conclusions about the storage of specific face information can therefore only be made indirectly. For example, one possible approach would be to systematically investigate how the priming effect (i.e., the identification performance) is modified when specific face information of the prime stimulus is altered. Face characteristics that would lead to an impairment of face recognition when altered seem to be essential for face identification and thus are most likely part of the face representation (see, e.g., Brooks et al., 2002; Mohr et al., 2018). This approach, however, does not allow precise conclusions about, for example, the valence of different face information for face recognition and retention (meaning, e.g., that some face information is more important than other face information). Thus, priming seems to be not as useful as adaptation, when investigating the characteristics of face information stored in representational memory.

When focusing on investigating specific face information, the face literature often distinguishes between different types of face information. Configural face information, for example, describes the second-order spatial relationships between different face features (e.g., the eye-mouth distance; see Maurer et al., 2002). It has long been assumed that this type of information is the core information when discriminating faces from each other (Diamond & Carey, 1986; Maurer et al., 2002; Piepers & Robbins, 2012). By now, other face characteristics such as non-configural information is also considered to be relevant in face recognition. Non-configural face information describes specific face information, that does not refer to any relational aspects of a face. Isolated face features (e.g., eyes or nose) or the face’s color would fall into this category (e.g., Rivest et al., 2009). Moreover, literature often distinguishes face information according to its variability. So-called invariant face information, allows the processing of face aspects that are robust to changes. The identity, ethnicity or gender, for example, represent types of invariant face information. Variant face information, however, describes rather changeable (also called “dynamic”) aspects of a face, such as the eye gaze, expression or the color of a face (see, e.g., Bruce & Young, 1986; Haxby et al., 2000). According to this classification, configural (i.e., relational) face information could be described as a rather invariant type of face information, since it allows the identification of a face, its ethnicity or gender and thus addresses rather unchangeable aspects of a face (namely the relations of a face). Non-configural face information, however, includes both invariant and variant aspects. While isolated face features or the skin texture would probably be referred to as invariant, the face’s color could be invariant (e.g., when addressing the basic face color or ethnicity) as well as variant (when e.g., different lighting conditions or tanning affect the color of a face). Since variant face information is very transient, it is assumed to be not important when identifying a face (see, e.g., Haxby et al., 2000). Thus, it is questionable whether this type of information is represented in face memory (and thus in face space) at all.

1.4 Motivation of the present work

Presumably, the limitations of the priming paradigm regarding the investigation of mental face information have caused the face space literature to mainly focus on adaptation when integrating study results on face perception into the face space framework. Although priming could potentially contribute to the understanding and refinement of the face space model (especially when investigating temporal aspects or the structure of the representations in face space), it was mainly neglected in face space literature. Accordingly, one of the aims of this thesis is to review the contribution of priming and adaptation to face perception and retention and hence to the mental face space. This is covered by the first manuscript enclosed in this work (Chapter 2.1). It provides an overview of the most relevant priming and adaptation studies by analyzing and comparing their findings with regard to the face space. In this review, priming and adaptation are examined according to the parameters timing and transfer but not according to the parameter face information. Since priming seems to be not very practical when investigating mental face information (see section 1.3.3), a comparison with adaptation results of this category would not be informative.

The second and third manuscripts enclosed in this thesis (Chapter 2.2 and 2.3), however, focus on the face information stored in face space. By applying adaptation paradigms only, the studies reported in the second and third manuscripts aim to clarify whether non-configural color information is represented in face memory and thus in the face space. So far, studies using adaptation as a tool to investigate which face information is represented, have mainly focused on configural face information (e.g., distortion; for a review see, Strobach & Carbon, 2013). These studies usually also investigated the robustness (i.e., the delay) and transferability of adaptation effects and thus provided a profound understanding of how the face memory represents configural face information (e.g., Carbon & Ditye, 2011; Carbon et al., 2007). Non-configural face information, however, such as color, has received little attention in face space literature. This is remarkable as several studies were able to show a high relevance of facial color in face perception. For example, Lee and Perrett (1997) showed that a loss of color in faces could lead to recognition impairments (for further indications that color is relevant in face perceptions see, e.g., Levin & Banaji, 2006; Re et al., 2011; Thorstenson et al., 2019). Adaptation studies could reveal whether color is also represented in face memory and thus the face space. The second and third manuscripts therefore focus on adaptation effects on color information. Since previous studies indicate that different color dimensions are perceived and interpreted very differently in faces (e.g., a study by Tan & Stephen, 2013, indicates, that facial redness is perceived as more salient than brightness), the second and third manuscripts investigate and compare different color dimensions to see whether the differences in the perception are also reflected in the representation of these color dimensions. To do so, brightness and saturation alterations are applied. Moreover, both color dimensions seem to be suitable for contrasting effects on variant and invariant face information. While brightness alterations are perceived either as a change of lighting conditions (variant) or as a change of the basic face color (invariant; see, e.g., Levin & Banaji, 2006), saturation alterations are most likely associated with only dynamic (i.e., variant) face information, such as the health or emotional state of a person (Re et al., 2011; Thorstenson et al., 2019). Possible differences in the representation of brightness and saturation will therefore be discussed in terms of differences in the information's variability (i.e., variant and invariant color information). By also applying the parameters timing and transfer, the studies can elucidate how robust possible face adaptation effects on non-configural color information would be and how this information type would be organized in face space.

2 Summary of the included manuscripts

2.1 *First manuscript: Face adaptation and face priming as tools for getting insights into the quality of face space*

2.1.1 Research aim and general method

Since the literature has mainly neglected the phenomenon face priming when reviewing the face space, the aim of the first manuscript was to compare face priming and face adaptation regarding their contribution to the face space. A total of 22 priming and 32 adaptation studies were selected (the most relevant studies in the field of face perception) and reviewed according to their timing characteristics (adaptor/prime duration, test duration and delay) and the transferability of the effects (i.e., between images differing in specific image dimensions or the transfer on a pictorial, structural and cross-identity level). The results of these studies were compared, similarities and differences were highlighted and evaluated in the context of the face space.

2.1.2 Outcomes and discussion

The review article points out that face priming and face adaptation are able to alter our facial perception and thus the mental face representations in face space significantly. Yet, these effects can be affected strongly by temporal parameters (prime/adaptor duration, test duration and delay). A prolonged presentation duration of the adaptor, for example, results in an increasing adaptation effect (e.g., Rhodes et al., 2007; Strobach et al., 2011) and thus a greater or more robust alteration of the mental face representation. A prolonged presentation of the prime, however, causes a decreased and sometimes even a negative priming effect (reflecting recognition impairments; e.g., Rieth & Huber, 2010). Thus, the activation of the mental face representations in face space somehow decreases with increasing presentation duration of the prime. This activation reduction could possibly be provoked by a neural habituation (that serves as an automatic mechanism to avoid confusion with subsequent faces; Rieth & Huber, 2010) or by an adaptation process (caused by a lack of fit between the prime stimulus and the mental representation). Hence, a prolonged prime would then act as an adaptor, altering the mental face representation in face space toward this image. In order to evoke the greatest possible priming effect, the prime should therefore be presented very briefly.

Also, the test duration of the test stimulus within a priming paradigm should be presented briefly to evoke a robust priming effect. A prolonged presentation of the test stimulus would probably cause, just like a relatively long presentation of the prime, neural habituation (or adaptation effect) and thus an activation reduction of the mental face representations in face space (e.g., Rieth & Huber, 2010). The presentation duration of a test stimulus in an adaptation paradigm should be kept relatively short as well, since prolonged exposure to a test stimulus causes a decreased adaptation effect (e.g., Leopold et al., 2005; Rhodes et al., 2007). This decreased effect is probably provoked by a readaptation process of the representation back to the original (or pre-adaptation) image. Since the test stimuli in an adaptation paradigm either display non- or only slightly manipulated images (compared to the strongly manipulated adaptor seen before), prolonged exposure to the test stimuli would probably trigger an adaptation process, leading to an alteration of the representation back to the pre-adaptation state (Carbon et al., 2007).

The examination of the delay (i.e., the time interval between the prime or adaptor and the test stimuli) revealed similar robustness for both phenomena. Thus, face priming and face adaptation effects can last up to weeks (Carbon & Ditye, 2011, 2012; Lewis & Ellis, 1999; effects lasting even up to several months were observed for priming, see e.g.; Maylor, 1998). This indicates that the mental representations stored in face space are altered enduringly by adaptation. It also implies that priming leads to a long-lasting activation of the representations or to a facilitated reactivation. Both priming and adaptation effects, however, somehow continuously decrease over time. In the context of priming, this continuous decrease probably indicates either a decline in activation or a reduced reactivation capability of the mental representation. For adaptation, a readaptation process might account for the decrease in effect. Possible exposures to the original face could evoke this readaptation during a long delay (e.g., subsequently to an adaptation, an exposure outside the experimental setting to the same nonmanipulated celebrity face in the media would evoke a readaptation process to the nonmanipulated face depiction). Alternatively, an automatic readaptation process occurs initiated by the robustness of the original mental representation (which probably developed over a more extended period of time than the representation formed by the adaptation paradigm).

Despite the temporal aspects of the priming and adaptation paradigm, the review article shows that also the transferability of effects can contribute to the understanding of the face space. The reviewed studies reveal that the transfer of priming or adaptation effects across changes of specific image dimensions (e.g., the size, position or contrast of the image) is possible, although the transfer across these alterations usually reduces the effects (e.g., Brooks et al., 2002; Bruce et al., 1994; Kovács et al., 2007; Yamashita et al., 2005). This indicates that the effects are, to some extent, retinotopic. However, the impact of these alterations on the priming or adaptation effects seems to differ depending on the image dimensions. Thus, dimensions of a more metric nature (e.g., size or position) have a smaller impact on adaptation effects than dimensions that affect faces in a qualitative way (e.g., spatial frequency or contrast polarity; Brooks et al., 2002; Yamashita et al., 2005). This indicates that more qualitative image dimensions have an impact on face recognition and are therefore maybe even represented in face space.

The review article further shows that priming and adaptation effects do not only transfer across specific image dimensions but also across different depictions of the same identity (structural level) or even across different identities (cross-identity level; e.g., Bruce & Valentine, 1985; Carbon & Leder, 2005; Carbon et al., 2007; Ellis et al., 1987). The transfer on a structural level indicates that the effects are not just image-specific but must involve identity-specific aspects as well. Thus, face representations must be very flexible, containing either a wide range of different face information or a basic and minimalistic face structure, so that faces can be recognized despite various changes. The results on a cross-identity level, however, reveal that a transfer of effects is possible even when different identities are displayed. In the context of adaptation, this indicates processing on a hierarchically higher level in face space. Thus, when altering specific face representations, superordinate concepts (e.g., female faces or faces of a specific ethnicity) or a general face norm seem to be altered too (e.g., Jaquet & Rhodes, 2008; Jaquet et al., 2008). Some study results suggest that effects are stronger for superordinate concepts that individuals encounter most (e.g., the own age or ethnicity; O'Toole et al., 1996; Webster et al., 2004). For priming, the results on a cross-identity level are rather ambiguous. Some studies assume that the transferability of priming effects to images of other identities might depend on the similarity of the displayed images (Zarate & Sanders, 1999) or on the degree of association the test stimuli have with the prime (Young et al., 1994). Whether a co-activation of other face representations is caused by an activation of a superordinate face concept to which the associated identities belong is not yet clear. An alternative explanation for this co-activation could be a strong and exclusive associative bond between specific identities, without affiliation to a specific concept.

Adaptation studies further indicate that the transferability of effects might depend on the type of face information that is focused on. For example, transferring adaptation effects across changes in invariant face information (e.g., from a female face in the adaptation phase to a male face in the test phase or from one adaptor identity to another identity in the test phase) seems to have a greater impact on adaptation effects (i.e., effects decrease) than transferring the effects across changes in variant or more variable information (from one facial expression to another; see Barrett & O'Toole, 2009; Fox & Barton, 2007; Fox et al., 2008; Lai et al., 2012). The lower impact that variant face information has on face adaptation effects could indicate that this type of information does not affect face recognition as much as changes in invariant information do.

Thus, variant information might play a rather subordinate role in face recognition and maybe even in face representation. This could be an indication that face information is stored in face space with different valences and according to its importance for face recognition.

Summing up, the review reveals that both paradigms can help to gain a better understanding about the content, the flexibility, and the structure of the mental face space. Temporal aspects of both paradigms provide information on the parameters for achieving the greatest possible effects. They might even reveal the underlying mechanisms of the two phenomena (e.g., a more extended presentation of a prime might lead to an adaptation effect). The robustness and decay of priming and adaptation effects contribute to the understanding of the flexibility or stability of representations stored in face space. The transferability, however, reveals information about the face space structure (e.g., subdivision into different sub-face spaces) and can also provide insights into the content of the face space (e.g., variable and invariant face information). Thus, the systematic evaluation reported in the first manuscript points out the valuableness of priming and adaptation for the understanding of face perception and representation. It also shows that although priming has been mainly neglected in face space literature it is an important and useful tool for the investigation of the face space.

2.2 Second manuscript: Face adaptation effects on non-configural face information

2.2.1 Research aim and general method

So far, studies investigating which face information is represented in face space have mainly focused on configural face information (e.g., distortion; for a review see, Strobach & Carbon, 2013). Non-configural color information, however, has been mainly neglected in face space literature, although previous studies were able to reveal a high relevance of color to face processing. The second manuscript therefore aims to clarify whether non-configural color information is also represented in face memory and thus in the face space. Adaptation seems to be a particularly useful tool in the study of facial information since it not only addresses the representation as a single entity but can examine isolated face information enclosed in the representation (see Chapter 1.3.3). The experiments reported in the second manuscript therefore applied adaptation to examine whether color information is part of the facial representation.

The reported experiments used non-configural color information in the form of brightness alterations. Brightness information appears to be rather variable and transient information (e.g., due to changes in illumination) at first. However, in our experiments, we altered the brightness of faces independently of the background (also, the hair was not altered). Hence, an alteration in brightness could also be considered to be a change of the face’s basic color and thus an inherent characteristic when taking into account the unaltered context conditions. Five experiments were conducted following the same procedure: Depending on the group the participants belonged to, either nonmanipulated celebrity images[2] (control condition) or images strongly decreased or increased in brightness were presented as adaptors (between-subject factor). In the test phase, participants were asked to select the nonmanipulated image version out of two alternatives: the nonmanipulated image and an only slightly manipulated image version (either decreased or increased; see Figure 4). In case an adaptation effect occurs, participants are expected to choose the image version that is more similar to the previously seen adaptor. The five experiments differed in their time interval between adaptation and test phase (delay) and in their stimulus material used in the adaptation phase. By applying three different time intervals between the adaptation and test phase (300 milliseconds, 3 seconds, and 5 minutes) it can be elucidated how robust possible adaptation effects on non-configural face information are. Experiments 1, 2, and 3 using 300 milliseconds and Experiment 4 using 3 seconds as time intervals between adaptation and test phase applied a trial-wise procedure (i.e., adaptation and test phase are presented within one trial). Experiment 5 using a time interval of 5 minutes, applied a block-wise procedure (adaptation and test phase were presented separately, see Figure 4). By systematically extending the delay, it is possible to investigate the processing level of the adaptation effects (i.e., longer time intervals indicate robust effects that might affect a cognitively higher level such as the face memory, while rather short time intervals only indicate processing on a sensory level; see e.g., Carbon & Ditye, 2011; Carbon et al., 2007). Furthermore, two experiments are included, presenting either scrambled-/nonface stimuli (Experiment 2) or inverted faces as adaptors (Experiment 3; these images were also altered in brightness, see Figure 4). The scrambled face stimuli displayed homogeneous color areas created by scrambling the adaptor stimuli used in the other experiments beyond recognition. Since identifying inverted faces is supposed to be much more difficult than identifying an upright face (e.g., Valentine, 1988), both conditions (scrambled and inverted face stimuli) somehow hinder face recognition. By implementing these different types of adaptors, the face-specificity of the adaptation effects can be investigated. If adaptation effects transfer from nonface or inverted face stimuli to upright test faces, the effects seem to be not face-specific, but might be simple color after effects. In case no effects can be found when applying nonface or inverted face stimuli, the effects are very likely to be face-specific. By applying the three

[2] Familiar celebrity images are used since their representations stored in face memory are probably already very elaborated (due to many encounters with the celebrities in the media) while unfamiliar faces are most likely not represented yet (e.g., Rossion et al., 2001).

different transfer levels *pictorial*, *structural* and *cross-identity* in all experiments (within-participants factor) it can be analyzed how brightness information is stored and organized in face space. While effects on brightness only occurring on a pictorial transfer level would indicate an image-specific processing, effects on a structural transfer level would indicate an involvement of identity-specific face representations. Effects on a cross-identity transfer level, however, would imply that adaptation on brightness also affects other identity representations and thus probably superordinate face concepts (such as a generic face norm).

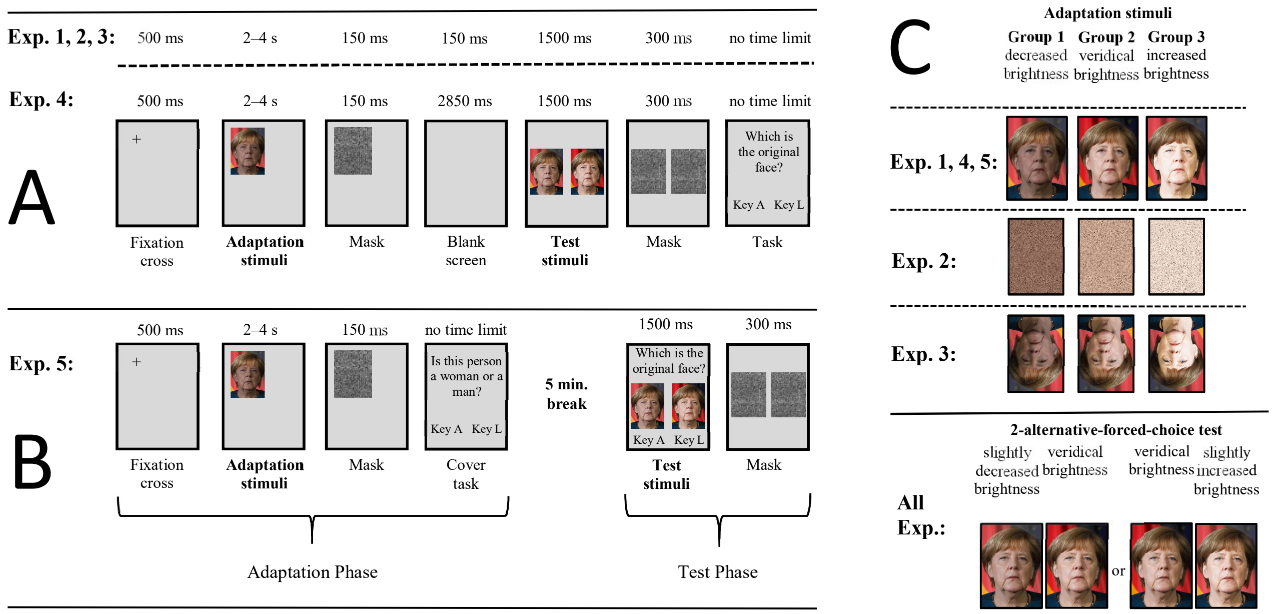

Figure 4. **Panel (A) illustrates the trial structure of the experiments using time intervals of 300 milliseconds and 3 seconds between adaptation and test phase (trial-wise procedure). Panel (B) illustrates the experimental structure using a time interval of 5 minutes between adaptation and test phase (block-wise procedure). Panel (C) presents the image versions of the five experiments. The upper part illustrates the adaptation stimuli of the different experiments (Exp. 1, 4, and 5: upright face stimuli; Exp. 2: scrambled face stimuli; Exp. 3: inverted face stimuli). The lower part illustrates the stimulus material of the test phase that was the same for all experiments. Adapted from Mueller et al. (2021b). Permissions and image licenses have been obtained from the copyright holders [Sources: © Drop of Light/Shutterstock.com].**

2.2.2 Outcomes and discussion

The reported experiments reveal that face adaptation effects occur for non-configural brightness information. Thus, after being exposed to strongly manipulated adaptors (decreased or increased in brightness) participants showed a clear bias in their selection: When being asked to select the original (i.e., nonmanipulated) image, participants tended to select slightly toward the adaptor manipulated test faces. Hence, nonmanipulated test images were perceived to be slightly manipulated in the opposite direction of the adaptors (i.e., after being exposed to a decreased adaptor image the original image would be perceived as being slightly increased in brightness, while adaptors increased in brightness cause original images to appear slightly decreased in brightness). The experiments applying different delays (300 ms, 3 s, and 5 min) revealed that the adaptation effects on upright faces manipulated in brightness last up to five minutes. Moreover, since a block-wise procedure was implemented when applying the five-minutes delay, the adaptation effects might last much longer. That is, considering the adaptation performance across both blocks (i.e., the adaptation and test phase), the adaptation effects might even last up to 50 minutes (i.e., the duration of the entire experiment). These long-lasting adaptation effects indicate a processing not only on a sensory basis but rather on a cognitively higher level, affecting at least short-term memory and probably even long-term memory components. Moreover, the experiments using nonface and inverted face stimuli as adaptors showed no adaptation effects. This indicates that the adaptation effects observed in the other experiments (using upright face stimuli) are probably face-specific. Hence, it seems as if brightness information is part of the mental face representation and thus of the face space. Since in our experiments we altered the brightness of faces independently of their background, brightness alterations might be perceived as a change of the face's basic color and thus as an inherent characteristic. This could be an explanation for the rather long-term retention of brightness information. Although the adaptation effects on brightness alterations seem to be long-term, the experiment using the 5-minute delay also indicates that the effects might not be permanent, since they are decreased compared to the other experiments using shorter delays. This could reflect a "resetting" mechanism, due to the robustness of the original representation or due to a mental re-encounter with the original image.

The experiments using upright face images altered in brightness revealed adaptation effects on all three transfer levels. However, the effects on the pictorial transfer level were usually larger compared to the effects on a structural or cross-identity level (see also, Carbon & Ditye, 2012; Carbon et al., 2007). Thus, there must be some kind of image-specific component within the effects. Nevertheless, the effects transfer well to other images of the same identity, indicating also an identity-specific component. The effects on the cross-identity level furthermore reveal that a transfer is also possible across different identities. This indicates a hierarchical processing where adaptation effects alter not only the representation of a specific identity but also superordinate categories or a generic face norm. This subsequently leads to an adaptation effect also on other identities belonging to the same subpopulation as the adapted identity.

Taken together, the reported experiments reveal that adaptation on non-configural brightness alterations is possible. The long-lasting effects indicate a processing on a cognitively high level, probably affecting the representational memory. Thus, non-configural brightness information probably plays an important role in face retention and identification. The continuous update of brightness information in face memory probably facilitates the recognition of a face and the differentiation from other faces. The results on a cross-identity level further suggest that superordinate category representations or generic face norms are also updated by adaptation effects on brightness alterations. The update of superordinate category representations probably facilitates the differentiation of face categories and thus faces in general.

2.3 Third manuscript: Face adaptation – Investigating non-configural saturation alterations

2.3.1 Research aim and general method

The experiments reported in the second manuscript reveal adaptation effects for brightness alterations only. Thus, it remains unclear whether the observed adaptation effects occur similarly for other color information. Since previous studies revealed differences in the perception and interpretation of different color dimensions in faces (see Chapter 1.4) it could be possible that these differences are also reflected in the representation of faces. Study results of Tan and Stephen (2013), for example, indicate that participants perceive facial redness as more salient than brightness. To analyze whether these observed differences also lead to differences in the representation, the third manuscript investigates adaptation effects on saturation alterations (increased saturation usually leads to a greater facial redness) and compares the results with adaptation effects on brightness. Moreover, by focusing on other non-configural face information (other than brightness) the manuscript also aims to expand the adaptation literature on non-configural face information.

Five experiments were conducted following the same adaptation procedure as the experiments in the second manuscript (i.e., either strongly manipulated or nonmanipulated face images were presented in the adaptation phase [between-subject factor] and only slightly manipulated or nonmanipulated face images in the test phase; see Chapter 2.2.1). The stimulus material, however, was manipulated in saturation (decreased and increased) instead of brightness (see Figure 5). Similar to the study on brightness, the three different transfer levels (pictorial, structural, and cross-identity) were implemented as well as the three different time delays (300 ms, 3 s, and 5 min) in three different experiments (see Figure 4). Moreover, an experiment was conducted presenting scrambled face stimuli manipulated in saturation as adaptors (see Figure 5). To contrast possible effects on saturation with the adaptation effects on brightness, one further experiment was implemented presenting trials that display either saturation or brightness alterations within one paradigm (see Figure 5). This way a direct comparison of both color dimensions is possible.

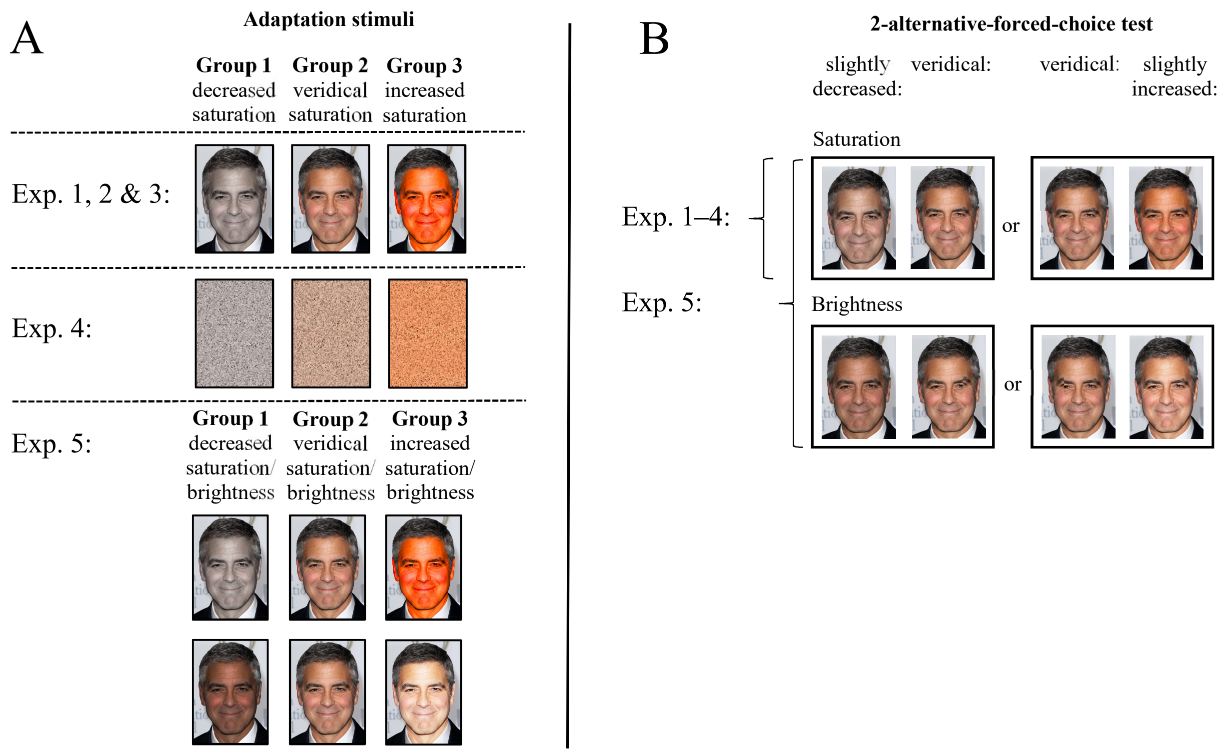

Figure 5. **Panel (A) illustrates the adaptation images of the five experiments (Exp. 1, 2, and 3: upright face stimuli manipulated in saturation; Exp. 4: scrambled face stimuli manipulated in saturation; Exp. 5: upright face stimuli manipulated in saturation and brightness). Panel (B) illustrates the stimulus material of the test phase. Experiments 1–4 used face stimuli manipulated in saturation only. Experiment 5 used face stimuli manipulated in saturation and brightness. Adapted from (Mueller et al., 2021a). Permissions and image licenses have been obtained from the copyright holders [Sources: © Drop of Light/Shutterstock.com].**

2.3.2 Outcomes and discussion

The reported experiments show that adaptation effects also exist for saturation alterations. However, these effects were observed only for the adaptation group being exposed to increased saturation images but not for the adaptation group seeing decreased saturation images. This is revealed by a clear bias in the participants' selection in the test phase. After being exposed to strongly increased saturation stimuli, participants selected slightly increased saturation test stimuli to be the original or nonmanipulated image. For the participant group seeing adaptors decreased in saturation the expected response behavior (i.e., a selection of slightly decreased saturation stimuli) could not be detected. The missing adaptation effect in the "decreased" participant group could be caused by a specific response bias of the control group (i.e., adaptation group seeing nonmanipulated images). Participants of the control group showed a tendency to select an above-average number of test images with decreased saturation (in fact it would be expected that this group primarily selects nonmanipulated images in the test phase, since participants did not adapt to any manipulations). This response pattern, however, is similar to the expected response behavior of the adaptation group seeing decreased saturation stimuli, so that a significant deviation of the "decreased" adaptation group from the control group (i.e., an adaptation effect) may not be detected. Reasons for this bias of the control group are not yet clear. It might be caused by a different perception of decreased and increased saturation (e.g., increased saturation might be more easily detected as manipulation, while a slight decrease might be almost indistinguishable from a nonmanipulated version – this could lead to the bias of selecting decreased image versions more often).

The experiments applying different delays (300 ms, 3 s, and 5 min) revealed that the adaptation effects on faces increased in saturation, lasted up to three seconds but do not appear when implementing a delay of five minutes. Hence, the effects might not be as robust as the effects on brightness, which were still observable after five minutes (see, Chapter 2.2.3). Hence, it is not yet clear whether saturation information is represented in long-term memory and thus in the face space at all or whether the observed effects are only sensory based. The difference in the robustness of effects (compared to brightness) could possibly be related to a different "resetting" mechanism. Thus, the face representation stored in memory might initially integrate altered saturation information, but due to an automatic and very fast resetting process back to the pre-adaptation status (maybe because of the great robustness of the original representation), adaptation effects on increased saturation are very transient. This relatively fast resetting mechanism of saturation information might be related to a lower importance of saturation for face identification. Since increased saturation is considered to be a rather variant type of information (it is often associated with the health or emotional state of a person, see Chapter 1.4 or Re et al., 2011; Thorstenson et al., 2019) it might not provide essential and stable information for face identification. Brightness information, however, could be considered as a rather invariant type of information, since it might refer to a person's skin tone or ethnicity (see Chapter 2.2.1). Hence, it could be more relevant in face identification so that adaptation effects on brightness alterations are more robust than effects on saturation. This could indicate that the robustness of adaptation effects might depend on the variability of the adapted information.

The experiments further show that the observed adaptation effects on increased saturation exist at all three transfer dimensions (i.e., pictorial, structural and cross-identity). Adaptation on the structural level indicates that the effects are not just image-specific but probably also contain identity-specific components. Thus, it is likely that adaptation on increased saturation alters the entire mental representation of the identity (i.e., including all different exposures or mental images of this identity) and not just the mental image used as the adaptor. The effects on a cross-identity level, however, reveal that the adaptation on increased saturation seems to also affect superordinate category representations or a generic face norm. Thus, when adapting to saturation information, not only the representation of the respective identity would be altered toward the adaptor but also superordinate concepts or a generic face prototype. The experiment using nonface stimuli did not reveal any adaptation effects, indicating that the observed adaptation effects on face stimuli increased in saturation are maybe face-specific. When considering the possible face-specificity of the effects on increased saturation, the findings on the structural and cross-identity transfer level might be better explained by alterations of the face representations than by purely sensory processes.

The experiment that displayed saturation and brightness alterations within one paradigm did not show any differences in the adaptation effects on increased saturation or increased brightness. However, numerical differences almost reached conventional level of significance. Since subsequent analyses further revealed a rather low test power, the nonsignificant difference should be questioned. In case of a genuine effect, brightness would lead to stronger adaptation effects than saturation.

Taken together, the reported experiments clearly revealed face adaptation effects for increased saturation information. Hence, adaptation effects for non-configural face information other than brightness can be evoked. The observed effects might be face-specific and transferable to other depictions of the same and other identities, indicating that increased saturation is maybe even part of the face representation. However, adaptation effects on this type of information do not seem to be represented in the long term. Adaptation effects on saturation alterations, therefore, differ from effects on brightness in their robustness and probably even in their effect size. Thus, the differences in the perception and interpretation of different color dimensions in faces indeed seem to be reflected also in the representation of these color dimensions in face memory. The actual differences between brightness and saturation might be based on the different variability of these information types. Saturation as a more variant type of information would therefore not be as relevant in face representation and identification as brightness, which can be considered as rather invariant face information. The lower relevance probably results in the smaller and less robust adaptation effects. The results indicate that the face information represented in face space is stored with a different valence and according to its relevance for face identification.

3 General Discussion

The face space is a valuable model for the visualization of cognitive processes involved in face identification and retention. However, this model is described just as incompletely as the current understanding of face recognition. The reported manuscripts aimed to contribute to the comprehension and complementation of the face space model and thus also to the understanding of face recognition and retention. The paradigms of face priming and adaptation are very useful for investigating face recognition and retention processes. However, they differ significantly from each other. Priming activates face representations stored in memory and thus facilitates the recognition of corresponding faces. Adaptation alters the mental representations leading to a more difficult recognition of nonmanipulated faces. The paradigms, therefore, result in opposite effects. Nevertheless, face priming and adaptation both somehow affect the face memory, making them good tools for investigating the face space. By varying the parameters *timing*, *transfer* and *face information* very different aspects of the face space can be examined.

3.1 Face priming and adaptation – Implications of temporal aspects for the face space

The review on the time interval between priming/adaptation phase and test phase (delay), revealed that both phenomena can last up to weeks (priming even up to months, see e.g., Carbon & Ditye, 2011, 2012; Lewis & Ellis, 1999; Maylor, 1998). This indicates that face priming and adaptation lead to long-term modifications in face memory and thus the face space. For adaptation this means that robust alterations of the face representations are evoked by the integration of new visual information. This updating mechanism presumably enables a very accurate face identification since up-to-date (and not outdated) face information is used when matching the mental representation against perceived face information (e.g., Carbon & Ditye, 2011; Carbon et al., 2007). However, during the adaptation process, the previous face information stored in the mental representation is probably not replaced by the new visual information but is instead averaged with it (see Chapter 1.2). Each subsequent encounter with the adaptor, therefore, should result in an increasing adjustment to the adaptor. New visual face information perceived once would therefore not have as large an impact on face representations as a frequent exposure with this information. Although, to the best of the author's knowledge this correlation between the number of exposures and the magnitude of adjustment has not been investigated so far, this mechanism could be very reasonable from a behavioral perspective. Thus, the dependence of the adaptation effect on the number of encounters could possibly enable differentiation between real and robust facial changes and transient changes that are not inherent in the face but are maybe evoked by environmental transformations (e.g., lighting conditions) or illusions. Transient changes that would be perceived once would therefore not alter the mental representations greatly, while stable changes that are perceived frequently would evoke greater alterations. Such a successive approach to the adaptor may also facilitate the recognition of a specific identity. Assuming the case that new visual information would not be integrated and averaged with the existing information but rather replaced with it, the difference between the previous mental representation and the new visual information could be too large for identification. Previous studies on episodic face memory in fact suggest that if new face information deviates largely from the previous face representation it would not be integrated into the existing face representation of the identity but a new representation would be created (Schneider & Carbon, 2017; the authors actually assume that multiple representations exist for the very same identity reflecting different temporal depictions of a face). However, by averaging the new face information (if not too dissimilar) with the existing face information stored in the representation, part of the previous representation will be retained enabling a recognition of the corresponding identity despite changes.

The underlying factors for the decrease of adaptation effects over time (see, e.g., Carbon & Ditye, 2011; Carbon & Leder, 2006; Carbon et al., 2007; Strobach et al., 2011) are not yet fully understood. The decrease indicates that during the delay (i.e., the time period between the adaptation and test phase) some kind of readjustment back to the previous representation is performed. However, this readjustment could be either provoked by a readjustment due to an extreme robustness of the original mental representation or by exposures (whether mental or real) to the identity outside the experimental setting (Carbon & Ditye, 2011). Since in experimental settings the adaptors usually represent artificial manipulations, encounters with the identity outside this setting probably show the identity in a natural or nonmanipulated way. These “natural” encounters could probably evoke a readaptation process back to the original representation. Alternatively, the readjustment of the mental representation might be caused by the great robustness of the previous representation, which is probably formed by many encounters. In order to permanently alter the representation toward the adaptor, more encounters with the adaptor are probably necessary than just the one (and often short) encounter the participant has within the experimental context. Thus, the exposure in an experimental setting might just evoke adaptation effects that continuously decrease, slowly replacing the new information with the very robust original representation.

Priming improves the recognition of identities by activating or facilitating the activation of the corresponding identity (e.g., Ellis et al., 1993; Schweinberger et al., 1995). When reencountering the primed identity, the ongoing activation or facilitated reactivation enables a fast access to the information contained in the corresponding mental representation and thus facilitates the identification of the identity (e.g., Schweinberger et al., 1995). Assuming that also other types of personal information (i.e., nonphenotypical information such as the name) are activated when the mental representation is primed, the phenomenon priming probably enhances social interactions greatly since it enables fast access to relevant information about the identities one is often encountered with. Since priming effects were observed up to several months (e.g., Lewis & Ellis, 1999; Maylor, 1998) a facilitated reactivation ability might be more likely than a continuous activation of the representation. By reactivating a mental representation probably fewer cognitive resources are consumed than by maintaining activation of the representation over such a long period of time.

The decrease of priming effects over time (e.g., Lewis & Ellis, 1999) might be a mechanism to save cognitive resources as well. The decrease indicates that the access to information about identities (i.e., information contained in the mental representations) one has not encountered recently becomes more difficult over time. Accordingly, priming seems to occur primarily with identities one frequently interacts with. In this context, priming seems to be in fact most efficient, as it enables a swift information retrieval and thus successful social interactions. However, for identities one does not encounter frequently, a permanent activation (or facilitation of reactivation) might not be very reasonable, since it probably consumes many cognitive resources. It would possibly require an enormous memory capacity to keep accessible all the information on every identity one has ever met. From a behavioral perspective it is more reasonable to limit the access only to the information that is frequently used. Information that is rarely accessed (i.e., information about identities one has not interacted with for a while) would therefore be more difficult to retrieve since the reactivation ability of the mental representation (i.e., the priming effect) decreases over time. This may complicate social interactions with identities one has not met for a while but saves cognitive resources in the long term.

Just like the parameter delay, the temporal aspects of prime/adaptor duration and test duration provide little information about the structure of the face space. Rather, these parameters reveal how priming and adaptation paradigms should be constructed to obtain the greatest priming or adaptation effects and thus the greatest activation or alteration of the mental representation in face space (on temporal parameters of adaptation paradigms, see e.g., Strobach & Carbon, 2013). Adaptation studies reveal that the adaptor duration should rather be extended to observe a strong adaptation effect (e.g., Leopold et al., 2005; Rhodes et al., 2007). This indicates that a prolonged adaptor presentation results in a greater adjustment of the mental representation to the adaptor. New visual face information perceived for a very short duration would therefore not have as large an impact on face representations as a very long exposure. Thus, this mechanism would be very similar to the mechanism that is possibly involved when participants are exposed to an adaptor several times (i.e., a frequent exposure to the adaptor probably results in an increasing adjustment to the adaptor; see above). However, to the best of the author's knowledge, the correlation between the magnitude of adjustment of the mental representation and the presentation duration of the adaptor, has also not yet been systematically investigated.

While for adaptation the presentation duration of the adaptor should rather be prolonged to obtain the greatest possible effect, the presentation duration of the prime should be kept relatively short (Rieth & Huber, 2010). A longer prime presentation leads to a decrease or sometimes even to a negative priming effect (reflecting recognition impairments). Some authors assume a neural habituation effect to be the source of this recognition impairment (Rieth & Huber, 2010). Hence, the prolonged presentation of a prime would lead to a habituation and thus to an activation reduction of the mental representation. According to the authors, a habituation or representation deactivation would occur to avoid confusion with subsequent faces. Thus, the mental representation of the previously inspected identity would be deactivated in order to avoid confusion when activating the mental representation of the subsequent identity. This would imply that parallel activation of several representations would not be possible. However, an alternative explanation should be considered as well. The negative priming effect could also result from an adaptation effect. When perceiving a face prime, the presented image would probably never correspond exactly to the mental representation stored in memory (since the representation represents the average of all encounters one had with the identity). Thus, prolonged exposure to the prime could possibly trigger an adaptation process, leading to an alteration of the mental representation toward the face prime. Since the subsequent test face would not match the representation anymore after this adaptation process, identification would be more difficult. This could explain the negative priming effect occurring after a prolonged prime exposure and could, furthermore, elucidate the relation between priming and adaptation. While short stimuli presentations might evoke an activation of the mental representation (i.e., a priming effect) a relatively long stimuli presentation potentially results in an alteration of the representation (i.e., an adaptation effect). This possible relation between priming and adaptation should be investigated more closely in future studies.

Similarly to the prime duration, which should be kept short to evoke a strong priming effect, the presentation duration of the test image should also be limited to a short time period. Although to the best of the author's knowledge, no negative priming effect could be observed using a long test duration; the priming effect still decreased with increasing presentation duration of the test stimulus (Rieth & Huber, 2010). Presumably, this decrease of effect is based on the same mechanism as the decrease observed with a relatively long prime duration. Thus, either a neural habituation with the aim of avoiding confusion with subsequent faces could evoke this successive deactivation of the mental representation (see Rieth & Huber, 2010) or an adaptation process occurs due to the mismatch of the test stimulus with the mental representation (see above). Not only should the test stimulus within a priming paradigm be kept short, but also the adaptation test stimulus should be presented briefly to obtain a strong adaptation effect (e.g., Leopold et al., 2005; Rhodes et al., 2007). Since the test stimulus displays a face image that is closer to the original face than the strongly manipulated adaptor, a readaptation process back to the original face could be triggered by a test image that is presented for a relatively long time. Subsequently, the participants would select a test image that is closer to the original face in the test phase and thus the adaptation effect would diminish.

3.2 Face priming and adaptation – Implications of the transferability for the face space

Next to the temporal parameters of the paradigms the transferability of priming and adaptation effects can also give insights into the nature of mental representations. The transferability of priming and adaptation effects on a structural level (i.e., the transfer of effects between different images of the same identity), for example, shows that the effects are not bound to pictorial depictions but are generalizable to other depictions of the identity (e.g., Bruce & Valentine, 1985; Carbon & Leder, 2005; Carbon et al., 2007; Ellis et al., 1987; Ellis et al., 1993). Thus, the mental representations that are addressed must contain some kind of identity-specific structure that enables a very flexible identification of identities despite large changes. Hence, during priming or adaptation processes not only is the mental representation of the presented image activated or primed, but also a more holistic representation of the identity. This representation is probably either very minimalistic, consisting of only the basic face information or it contains wide-ranging face information (see, e.g., Carbon et al., 2007). Since adaptation effects can be evoked by applying alterations on very divers face information, the representations probably contain a variety of face information rather than just a basic structure.

While the structural transfer level gives insights into the quality of face representations, the transfer on a cross-identity level can clarify how these representations are arranged in face space. The transferability of adaptation effects on a cross-identity level, for example, shows that adaptation not only affects a specific identity but also transfers to other identity faces not displayed during the adaptation phase (e.g., Carbon et al., 2007; Fox & Barton, 2007; Strobach et al., 2011). This might indicate that adaptation addresses the entire face space, leading to an alteration of all face representations in face space along the altered face dimension (e.g., an adaptation to a strongly distorted head width would alter all face representations within the face space toward the adaptor; see, e.g., Benton & Burgess, 2008). This approach would refer to the exemplar-based face space model (Valentine, 1991; or see Chapter 1.1). Alternatively, it could be assumed that adaptation alters superordinate concepts or a generic face norm next to the representation that is adapted. This approach referring to the norm-based face space model (Valentine, 1991; or see Chapter 1.1) would indicate that the face space must be arranged in a very hierarchical way. According to this theory, superordinate concepts or sub-face spaces would exist, subsuming all identities owning a specific characteristic (e.g., a specific ethnicity or gender). When the representation of one of these identities would be altered by adaptation, the generic norm of the sub-face space would be altered too, and so would all other identities belonging to this sub-face space (e.g., Little et al., 2008; Rhodes et al., 2005; Valentine, 2001; Valentine et al., 2016). Results of adaptation studies investigating the transfer of adaptation effects to different ethnicities or gender support this approach. They revealed decreased adaptation effects when transferring the effects to a different ethnicity or gender compared to the transfer to different identities but of the same ethnicity or gender (see Jaquet & Rhodes, 2008; Jaquet et al., 2008 or the included review on face adaptation and face priming). This indicates that adaptation primarily affects the sub-face space, to which the adaptor belongs to. Thus, the face space seems to be in fact organized in several sub-face spaces.

Such a division of the face space into different sub-face spaces might be very reasonable and an essential aspect for face identification since it probably leads to a very precise differentiation of identities. It could be assumed, for example, that sub-face spaces are created and even divided into further sub-face spaces by experience with the identities belonging to these sub-face spaces (e.g., a prolonged exposure to different Asian people would create the sub-face space "Asian faces" which might be further divided into "Asian female faces" and "Asian male faces" or Asian faces of different ages). Thus, greater differentiation of a sub-face space would reflect a greater facial expertise for that sub-face space and would therefore involve an increased ability in the differentiation and identification of faces belonging to this sub-face space. This theory is supported by studies revealing an increased ability in identifying the gender of identities belonging to the own ethnicity (there is usually a high level of facial expertise for one's own ethnic group due to constant exposure to this group). The identification of the gender of identities belonging to a different ethnicity, however, seems to be more difficult (e.g., O'Toole et al., 1996; see also the review on face adaptation and face priming included in this thesis). This decreased identification ability could be caused by the missing experience with faces of other ethnicities and the resulting lack of differentiation of the corresponding sub-face spaces.

Although adaptation studies usually reveal adaptation effects on all three transfer levels (i.e., pictorial, structural and cross-identity) they often indicate a decrease of the effects the greater the abstraction level of the test images is compared to the adaptor. Thus, adaptation effects on a pictorial level are usually greater than effects on a structural and cross-identity level. Moreover, the effects on a cross-identity level are usually the weakest (e.g., Carbon & Ditye, 2011, 2012; Carbon et al., 2007). This reduction in effects might be reflected in the different impact the adaptation effects have on the various hierarchical levels in face space. It could be assumed, for example, that the adaptation effect primarily affects mental retention of the previously seen adaptor image (pictorial transfer). Parts of the effect (effects on a structural level), however, would also affect the mental representation of the corresponding identity, although the effect is attenuated since image-specific components of the effect (pictorial transfer) are no longer active. Moreover, to a certain extent superordinate concepts (such as specific sub-face spaces or generic norms) would be affected as well (indicated by effects on a cross-identity transfer level) but not to the same extent as the mental representation of the specific identity or the mental retention of the adaptor image (probably because image-specific and identity-specific components are no longer active on a cross-identity transfer level). Thus, it could be assumed that the higher the level in the hierarchically structured face space is the smaller is the impact of the adaptation effect.

A decrease in effect can also be observed for priming on a structural transfer level (e.g., Ellis et al., 1987). Thus, although the prime somehow activates the entire mental representation of the specific identity, leading to a recognition improvement when other depictions of the identity (other than the prime) are presented, the effect is somehow smaller than the priming effect on a pictorial level. Thus, the effect probably contains some kind of image-specific aspects that are no longer activated when displaying a different depiction of the identity. Despite this general decrease in effect on the structural transfer level, priming effects also differ in size within the structural level depending on the similarity of the prime and test stimulus (e.g., Ellis et al., 1987). Depictions of the specific identity that are more similar to the prime show a greater priming effect than depictions that are dissimilar. This indicates that the priming effect decreases the lower the inter-item similarity is. The perceptual system thus does not seem to process differences of the images in a categorical way (e.g., the perception of "identical images" on the one hand generates a strong priming effect and the perception of images displaying the "same identity but in another depiction" induces a slightly decreased priming effect). Rather, it perceives differences in a very gradual way (the size of the effect depends on the similarity to the reference face – the greater the similarity the greater the effect). Whether this dependence on the inter-item similarity also emerges on a cross-identity level and/or in adaptation effects has, to the best of the author's knowledge, not yet been investigated. If a relationship between the inter-item similarity and the strength of the effect can be observed for adaptation effects and/or on a cross-identity level, the assumptions about sub-face spaces would have to be reconsidered. Adaptation effects that transfer to other identities would maybe not depend on the categorization of the identities into common sub-face spaces (e.g., the same gender), but on their similarity to the adaptor (independently of their common categorization; regarding the relevance of similarity in face space, see also Lewis, 2004). Therefore, the boundaries of sub-face spaces could not be clearly defined but would rather be blurred due to the dimensional (not categorical) nature of facial characteristics.

For priming, the results on a cross-identity level are rather ambiguous. Some studies assume that the priming effects transfer to images of other identities depending on the similarity of the displayed images and not on belonging to the same category or sub-face space (e.g., the same ethnicity; Rostamirad et al., 2009; Zarate & Sanders, 1999; see Chapter 2.1.3 or the included review on face priming and adaptation). This suggests that activation of the representation of other identities is possible as long as they are very similar to the prime. Higher concepts or sub-face spaces, however, seem to be not affected by priming. This seems to be reasonable as priming should ensure the fast retrieval of information about the identity to which one is currently exposed (see Chapter 3.1.1). Information of other identities not involved in the interaction is probably not relevant. The activation of an entire sub-face space including the representations of the identities belonging to this sub-face space is therefore not necessary.

However, the reason why representations of very similar identities are co-activated through priming remains an open issue. It might be that mental representations are not clearly defined entities but rather dimensional in nature as well. Thus, distinct transitions to representations of other identities would not exist. According to this approach, a representation of an identity would have to be imagined as very diffuse and variable. Thus, priming would not cause an activation of the representation as a single entity, but rather an activation dispersion around the location that would represent the prime in face space. As the distance to this point (i.e., the point of the prime in face space) increases, the activation would decrease. Images that are very similar to the prime (and thus are located in the face space very close to the prime) would be activated more strongly than face images that are very dissimilar – regardless of whether they belong to the same or another identity. Hence, it could be possible that images of other identities, which are very similar to the primed identity, are also activated (see Figure 6). Such an approach would be very reasonable since a representation of a specific identity should also contain images that display the identity in a very atypical way to identify the identity in all kinds of situations. However, some images may be so atypical that they cannot be directly attributed to the person (e.g., if you do not recognize friends in photos at first glance) and are sometimes even perceived as another identity. Accordingly, it might be that priming results in an activation dispersion that includes face images that are attributed to other (but similar) identities than the primed one. Therefore, the term "face representation" as we have used it so far might need to be reconceptualized, as it possibly even includes face depictions of other identities.

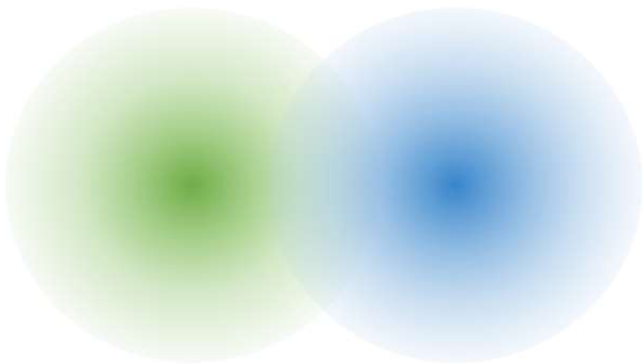

Figure 6. **A very basic illustration of mental face representations that are rather dimensional in nature. According to this approach, representations cannot be understood as distinct units but are seen in the context of priming as an activation dispersion emanating from the mental representation of the prime. The circular structures illustrate the activation dispersion (the two colored circles represent two different identity primes). The core of the circle represents the mental representation of the prime. The gradient around it illustrates all other represented face images of this identity. Thus, activation affects many different mental images of an identity and decreases the further away an image is from the mental representation of the prime (or the more dissimilar it is to it). The outer edge of the activation might contain mental face images that can no longer be clearly attributed to a specific identity but reveal overlaps with images of other similar identities (illustrated by the overlap of the two circles). The depiction of two parallel activations is used only to illustrate this overlap. Source: Author's own work.**

Next to the inter-item similarity, the size of the priming effects also seems to depend on the semantic association between the displayed identities (e.g., Young et al., 1994; see Chapter 2.1.3 or the included review on face priming and adaptation). Thus, priming effects can be transferred to identities that are strongly associated to the prime (e.g., Michelle and Barack Obama). When activating the mental representation of one identity, the representation of the associated identity would be activated as well. This exclusive bond between associated identities might be reasonable from a behavioral perspective. Presumably, this strong association between identities is formed by frequent co-occurrences of these identities. Therefore, when perceiving one of the associated persons, it would be useful to also activate the representation of the other one, since there is a high probability that this person will appear as well. Hence, a fast information retrieval and successful interaction is possible.

3.3 Face priming and adaptation – Implications of the face information for the face space

While the transfer of effects is very informative regarding the structure of the face space, the face information that is activated or altered by priming and/or adaptation can reveal much about the content of the face space. However, since priming usually activates the entire mental face representation instead of isolated face characteristics, it seems to be not as informative as adaptation, when investigating the characteristics of face information stored in representational memory (e.g., Mohr et al., 2018; see Chapter 1.3.3). These limitations of the priming paradigm might have caused the face space literature to mainly focus on adaptation when investigating the face information stored in face space. So far, face adaptation studies have mainly focused on configural information when investigating specific types of face information (e.g., Carbon et al., 2007; Webster et al., 2004). Most of these studies were able to observe strong adaptation effects when using configural face alterations (for a review, see Strobach & Carbon, 2013). The studies presented in this thesis, however, aimed to focus on the so far poorly investigated non-configural color information. The reported experiments are probably the first to systematically show that specific color information in forms of brightness and saturation alterations can evoke adaptation effects, which, in case of brightness alterations, last up to five minutes and maybe even up to 50 minutes (see Chapter 2.2.3 or the included second manuscript). For saturation, adaptation effects only occurred for increased saturation alterations. Since the effects on brightness as well as increased saturation seem to be face-specific and transferable to different depictions of the same identity (structural transfer level) and to other identities (cross-identity transfer level) they most likely affect the representational memory basis (see Chapter 2.2.3 and

2.3.3). Thus, brightness and increased saturation alterations evoke a shift in the mental representation of the corresponding identity toward the adaptor and seem to affect higher face concepts. Hence it can be assumed that both color dimensions are part of face representations and the face space.

However, it seems that different face information is stored with a different valence in face space. For instance, while experiments applying alterations on configural face information lasted up to a week (Carbon & Ditye, 2011), the adaptation effects on brightness reported in this thesis already decreased after 5 minutes (i.e., the adaptation effects in the experiment applying a 5-minute time interval were decreased compared to the experiment using a 300-millisecond or 3-second time interval, see Chapter 2.2.2). This could suggest that brightness information may not be stored as long term as configural face information (however, this can only be speculated on, as adaptation studies on brightness exceeding a 5 minutes' delay are still needed). Differences in the robustness of effects were also observed between brightness and saturation information (see Chapter 2.2.2 and 2.3.2). Compared to the adaptation effects on brightness, the effects on increased saturation were even more transient: they were observable after a delay of 3 seconds but not after a delay of 5 minutes. Yet, the effects seem to be based on representational processes rather than retinal or sensory processes. This is indicated by the transfer on a structural and cross-identity level, implying that the effects alter mental representations and even higher concepts. Since there were no adaptation effects using nonface stimuli, the effects also seem to be face-specific. Thus, although the representational memory probably is affected by increased saturation alterations, these effects are very transient. Increased saturation information might be initially stored in representational memory, but due to a fast resetting mechanism back to the pre-adaptation status, this information is not stored in the long-term.

Possibly, the robustness and thus the resetting of effects could be related to the valence the face information has for face recognition. Thus, it could be that invariant types of information trigger a more long-term adaptation effect while adaptation effects on information that is highly variable evoke a faster resetting mechanism. Configural face information, for example, can be considered as highly invariant (see e.g., Carbon & Leder, 2005; Haxby et al., 2000; Leder & Carbon, 2006), as basic face configurations change little across the lifespan (except perhaps in childhood). Configural alterations may therefore be experienced as very important for face recognition and stored in the long term. Brightness or saturation information, on the other hand, is often more variable and transient. While increased saturation is often associated with the emotional or health state of a person (Re et al., 2011; Thorstenson et al., 2019), brightness can either provide information about the lighting situation of the environment or is related to a person's skin tone (e.g., Levin & Banaji, 2006; see also Chapter 2.3.3). Since only the face's brightness was altered in the reported experiments, keeping the context of the image constant, the applied brightness alterations might have been rather interpreted as alterations of the skin tone. Although the skin tone of a person probably reveals information about the person's ethnicity (e.g., Herring et al., 2004), which could be considered as an invariant type of information, it can also be subject to variations (e.g., due to sun exposure). Hence, it might be a more variable type of information than configural face information and thus not stored as long in representational memory as configural information. Moreover, the skin tone (i.e., brightness information) probably can be seen as a more invariant type of information than a person's emotional or health state (i.e., increased saturation information). The more transient adaptation effects on increased saturation might reflect this transience of saturation alterations. Increased saturation would therefore be considered as less important for face recognition due to its variant nature and, thus, would be stored in representational memory for an even shorter time period than brightness alterations. Considering all these results, face information stored in face space (i.e., the dimensions of the face space) might be valuated differently, depending on the valence the information has for face recognition.

This assumption is supported by results of adaptation studies investigating the transfer of adaptation effects between images differing in specific image dimensions (see Chapter 2.1.3). These studies have usually focused on the adaptation to specific face information (e.g., a manipulated eye–mouth distance) but also varied other image dimensions (e.g., the size or the contrast of the image) between the adaptor and test images (e.g., Hole, 2011; Yamashita et al., 2005). The authors were able to observe differences in the size of the adaptation effects depending on the transfer dimension (i.e., the image dimension that was altered additionally to the adaptor information). The transfer to alterations of some image dimensions, such as contrast or spatial frequency, reduced the adaptation effects. These image dimensions therefore seemed to have a greater impact on the adaptation effects than the transfer on other image dimensions that only marginally affected adaptation, such as the size or the position of the image. The authors assumed that the transferability of effects depends on the impact these dimensions have on the recognizability of faces. Hence, dimensions that affect the recognizability to a greater extent when altered (probably contrast or spatial frequency), seem to have a greater impact on the transferability of effects. These dimensions would therefore play a greater role in face recognition and thus the face space. Other dimensions (e.g., the image size or position), however, are probably less relevant for face recognition, yet they seem to be not irrelevant, since they still marginally affect adaptation effects. Possibly, the variability of the facial information is the decisive factor here as well. While the contrast or the spatial frequency probably alters the face characteristics significantly, the size or the position of the face represents rather variable types of information (a change in the size of the face is probably not perceived as an actual change in the face but rather as a change in the distance to the face). Thus, the size and the position of a face as more variant face information would be less important for face recognition and representation, while contrast and spatial frequency, as more invariant face information, would play a greater role. Hence, these results support the idea that face information is represented in face space with different valence, depending on its variability and importance for face recognition. Such a system, where invariant face information is valuated as less important, is very reasonable from a behavioral perspective. Since this information changes very quickly, it does not provide reliable information about the identity of a person. It is therefore reasonable that changes are not stored in the long term. As these types of information nonetheless provide important input about the condition of a person (e.g., about the health or emotional status), the information should still be processed and represented during the social interaction with this person.

However, there also seems to be information that is not represented in face space at all. The experiments on saturation, for example, show that decreased saturation alterations might not evoke any adaptation effects, indicating that this kind of face information is probably not stored in representational memory and thus not relevant in face recognition processes (this result, however, should be interpreted with caution due to the specific bias of the control group toward the decreased saturation condition; see Chapter 2.3.2). It might be that this possible irrelevance of decreased saturation for face recognition could be caused by a lack of experience with this kind of face information. Decreased saturation usually results in a loss of color (faces are presented in grayscale). A complete loss of color in faces does not occur naturally (even when a face pales, it probably still has a certain amount of color) so that this type of information has possibly not been represented so far. Furthermore, due to its artificial nature, this facial information does not provide any other information about the person, such as the emotional or health state, ethnicity or gender. This could be another reason for the possible irrelevance of decreased saturation for face representation and recognition. Considering the missing adaptation effects on decreased saturation, it could be assumed that the face space does not store all possible face information but only a selection of information relevant for face recognition (for a precise number of face information/dimensions stored in face space, see Lewis, 2004; Meytlis & Sirovich, 2007). However, the face information existing in face space (i.e., the dimensions of the face space) appears to be valuated differently, depending on the information's valence for face recognition.

4 Conclusions

The aim of this PhD thesis is to broaden the theoretical understanding of face recognition, and thus the face space. While previous work investigating the quality of face space has primarily relied on face adaptation, the results presented here show that face priming is also an effective tool for investigating the nature of the mental face space. Future research should therefore also include priming in the study of the face space to gain an even better understanding of the face space model and thus of face recognition. The parameters timing, transferability and face information of both paradigms can provide information about very different aspects of the face space. The parameter timing mainly shows how robust and flexible mental representations are. The reviewed studies as well as the reported experiments of this thesis indicate that the mental representations are very flexible and continuously updated, enabling accurate face recognition. The parameter transferability, however, reveals how the face space might be structured. The results suggest that there are probably some kind of higher face concepts. Moreover, it can be assumed that mental face representations as well as higher face concepts should be considered in a more dimensional way. The previous assumption that representations and categories can be clearly distinguished from each other must be questioned. Future studies using computational models could verify whether a dimensional approach is more consistent with findings in face perception than a categorical approach. Furthermore, results regarding the parameter face information revealed that different face information is probably represented with a different valence in face space. The valence of face information, however, most likely depends on the relevance the face information has for face recognition. Future studies should investigate this aspect more intensively by comparing the robustness of even more types of face information. Since the different valence of face information in face space, as well as the rather dimensional nature of face representations are aspects that have not yet been considered in the face space theory so far, this thesis indicates that the current model of the face space may need to be modified. A critical testing of the model through future research and a possible modification, could lead to a much better understanding of face recognition.

5 References

Barrett, S. E., & O'Toole, A. J. (2009). Face adaptation to gender: Does adaptation transfer across age categories? *Visual Cognition*, *17*(5), 700–715. doi: 10.1080/13506280802332197

Benton, C. P., & Burgess, E. C. (2008). The direction of measured face aftereffects. *Journal of Vision*, *8*(15), 1–6.

Boehm, S. G., Klostermann, E. C., Sommer, W., & Paller, K. A. (2006). Dissociating perceptual and representation-based contributions to priming of face recognition. *Consciousness and Cognition*, *15*(1), 163–174. doi: 10.1016/j.concog.2005.06.001

Brooks, B. E., Rosielle, L. J., & Cooper, E. E. (2002). The priming of face recognition after metric transformations. *Perception*, *31*(3), 297–313. doi: 10.1068/p3283

Bruce, V., Burton, A. M., Carson, D., Hanna, E., & Mason, O. (1994). Repetition priming of face recognition. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp.179–202). Bradford Book.

Bruce, V., & Valentine, T. (1985). Identity priming in the recognition of familiar faces. *British Journal of Psychology*, *76*(3), 373–383. doi: 10.1111/j.2044-8295.1985.tb01960.x

Bruce, V., & Valentine, T. (1986). Semantic priming of familiar faces. *The Quarterly Journal of Experimental Psychology Section A*, *38*(1), 125–150. doi: 10.1080/14640748608401588

Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, *77*(3), 305–327. doi: 10.1111/j.2044-8295.1986.tb02199.x

Byatt, G., & Rhodes, G. (1998). Recognition of own-race and other-race caricatures: Implications for models of face recognition. *Vision Research*, *38*(15–16), 2455–2468. doi: 10.1016/S0042-6989(97)00469-0

Carbon, C. C., & Ditye, T. (2011). Sustained effects of adaptation on the perception of familiar faces. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(3), 615–625. doi: 10.1037/a0019949

Carbon, C. C., & Ditye, T. (2012). Face adaptation effects show strong and long-lasting transfer from lab to more ecological contexts. *Frontiers in Psychology*, *3*(2), 1–6. doi: 10.3389/fpsyg.2012.00003

Carbon, C. C., & Leder, H. (2005). Face adaptation: Changing stable representations of familiar faces within minutes? *Advances in Cognitive Psychology*, *1*(1), 1–7. doi: 10.2478/v10053-008-0038-8

Carbon, C. C., & Leder, H. (2006). The Mona Lisa effect: Is 'our' Lisa fame or fake? *Perception*, *35*(3), 411–414. doi: 10.1068/p5452

Carbon, C. C., Strobach, T., Langton, S. R. H., Harsányi, G., Leder, H., & Kovács, G. (2007). Adaptation effects of highly familiar faces: Immediate and long lasting. *Memory & Cognition*, *35*(8), 1966–1976. doi: 10.3758/bf03192929

Diamond, R., & Carey, S. (1986). Why faces are and are not special: An effect of expertise. *Journal of Experimental Psychology*, *115*(2), 107–117. doi: 10.1037//0096-3445.115.2.107

Ellis, A. W., Young, A. W., Flude, B. M., & Hay, D. C. (1987). Repetition priming of face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *39*(2), 193–210. doi: 10.1080/14640748708401784

Ellis, H. D., Ellis, D., M., & Hosie, J. A. (1993). Priming effects in children´s face recognition. *British Journal of Psychology*, *84*(1), 101–110. doi: 10.1111/j.2044-8295.1993.tb02465.x

Fox, C. J., & Barton, J. J. S. (2007). What is adapted in face adaptation? The neural representations of expression in the human visual system. *Brain Research*, *1127*(1), 80–89. doi: 10.1016/j.brainres.2006.09.104

Fox, C. J., Oruc, I., & Barton, J. J. (2008). It doesn't matter how you feel. The facial identity aftereffect is invariant to changes in facial expression. *Journal of Vision*, *8*(3), 111–113. doi: 10.1167/8.3.11

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*(6), 223–233. doi: 10.1016/s1364-6613(00)01482-0

Herring, C., Keith, V., & Horton, H. D. (2004). *Skin deep: How race and complexion matter in the 'color-blind' era*: University of Illinois Press.

Hole, G. (2011). Identity-specific face adaptation effects: Evidence for abstractive face representations. *Cognition*, *119*(2), 216–228. doi: 10.1016/j.cognition.2011.01.011

Jaquet, E., & Rhodes, G. (2008). Face aftereffects indicate dissociable, but not distinct, coding of male and female faces. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(1), 101–112. doi: 10.1037/0096-1523.34.1.101

Jaquet, E., Rhodes, G., & Hayward, W. G. (2008). Race-contingent aftereffects suggest distinct perceptual norms for different race faces. *Visual Cognition*, *16*(6), 734–753. doi: 10.1080/13506280701350647

Jiang, F., Blanz, V., & O'Toole, A. J. (2009). Three-dimensional information in face representations revealed by identity aftereffects. *Psychological Science*, *20*(3), 318–325. doi: 10.1111/j.1467-9280.2009.02285.x

Kovács, G., Zimmer, M., Harza, I., & Vidnyánszky, Z. (2007). Adaptation duration affects the spatial selectivity of facial aftereffects. *Vision Research*, *47*(25), 3141–3149. doi: 10.1016/j.visres.2007.08.019

Lai, M., Oruc, I., & Barton, J. J. (2012). Facial age after-effects show partial identity invariance and transfer from hands to faces. *Cortex*, *48*(4), 477–486. doi: 10.1016/j.cortex.2010.11.014

Leder, H., & Carbon, C.-C. (2006). Face-specific configural processing of relational information. *British Journal of Psychology*, *97*(1), 19–29. doi: 10.1348/000712605X54794

Lee, K. J., & Perrett, D. (1997). Presentation-time measures of the effects of manipulations in colour space on discrimination of famous faces. *Perception*, *26*(6), 733–752. doi: 10.1068/p260733

Leopold, D. A., O'Toole, A. J., Vetter, T., & Blanz, V. (2001). Prototype-referenced shape encoding revealed by high-level aftereffects. *Nature Neuroscience*, *4*(1), 89–94. doi: 10.1038/82947

Leopold, D. A., Rhodes, G., Müller, K. M., & Jeffery, L. (2005). The dynamics of visual adaptation to faces. *Proceedings of the Royal Society B*, *272*, 897–904. doi: 10.1098/rspb.2004.3022

Levin, D. T., & Banaji, M. R. (2006). Distortions in the perceived lightness of faces: The role of race categories. *Journal of Experimental Psychology*, *135*(4), 501–512. doi: 10.1037/0096-3445.135.4.501

Lewis, M. (2004). Face-space-R: Towards a unified account of face recognition. *Visual Cognition*, *11*(1), 29–69. doi: 10.1080/13506280344000194

Lewis, M. B., & Ellis, H. D. (1999). Repeated repetition priming in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *52*(4), 927–955. doi: 10.1080/027249899390873

Lewis, M. B., & Johnston, R. A. (1998). Understanding caricatures of faces. *The Quarterly Journal of Experimental Psychology Section A*, *51*(2), 321–346. doi: 10.1080/713755758

Lewis, M. B., & Johnston, R. A. (1999). A unified account of the effects of caricaturing faces. *Visual Cognition*, *6*(1), 1–42. doi: 10.1080/713756800

Little, A., DeBruine, L. M., Jones, B. C., & Waitt, C. (2008). Category contingent aftereffects for faces of different races, ages and species. *Cognition*, *106*(3), 1537–1547. doi: 10.1016/j.cognition.2007.06.008

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences*, *6*(6), 255–260. doi: 10.1016/S1364-6613(02)01903-4

Maylor, E. A. (1998). Retrivieng names in old age: short- and (very) long-term effects of repetition. *Memory & Cognition*, *26*(2), 309–319. doi: 10.3758/BF03201142

McNamara, T. P. (2005). *Semantic priming: perspectives from memory and word recognition*: Psychology Press. doi: 10.4324/9780203338001

Meytlis, M., & Sirovich, L. (2007). On the dimensionality of face space. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *29*(7), 1262–1267 doi: 10.1109/TPAMI.2007.1033

Mohr, S., Wang, A., & Engell, A. D. (2018). Early identity recognition of familiar faces is not dependent on holistic processing. *Social Cognitive and Affective Neuroscience*, *13*(10), 1019–1027. doi: 10.1093/scan/nsy079

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2020). Face adaptation and face priming as tools for getting insights into the quality of face space. *Frontiers in Psychology*, *11*(166), 1–17. doi: 10.3389/fpsyg.2020.00166

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2021a). Face adaptation — Investigating nonconfigural saturation alterations. *i-Perception*, *12*(6), 1-24. doi: 10.1177/20416695211056362

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2021b). Face adaptation affects on non-configural face information. *Advances in Cognitive Psychology*, *17*(2), 99–106. doi: 10.5709/acp-0325-3

O'Toole, A. J., Peterson, J., & Deffenbacher, K. A. (1996). An 'other-race effect' for categorizing faces by sex. *Perception*, *25*(6), 669–676. doi: 10.1068/p250669

Piepers, D. W., & Robbins, R. A. (2012). A review and clarification of the terms "holistic," "configural," and "relational" in the face perception literature. *Frontiers in Psychology*, *3*, 559. doi: 10.3389/fpsyg.2012.00559

Re, D. E., Whitehead, R. D., Xiao, D., & Perrett, D. I. (2011). Oxygenated-blood colour change thresholds for perceived facial redness, health, and attractiveness. *PLoS One*, *6*(3), e17859. doi: 10.1371/journal.pone.0017859

Rhodes, G., Jeffery, L., Clifford, C. W. G., & Leopold, D. A. (2007). The timecourse of higher-level face aftereffects. *Vision Research*, *47*(17), 2291–2296. doi: 10.1016/j.visres.2007.05.012

Rhodes, G., Robbins, R., Jaquet, E., McKone, E., Jeffery, L., & Clifford, C. W. G. (2005). Adaptation and face perception: How aftereffects implicate norm-based coding of faces. In C. W. G. Clifford & G. Rhodes (Eds.), *Fitting the mind to the world: Adaptation and after-effects in high-level vision* (pp.213–240). Oxford University Press.

Rieth, C. A., & Huber, D. E. (2010). Priming and habituation for faces: Individual differences and inversion effects. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(3), 596–618. doi: 10.1037/a0018737

Rivest, J., Moscovitch, M., & Black, S. (2009). A comparative case study of face recognition: The contribution of configural and part-based recognition systems, and their interaction. *Neuropsychologia*, *47*(13), 2798–2811. doi: 10.1016/j.neuropsychologia.2009.06.004

Rossion, B., Schiltz, C., Robaye, L., Pirenne, D., & Crommelinck, M. (2001). How does the brain discriminate familiar and unfamiliar faces?: A PET study of face categorical perception. *Journal of Cognitive Neuroscience*, *13*(7), 1019–1034. doi: 10.1162/089892901753165917

Rostamirad, S., Barton, J. J. S., & Oruc, I. (2009). Center-surround organization of face-space: Evidence from contrast-based face-priming. *Neuroreport*, *20*(13), 1177–1182. doi: 10.1097/WNR.0b013e32832f078d

Schneider, T. M., & Carbon, C. C. (2017). How a face becomes familiar? Episodic facial prototypes and representations are generated across life-span. *Perception*, *46*(S), 34.

Schweinberger, S. R., Pfütze, E.-M., & Sommer, W. (1995). Repetition priming and associative priming of face recognition: Evidence from event-related potentials. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(3), 722–736. doi: 10.1037//0278-7393.21.3.722

Strobach, T., & Carbon, C. C. (2013). Face adaptation effects: Reviewing the impact of adapting information, time, and transfer. *Frontiers in Psychology*, *4*, 318. doi: 10.3389/fpsyg.2013.00318

Strobach, T., Ditye, T., & Carbon, C.-C. (2011). Long-term adaptation effects of highly familiar faces are modulated by adaptation duration. *Perception*, *40*(8), 1000–1004. doi: 10.1068/p6986

Tan, K. W., & Stephen, I. D. (2013). Colour detection thresholds in faces and colour patches. *Perception*, *42*(7), 733–741. doi: 10.1068/p7499

Thorstenson, C. A., Pazda, A. D., Young, S. G., & Elliot, A. J. (2019). Face color facilitates the disambiguation of confusing emotion expressions: Toward a social functional account of face color in emotion communication. *Emotion*, *19*(5), 799–807. doi: 10.1037/emo0000485

Valentine, T. (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *British Journal of Psychology*, *79*(4), 471–491. doi: 10.1111/j.2044-8295.1988.tb02747.x

Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *43*(2), 161–204. doi: 10.1080/14640749108400966

Valentine, T. (2001). Face-space models of face recognition. In M. J. Wenger & J. T. Townsend (Eds.), *Computational, Geometric, and Process Perspectives on Facial Cognition: Contexts and Challenges* (pp.83–113). Lawrence Erlbaum Associates Publishers.

Valentine, T., & Bruce, V. (1986). The effects of distinctiveness in recognising and classifying faces. *Perception*, *15*(5), 525–535. doi: 10.1068/p150525

Valentine, T., Lewis, M. B., & Hills, P. J. (2016). Face-space: A unifying concept in face recognition research. *The Quarterly Journal of Experimental Psychology*, *69*(10), 1996–2019. doi: 10.1080/17470218.2014.990392

Walther, C., Schweinberger, S. R., Kaiser, D., & Kovacs, G. (2013). Neural correlates of priming and adaptation in familiar face perception. *Cortex*, *49*(7), 1963–1977. doi: 10.1016/j.cortex.2012.08.012

Webster, M. A., Kaping, D., Mizokami, Y., & Duhamel, P. (2004). Adaptation to natural facial categories. *Nature*, *428*, 557–561. doi: 10.1038/nature02420

Yamashita, J. A., Hardy, J. L., De Valois, K. K., & Webster, M. A. (2005). Stimulus selectivity of figural aftereffects for faces. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(3), 420–437.

Young, A. W., Flude, B. M., Hellawell, D. J., & Ellis, A. W. (1994). The nature of semantic priming effects in the recognition of familiar people. *British Journal of Psychology*, *85*(3), 393–411. doi: 10.1111/j.2044-8295.1994.tb02531.x

Zarate, M. A., & Sanders, J. D. (1999). Face categorization, graded priming, and the mediating incfluences of similiarity. *Social Cognition*, *17*(4), 367–389. doi: 10.1521/soco.1999.17.4.367

Zhao, L., & Chubb, C. (2001). The size-tuning of the face-distortion after-effect. *Vision Research*, *41*(23), 2979–2994.

II MANUSCRIPTS

1 List of included manuscripts

First manuscript:

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2020). Face adaptation and face priming as tools for getting insights into the quality of face space. *Frontiers in Psychology*, *11*(166), 1–17. doi: 10.3389/fpsyg.2020.00166

Second manuscript:

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2021). Face adaptation affects on non-configural face information. *Advances in Cognitive Psychology*, *17*(2), 99–106. doi: 10.5709/acp-0325-3

Third manuscript:

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2021). Face adaptation – Investigating nonconfigural saturation alterations. *i-Perception*. 12(6), 1-24. doi: 10.1177/20416695211056362

2 First manuscript: Face adaptation and face priming as tools for getting insights into the quality of face space

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2020). Face adaptation and face priming as tools for getting insights into the quality of face space. *Frontiers in Psychology*, *11*(166), 1–17. doi: 10.3389/fpsyg.2020.00166

Open Access (CC BY 4.0)

frontiers in Psychology

REVIEW
published: 07 February 2020
doi: 10.3389/fpsyg.2020.00166

Face Adaptation and Face Priming as Tools for Getting Insights Into the Quality of Face Space

Ronja Mueller[1,2]*, Sandra Utz[2,3,4], Claus-Christian Carbon[2,3,4] and Tilo Strobach[1]

[1] Medical School Hamburg, Hamburg, Germany, [2] Bamberg Graduate School of Affective and Cognitive Sciences, University of Bamberg, Bamberg, Germany, [3] Department of General Psychology and Methodology, University of Bamberg, Bamberg, Germany, [4] Research Group EPAEG (Ergonomics, Psychological Æsthetics, Gestalt), Bamberg, Germany

During the recognition of faces, the incoming perceptual information is matched against mental representations of familiar faces stored in memory. Face space models describe an abstract concept of face representations and their mental organization, in which facial representations are located on various characteristic dimensions, depending on their specific facial characteristics. However, these models are defined just as incompletely as the general understanding of face recognition. We took two phenomena from face processing to better understand face recognition, and so the nature of face space: face adaptation and face priming. The face literature has mainly focused on face adaptation, largely neglecting face priming when trying to integrate outcomes regarding face recognition into the face space framework. Consequently, the present paper aims to review both phenomena and their contributions to face recognition, representation, and face space.

Keywords: face space, face adaptation, face priming, mental representation, face perception, face processing model

OPEN ACCESS

Edited by:
*Colin W. G. Clifford,
University of New South Wales, Australia*

Reviewed by:
*Jessie J. Peissig,
California State University, Fullerton, United States*
*Nuala Brady,
University College Dublin, Ireland*

***Correspondence:**
*Ronja Mueller
ronja.mueller@medicalschool-hamburg.de*

Specialty section:
This article was submitted to Perception Science, a section of the journal Frontiers in Psychology

Received: *30 September 2019*
Accepted: *22 January 2020*
Published: *07 February 2020*

Citation:
Mueller R, Utz S, Carbon C-C and Strobach T (2020) Face Adaptation and Face Priming as Tools for Getting Insights Into the Quality of Face Space. Front. Psychol. 11:166. doi: 10.3389/fpsyg.2020.00166

INTRODUCTION

It is a common assumption that familiar faces are encoded and recognized by matching the incoming perceptual information against facial representations stored in memory (Bruce and Young, 1986). To discriminate faces from each other, these stored representations must contain a large variety of characteristics, continuously differing from each other along many dimensions (Lee et al., 2000). The 'face space,' according to Valentine (1991), describes an abstract concept, that considers these dimensional relationships among mental representations. Valentine proposes a multidimensional space, in which each facial representation is located, depending on its characteristic value on each dimension. According to this model, face representations that are located close to each other are similar, whereas representations that are further apart, share fewer similarities. The facial information these dimensions contain and on which the representations vary is not further specified. They could be global properties (e.g., age, gender, or ethnicity) or more specific facial parameters, such as the eye–mouth distance or the size of the head (Valentine et al., 2016). How many dimensions are needed to encode all human faces one encounters, is not known exactly. Through computational modeling, Lewis (2004) was able to narrow down the number of dimensions to between 15 and 22 (other authors, however, estimate the number of dimensions to be much higher; see, Meytlis and Sirovich, 2007).

Within the face space framework several models about its specific structure exist. The two most well-known versions of the face space, the norm-based face space and the exemplar model, mainly differ in how the faces are arranged in space and in relation to each other (Valentine, 2001; Lewis, 2004; Valentine et al., 2016). The norm-based model assumes that faces are encoded relative to a specific prototypical face or central-norm face. Thus, a face must be located within the face space in relation to the norm. The deviation from the norm can be seen as a vector, in which the direction and the magnitude represent the distinctiveness and identity of a face (**Figure 1**). Within the exemplar model, however, faces are located in the face space without any reference to a norm or prototype. The distances between the face representations define the level of similarity (faces that are closer to each other are more similar; regarding facial similarity see also Tredoux, 2002). The distribution of the representations provide information about the distinctiveness (very distinct exemplars are located in areas of low representation density; Lewis, 2004; Valentine et al., 2016).

Studies investigating the perception, processing, and storage of faces can provide essential information about the functioning and structure of the face space. Two paradigms that are frequently used in this context are face adaptation and priming. In experimental settings, face adaptation effects are usually assessed by presenting familiar faces that were initially inspected as manipulated versions. In a subsequent test phase, participants are then asked to determine the veridical face out of the original and slightly altered faces. Results typically show a bias of the participants' selection toward the previously inspected, manipulated version. This implies that the original face seems to be perceived as altered in the direction opposite to the adaptor face (Strobach and Carbon, 2013). Unlike basic, low-level adaptation effects on, e.g., color, motion or orientation, face adaptation effects seem to be very robust over time and thus suggest a high-level processing and an adaptation on a representational memory basis (Carbon and Ditye, 2011; Walther et al., 2013).

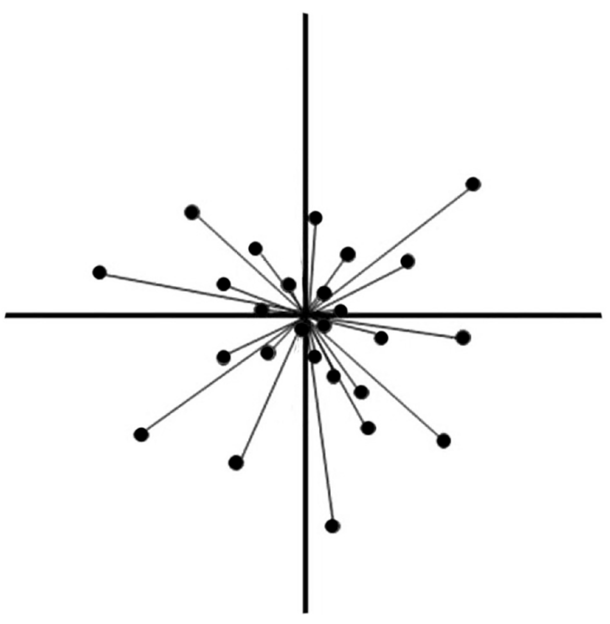

FIGURE 1 | A two-dimensional illustration of the norm-based model of the face space proposed by Valentine (1991). The two dimensions are used for illustrative purpose only. The actual model contains multiple dimensions, on which faces can be distinguished. The points in the illustration represent the mental representations of familiar faces, which are located depending on their expressions on each dimension. The center represents the general face norm. The graph is based on the ideas of Valentine (1991). The permission and figure license has been obtained from the copyright holder [© SAGE Publications].

Priming is another phenomenon often used to demonstrate how recent perceptual experiences can alter the perception and recognition of faces. While adaptation usually leads to a perceptual bias opposite to the adaptor (i.e., original face versions are shifted away from the adaptation faces), priming often results in faster and/or more accurate responses in facial recognition after inspecting the same or similar faces (Ellis et al., 1987; Walther et al., 2013). Different priming paradigms can be distinguished, each addressing different mental concepts. For instance, repetition priming describes a paradigm in which a stimulus is initially presented as a prime and presented again in the subsequent test phase next to alternative stimuli. Repetition priming can facilitate the processing of that initially presented stimulus through activating its specific mental representation. Thus, the presentation of a face can facilitate the subsequent perception and recognition of the same face by activating its mental face representation (Ellis et al., 1993; Schweinberger et al., 1995). Semantic or associative priming characterizes a paradigm in which a stimulus is initially presented and an associated or unrelated stimulus is shown in the subsequent test phase. Associate priming can facilitate the processing of semantically related stimuli through activating a semantic network or an associated concept (Schweinberger et al., 1995; McNamara, 2005). Thus, the presentation of a person's face can facilitate the recognition of an associated person (e.g., Barack and Michelle Obama) by activating a semantic network.

Both phenomena (i.e., face adaptation and priming) seem to differ substantially from each other and even seem to cause opposite effects (priming usually leads to an improvement of recognition and identification, whereas a correct facial identification becomes more difficult through adaptation). Nevertheless, they generally lead to a similar result: in one way or another, they both alter subsequent face recognition by either activating or altering mental representations of faces. Thus, both phenomena could potentially be used to gain insights into the structure and the characteristics of the face space. However, previous studies have so far mainly focused on adaptation when trying to integrate outcomes regarding face perception into the face space framework. Although priming could contribute as well to the understanding of the face space, this phenomenon has been mostly neglected in the face space literature. Consequently, the present paper aims to review both phenomena and their contributions to facial perception, processing and storage and thus also to the face space. To enable a systematic evaluation and categorization of the face adaptation and priming literature, both phenomena will be examined by taking into account two different dimensions: temporal aspects of the paradigms *(timing)* and the transferability of the effects to other face images or identities (*transfer*; Strobach and Carbon, 2013).

TEMPORAL CHARACTERISTICS

The dimension *timing* categorizes adaptation and priming effects according to different temporal information. The first temporal information type *adaptor/prime duration* focuses on the length of the presentation time of the adaptor or prime. It reveals the impact the presentation duration can have on the adaptability or priming ability of faces. The second type of temporal information focuses on the *test duration*, the time span of the presented test stimuli. Similar to the *adaptor/prime duration*, this temporal information type provides insights into how the duration of the presentation of test faces can modulate the size of the adaptation or priming effects. Finally, we focus on the *delay*, the time interval between the adaptation or priming stimuli and the test phase. Here we distinguish between two general test designs: (1) a design in which a test stimulus is presented trial-wise after an adaptation or priming stimulus; and (2) a block-wise design in which there is first an adaptation or priming phase with several trials and then a separate test phase. The temporal information type *delay* provides essential information about the robustness and sustainability of adaptation or priming effects. It also gives us information about the recalibration ability of the visual system (meaning a recalibration back to the previous state of the visual system; Carbon and Ditye, 2011; Strobach and Carbon, 2013). The different temporal characteristics of all studies reported in this chapter, are summarized in **Table 1**.

Adaptor/Prime Duration

Adaptor Duration

Different presentation durations of the adaptor can cause differences in the strength of the adaptation effects. An increase in the presentation duration of the adaptation stimuli, for example, usually results in a stronger adaptation effect. For relatively short time intervals between adaptation and test phases Leopold et al. (2005) and Rhodes et al. (2007) have investigated adaptation effects on identity alterations (features of identities, who were unknown before starting the adaptation phase, were altered by morphing identities or by increasing or decreasing the identity strength through synthetically altering the person's features) and adaptation to (initially unknown) distorted faces, by varying the presentation duration of the adaptation stimulus (1,000, 2,000, 4,000, 8,000, 16,000 ms). They demonstrated stronger effects for longer adaptation durations. In fact, this relation can be expressed by a logarithmic function between adaptation duration and effect size. Thus, the adaptation effect constantly increases with longer presentation durations, but the size of the increase progressively decreases. However, it remains unanswered to what extent the approach to the adaptor can proceed. Hence, it is also an open question whether a complete adaptation (meaning a complete adjustment of the mental representation to the perceived face) could be possible with sufficiently long adaptation duration. For long-term adaptation effects (i.e., a

TABLE 1 | Adaptation/prime duration, delay and test duration in the selected face adaptation and priming studies, reported in this paper.

Phenomenon	Study	Adaptor/prime duration	Delay	Test duration
Adaptation	Carbon and Ditye, 2011	2000, 3000, 4000 ms (+200 ms feedback)	5 min, 24 h, 1 week	Unlimited
	Carbon and Leder, 2006	30 s	80 min	Unlimited
	Carbon et al., 2007	81 s	5 min, 24 h	Unlimited
	Webster and MacLin, 1999	5 min (+8 s top-up)	500 ms	8 s
	Leopold et al., 2001	5,000 ms	150, 300, 600, 1,200, 2,400 ms	200 ms
	Kloth and Schweinberger, 2008	1 min, 24 s (+3.5 s top-up in the first test block)	0–10 min	400 ms
	Leopold et al., 2001	5,000 ms	150, 300, 600, 1,200, 2,400 ms	200 ms
	Leopold et al., 2005	1, 2, 4, 8, 16 s	*nr*	100, 200, 400, 800, 1,600 ms
	Rhodes et al., 2007	1, 2, 4, 8, 16 s	1000 ms	100, 200, 400, 800, 1,600, 3,200 ms
	Rhodes et al., 2003	4,000 ms (+8 s top-up)	500 ms	1,500 ms
	Walther et al., 2013	500 ms	50 ms	300 ms
Priming	Barbot and Kouider, 2012	60, 1,000 ms	0 min	700 ms
	Ellis et al., 1997	5 s	5 min	2.5 s
	Ellis et al., 1993	Unlimited	5 min	Unlimited
	Johnston and Barry, 2006	Unlimited	3–5 min	Unlimited
	Lewis and Ellis, 1999	*nr*	24 h, 7 and 60 days	*nr*
	Maylor, 1998	10 s	4 min, 22 months	10 s
	Rieth and Huber, 2010	17, 50, 150, 400, 2,000 ms	0 min	33, 50, 100 ms
	Walther et al., 2013	500 ms	50 ms	300 ms

Delay = interval between adaptation and test; feedback = additional adaptor presentation following the adaptation trial and a cover task; top-up = additional adaptation stimulus preceding each test trial; nr = not reported.

break between the adaptation and test phase of 5 min and 24 h) Strobach et al. (2011) found a positive correlation between the presentation duration (comparing durations of 1,000, 2,000, and 3,000 ms) of adaptation stimuli with manipulated eye–mouth distances and the adaptation effect.

Prime Duration

For priming, previous studies show rather ambiguous results. Barbot and Kouider (2012), for example, compared a relatively brief duration (60 ms) with a longer duration (1,000 ms) of prime stimulation and found for both durations facilitation in later recognition for initially presented visible face prime stimuli (using familiar faces). However, for stimuli that were invisible to the participants, due to inter-ocular suppression, the authors could demonstrate a facilitated recognition of the primed test stimuli for the short prime duration while the longer prime duration led to a negative priming effect in the test phase, reflecting recognition impairments. Rieth and Huber (2010) systematically investigated priming effects of visible face primes, using face stimuli that were unfamiliar at the beginning of the experiment. By continuously varying the presentation duration of the prime stimuli (17, 50, 150, 400, and 2,000 ms), the authors were able to demonstrate that brief prime durations (up to 50 ms) provoke a facilitation effect while longer prime durations lead to a continuous decrease in performance and again to a negative priming effect (a negative priming effect was reported only for the prime duration of 2,000 ms). Referring to the study of Barbot and Kouider (2012), it might be possible that a negative priming effect would also have been observed for visible familiar face primes if the authors had increased the prime duration.

Study results investigating the priming duration by alternative means, should be taken into account as well. Lewis and Ellis (1999) for example, found a relationship between the number of prime repetitions (using familiar face primes) and the reaction time (to identify a subsequent face), which fits a negative power curve. Thus, the priming effect constantly increases with more prime repetitions (i.e., an increased prime duration), but the size of the increase progressively decreased. Negative priming effects, however, could not be detected in this study. Hence, it can be concluded that prolonged priming in the way of longer presentation durations are qualitatively different from a prolonged priming due to an increase of prime repetitions.

Implications of Adaptation and Prime Duration for the Face Space

Different adaptor and prime durations have very different effects on both phenomena. While a longer presentation duration of the adaptor seems to cause an increasing adaptation effect, a longer presentation duration of a prime leads to a continuous decrease of the effect and can even result in negative priming. In an adaptation process, the representation continuously changes in the direction of the adaptor (Strobach and Carbon, 2013): the longer the presentation duration, the larger the adaptation effect and thus the approximation of the representation to the adaptor. As a result of this approximation, the representation would change its position in face space (along a continuum between the original and the adaptor), in such a way that a greater approximation leads to a larger position shift in face space (Valentine et al., 2016; see **Figure 2** for an illustration).

In contrast to adaptation, a positive priming effect does not lead to a shift of the representation within the face space but to an activation increase of the representation. For the greatest possible priming effect, a prime should be presented briefly. This is probably the most effective way to achieve the greatest possible activation of its representation within the face space and a faster processing of the subsequent face stimulus. Rieth and Huber (2010) assumed that a longer prime presentation duration results in a neural habituation and thus leads to a continuous activation reduction of the representation of the previously inspected stimulus. The authors argued that by inhibiting the representation of the previously seen face, a confusion with subsequent faces will be avoided and hence the identification of them will be facilitated. Thus, an accumulation of activations of different representations within the face space does not seem possible.

Furthermore, the reversal into negative priming could be seen as an activation inhibition of face space representations (by habituation of the corresponding neuronal networks; Rieth and Huber, 2010). However, it is open as to whether this negative priming effect could also be explained by an adaptation mechanism and thus a change of the face representation's position in the face space. The negative priming effect is at least very similar to the effect of a facial adaptation process; both phenomena lead to slower or more difficult recognition of an original face. If one assumes that a mental facial representation never corresponds exactly to what one sees on the presented stimuli (even if the stimuli have not been manipulated), an adaptation process should occur due to the lack of fit between both images (e.g., Clifford et al., 2000; Clifford and Rhodes, 2005). Following this assumption, a longer prime presentation could probably trigger an adaptation process. It therefore remains unclear whether the effect of an extended presentation duration demonstrated by Rieth and Huber (2010) is rather that of a negative priming or that of an adaptation mechanism, or whether both phenomena may be used synonymously in this case.

While longer prime durations lead to a negative priming effect (or adaptation effect) prolonged priming due to an increase of prime repetitions also show a progressive decrease of improvement but no reverse into negative priming (Lewis and Ellis, 1999; Rieth and Huber, 2010). Thus, just like longer prime durations, repeated priming somehow seems to trigger a habituation process as well, leading to a continuous activation reduction of the representation in face space and hence to a decrease in performance. Nevertheless, compared to longer prime durations a high number of repetitions does not lead to negative priming effects. This might be explained by a dishabituation process, caused by interfering sensations (which can be mental or real) in between the prime repetitions. Thus, a previous habituation triggered by a prime could be diminished by the time interval between the prime repetitions, so that further repetitions continue to lead to a positive (although weakened) priming effect. Whether an even higher number of repetitions (even higher than reported by Lewis and Ellis, 1999) could lead to negative priming remains unanswered.

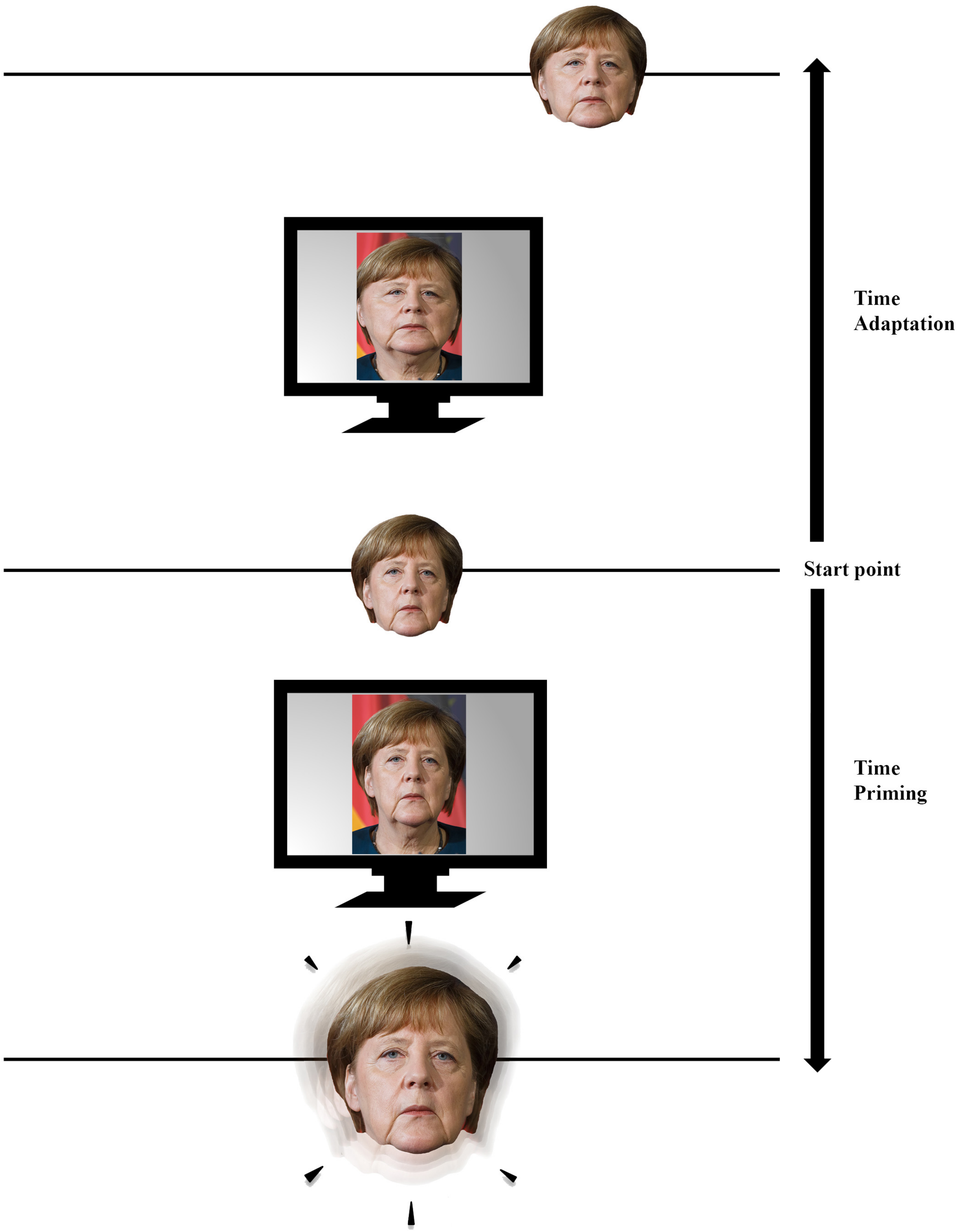

FIGURE 2 | A basic illustration of the processes that occur in face space during adaptation and priming. A picture of German chancellor Angela Merkel is used as an example. Both processes have the same starting point: a mental representation located in face space on a specific face dimension on which a face can vary. During an adaptation process (upwards from center), a strongly manipulated version of the person is then presented on a monitor (in this case a manipulation of the face width was performed). The adaptation to the extreme version subsequently leads to a position shift of the representation toward the adaptor. During a priming process (downwards from center), however, a non-manipulated picture of the person is presented as a prime on a monitor. Although the prime subsequently leads to an activation of the representation within the face space (represented by the "glow" and the enlargement of the image), it does not lead to a position shift. The presented images are used for illustrative purpose only. Permissions and image licenses have been obtained from the copyright holders [Source: © Drop of Light/Shutterstock.com].

Test Duration

Adaptation Test Duration

The presentation duration of a test stimulus can, similar to the adaptor presentation duration, modulate the magnitude of adaptation effects. An increase of the test duration usually leads to a decrease of the adaptation effect. Using familiarized face stimuli (by implementing a discrimination training before starting the adaptation phase), Leopold et al. (2005) and Rhodes et al. (2007) have investigated facial adaptation effects, varying the presentation duration of the test stimulus (i.e., 100, 200, 400, 800, 1,600, and 3,200 ms). The study results indicate an exponential decay of the adaptation effect, so that the adaptation effect constantly decreases is with longer test stimulus presentation duration, but the size of the decrease is progressively reduced.

Priming Test Duration

Presenting face stimuli that were unfamiliar at the beginning of the experiment and by using no time interval between adaptation and test phase, Rieth and Huber (2010) investigated the relationship between test stimulus presentation duration and face priming and were able to demonstrate that longer test durations lead to a decrease of the priming effect (employing test durations of 33, 50, and 100 ms). However, to the best of the authors' knowledge, there is no systematic investigation of this issue using familiar faces or longer test durations than 100 ms (for results in the adaptation area see, Leopold et al., 2005; Rhodes et al., 2007). This under-representation of studies could be caused by the generally preferred test design. Usually a design is chosen where the test duration depends on the onset of the response the participant is executing, which makes a systematic analysis of the relation between test duration and priming effect difficult. Future research should therefore focus on studies that use a design in which test durations are controlled and determined in advance. In addition, investigations should also include familiar face stimuli, to see if the observed pattern by Rieth and Huber (2010; a decrease of the priming effect due to extended test durations) can also be observed for familiar face stimuli.

Implications of Adaptation and Prime Test Duration for the Face Space

It seems that the alteration of the test duration modulates the magnitude of the effects of both phenomena in similar ways. Adaptation studies have shown that an increase in the test duration leads to a decrease in the adaptation effect. In an adaptation process, a longer presentation duration of the test stimulus probably leads to a continuous decrease of the previously generated adaptation effect, due to a readjustment (or re-adaptation) of the representation to the original face (Carbon et al., 2007), since the test stimulus either corresponds to the original face or differs only slightly from the original face (compared to the adaptation stimulus). Referring to the face space this would mean that the adaptation to the adaptor leads to a position shift of the representation within the face space, but a longer test duration reduces this shift by provoking a re-adaptation to the original face and thus a shift of the representation back to the original face space position.

According to Rieth and Huber (2010) not only a prime should be presented briefly, but also the test stimulus, to achieve the greatest possible activation of its representation within the face space and thus the greatest possible priming effect. As mentioned before, a longer prime duration causes a decrease in the priming effect by a decrease of the representation activation due to a neuronal habituation. Because the test stimulus addresses the representation again (regardless of whether it corresponds exactly to the prime stimulus or not), a longer test duration probably has a similar effect as a longer prime duration and leads, as an overstimulation of the representation, to neuronal habituation and thus a decrease in the priming effect as well.

Delay

Delay Within the Adaptation Paradigm

In the early days of face adaptation research, adaptation effects were tested with a time delay of a few seconds or even less between the adaptation and test trials (Webster and MacLin, 1999; Leopold et al., 2001; Rhodes et al., 2003). Such a short delay, however, does not provide much information about the robustness of the effect. Kloth and Schweinberger (2008) conducted one of the first studies to systematically investigate the delay characteristics (using intervals of 1 s up to 539 s) of face adaptation effects with gaze direction information (i.e., the direction the presented identity is looking toward with the eyes while the head is orientated frontally). Although the effects continuously decreased over time, the authors were able to demonstrate those effects on gaze information up to 385 s. Carbon and colleagues extended this research to configural information of the eye–mouth distance and were able to demonstrate (weaker but still significant) adaptation effects even up to a delay of hours and even 1 week (Carbon and Leder, 2006; Carbon et al., 2007; Carbon and Ditye, 2011; Strobach et al., 2011). Thus, face adaptation effects seem to be extremely robust. However, it is still an open issue as to how long exactly an adaptation effect can last and whether these durations vary between different types of facial information (e.g., local information, age, gender, or emotion).

Delay Within the Priming Paradigm

The robustness of priming effects in faces is already represented by an adequate number of studies. Face priming effects could be demonstrated in a trial-wise test design for rather short delays (such as milliseconds, seconds, or minutes) between priming and test trials (see, e.g., Ellis et al., 1993, 1997; Johnston and Barry, 2006; Rieth and Huber, 2010; Barbot and Kouider, 2012; Walther et al., 2013) and also for very long delays (such as days, months, or even years) in a design in which both phases were separated (Maylor, 1998; Lewis and Ellis, 1999). Although the face priming effects also become weaker with increasing delays (e.g., Lewis and Ellis, 1999), these effects appear to be similarly robust as face adaptation effects.

Implications of the Adaptation and Prime Delay for the Face Space

Both phenomena seem to have a similar robustness and a similar decay pattern of the effects. For adaptation effects, the longest delay between adaptation and test phase investigated so far has been 1 week (Carbon and Ditye, 2011, 2012), which suggests an extremely robust effect. Referring to the face space, these results indicate that changes of the representation are 'sticky' and that the shift of representations within the face space is very persistent. However, the continuous decrease of the effect suggests that a readjustment of the representation to the preadaptation status is being performed. Moreover, little is known about the possible reasons for this readjustment to the original representation status before adaptation. It could be that a longer delay between adaptation and test phase provides more opportunities for an exposure (whether mental or real) to the presented identity; because changes of the adaptation stimuli are usually artificial, perceptual experiences outside the experimental setting will mostly contain original faces. This could lead to a re-adaptation process to the original representation in face space, resulting in a continuous reduction of the adaptation effect. Another possible explanation for a re-adaptation could be that to integrate the changes of the adaptation stimuli into the representation permanently, a more frequent and/or longer exposure to the change is necessary (probably in the sense of a threshold that must be overcome). This would indicate that the representations within the face space are extremely stable, so that with adaptation shorter than a potential threshold, a continuous re-adaptation back to the original is performed automatically.

Face priming effects seem to be similar or even more robust than adaptation effects. Studies were still able to demonstrate face priming effects after months or even years (Maylor, 1998; Lewis and Ellis, 1999). Hence, the prime either seems to cause a very stable and long-term activation of the representation located in the face space or it must somehow facilitate a reactivation of it. The latter may appear more likely, since the reactivation of a representation probably consumes fewer cognitive resources and capacities than maintaining an activation over a longer period of time. The continuous decrease of the effect over time is likely to be caused either by a constant decrease of the activation or by a constant decrease of the reactivation capability of the representation located in the face space.

TRANSFERABILITY

The dimension *transfer* categorizes adaptation and priming effects according to their transferability between different versions of the same image or between different face images and identities. Hence, two approaches can be distinguished: (1) an investigation of the transfer across different changes of specific image dimensions (e.g., orientation, position, or size) or (2) a transfer across different images of the same or different identities (Carbon et al., 2007; Strobach and Carbon, 2013). Studies investigating the transferability of adaptation and priming effects will be discussed according to these approaches.

The first approach (transferability between images differing in specific image dimensions) is often used to exclude low-level, retinal effects and to understand the role of the altered face dimensions in the storage of faces. This approach is less informative about the identity-specific transfer but rather focuses on image-specific characteristics and their role within the face representations and thus the face space. The second approach compares the identity specificity of the adaptation or priming effects. Here we have three different categories to systemize and compare the transferability (transfer levels). The first category (*pictorial level*) describes an experimental design where the identical image is presented in the adaptation/priming as well as in the test phase. Effects from this category can be contrasted with effects from the second category (*structural level*) in which the adaptation/priming and test image differ from each other but still show the same identity and the third category (*cross-identity level)*, in which different identities are shown in the adaptation/priming and test phase (see **Figure 3** for an illustration). By comparing the results of these three categories, it can be determined to what extent adaptation or priming effects are image- or identity-specific. Within the *cross-identity* condition, the strength of divergence between the adaptation/priming and test stimuli can be further varied by investigating the adaptation/priming effects to different groups of individuals, such as gender, ethnicity, age groups, or family members.

In general, the transfer dimension provides important information about the nature of face processing. It reflects the plasticity and flexibility of representations stored in memory, it can reveal common coding principles of faces within different levels of visual processing (from sensory, more retinotopic processing, to a high-level and probably face-specific processing) and can therefore offer important information on the organization of the representations in face space (Webster, 2011; Webster and MacLeod, 2011; Strobach and Carbon, 2013). The different transfer characteristics of all studies reported in this chapter, are summarized in **Table 2**.

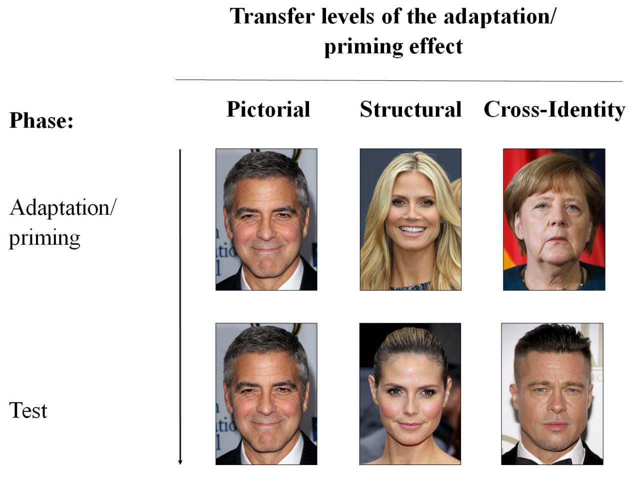

FIGURE 3 | Illustration of the different transfer levels. The presented images are used for illustrative purpose only. Permissions and image licenses have been obtained from the copyright holders [Sources: © Drop of Light/Shutterstock.com, Tinseltown/Shutterstock.com, s_bukley/Shutterstock.com].

TABLE 2 | Adaptation dimension or priming task, image transfer dimension and identity transfer dimensions in the selected face adaptation and priming studies reported in this paper.

Phenomenon	Study	Adaptation dimension/ priming task	Image transfer dimensions	Identity transfer dimensions
Adaptation	Afraz and Cavanagh, 2008	Identity	Position	Cross-identity
	Anderson and Wilson, 2005	Identity	Size, viewpoint	Cross-identity
	Barrett and O'Toole, 2009	Gender	*nr*	Cross-identity
	Carbon and Ditye, 2011	Distortion	Position	Pictorial, structural, cross-identity
	Carbon and Ditye, 2012	Distortion	Position	Pictorial, structural, cross-identity
	Carbon and Leder, 2005	Distortion	*nr*	Pictorial, structural
	Carbon et al., 2007	Distortion	*nr*	Pictorial, structural, cross-identity
	Fox and Barton, 2007	Expression	*nr*	Pictorial, structural, cross-identity
	Fox et al., 2008	Identity	Expression	Inter-identity transfer
	Guo et al., 2009	Contrast	Inversion	Pictorial, cross-identity
	Hole, 2011	Identity	Inversion, viewpoint, stretched image	Cross-identity
	Jaquet and Rhodes, 2008	Distortion	Size	Cross-identity
	Jaquet et al., 2008	Distortion	*nr*	Cross-identity
	Jiang et al., 2006	Identity	Viewpoint, face shape, reflectance	Cross-identity
	Kovács et al., 2007	Gender	Position	Cross-identity
	Lai et al., 2012	Age	*nr*	Structural, cross-identity
	Leopold et al., 2001	Identity	Position; size	Cross-identity
	Otten and Banaji, 2012	Expression	*nr*	Structural, cross-identity
	Rhodes et al., 2003	Distortion	Rotation of 45° or 90°	Cross-identity
	Rhodes et al., 2004	Distortion, gender	Size, inversion	Cross-identity
	Strobach et al., 2011	Distortion	*nr*	Pictorial, structural, cross-identity
	Watson and Clifford, 2003	Distortion	Rotation of 45° or 90°, inversion	Pictorial
	Watson and Clifford, 2006	Gender	Rotation of 45° or 90°, inversion, size	Cross-identity
	Webster et al., 2004	Gender, ethnicity, expression	*nr*	Structural, cross-identity
	Yamashita et al., 2005	Distortion	Size, spatial frequency content, contrast, color	Pictorial, cross-identity
	Zhao and Chubb, 2001	Distortion	Size, inversion	Pictorial
Priming	Boehm et al., 2006	Familiarity decision	Inversion	Pictorial
	Bourne et al., 2009	Familiarity decision	Blurring, configural, position	Pictorial
	Brooks et al., 2002	Identification	Inversion, size, position, mirror reversal	Pictorial, structural transfer
	Bruce et al., 1994	Familiarity decision	Color alterations, cartoons	Pictorial
	Bruce and Valentine, 1985	Identification, familiarity decision	*nr*	Pictorial, structural transfer
	Bruce and Valentine, 1986	Familiarity decision	Blurring	Cross-identity
	Ellis et al., 1990	Occupation, familiarity, expression, and gender decision	*nr*	Pictorial, cross-identity
	Ellis et al., 1987	Identification, familiarity decision	*nr*	Pictorial, structural transfer
	Ellis et al., 1993	Identification, expression identification, gender decision	*nr*	Pictorial, structural, cross-identity
	Ellis et al., 1979	Familiarity decision	Trimming to internal or external features	Pictorial
	Goshen-Gottstein and Ganel, 2000	Gender decision	*nr*	Pictorial, structural transfer
	Johnston and Barry, 2006	Occupation and nationality decision	*nr*	Pictorial, cross-identity
	Kaiser et al., 2013	Gender decision	Size	Pictorial, cross-identity
	Rostamirad et al., 2009	Identification	*nr*	Pictorial, cross-identity
	Walther et al., 2013	Identification	Size	Cross-identity
	Young et al., 1994	Identification, familiarity, and gender decision	*nr*	Cross-identity
	Zarate and Sanders, 1999	Gender and ethnicity decision	*nr*	Pictorial, cross-identity

Adaptation dimension = facial dimension examined within the adaptation paradigm; priming task = identification or classification task within the priming or test phase; image transfer dimension = investigated transferability across specific image dimensions; identity transfer dimensions = investigated transferability according to the three different identity-specific transfer categories; nr = not reported.

Transfer Between Images Differing in Specific Dimensions

Transfer Within the Adaptation Paradigm

Several authors were able to demonstrate adaptation effects regarding the identity or gender of the presented image (features of the identity were altered by morphing the identity with other identities or by increasing or decreasing the identity strength, through synthetically altering the person's features), despite changes in the (retinal) location of the presented test stimulus (Leopold et al., 2001; Kovács et al., 2007; Afraz and Cavanagh, 2008). The authors either used faces that were unfamiliar (Kovács et al., 2007) when starting the adaptation phase or that were learned in an initial training session (Leopold et al., 2001; Afraz and Cavanagh, 2008). The studies by Kovács et al. (2007) and Afraz and Cavanagh (2008) revealed a reduction of the adaptation effects when changing the position of the test image, suggesting that the effects must include both position-variant and position-specific components.

Furthermore, transfer effects across differences of the (retinal) size between the adapting and test image seem to be possible (at least for faces that were unfamiliar at the beginning of the adaptation phase; Leopold et al., 2001; Zhao and Chubb, 2001; Rhodes et al., 2004; Anderson and Wilson, 2005; Yamashita et al., 2005). However, the study results of Zhao and Chubb (2001), Rhodes et al. (2004), and Yamashita et al. (2005) indicate that the adaptive processes are not insensitive to changes in size but also show some kind of size specificity within the adaptation effect (which is indicated by a reduction of the adaptation effect when changing the size). A similar pattern could also be found for a transfer across different orientations in picture plane. Using faces that were unfamiliar when starting the adaptation phase, Rhodes et al. (2003) and Watson and Clifford (2003, 2006) were able to demonstrate adaptation effects regarding the gender or distortions (e.g., vertically or horizontally, expanded or contracted faces) despite a rotation of the adapting stimuli to either 45 or 90° to the right or the left side. Nevertheless, the study results of Watson and Clifford (2003, 2006) indicate a significantly weaker adaptation effect, when the adaptation and test stimuli were rotated in different directions from the upright position compared to when both were rotated identically. These results suggest again that there must be an invariant component and a dimension-specificity within the adaptation effect.

Previous studies applying an even larger rotation of images by 180° (i.e., an inversion) are very ambivalent in their results. Hole (2011), using familiar face stimuli, and Rhodes et al. (2004), presenting faces that were unfamiliar when starting the adaptation phase, were able to induce similar adaptation effects for upright and inverted faces regarding distortions or the identity of the presented personalities. While Hole (2011) inverted just the adaptation image, Rhodes et al. (2004) demonstrated a transfer of the adaptation effect from (1) inverted adaptation to upright test images and (2) from upright adaptation images to inverted test images. Rhodes et al. (2004), however, used a test design in which those opposite conditions were induced simultaneously (e.g., presenting a contracted, upright face simultaneously with a stretched inverted face in the adaptation phase). Other authors, however, detected an asymmetric pattern. By also presenting faces that were unfamiliar at the beginning of the adaptation phase, they either found much weaker (Watson and Clifford, 2003) or no effects (Watson and Clifford, 2006; Guo et al., 2009) when using inverted adaptation and upright test images, but equally strong effects (compared to no inversion at all) when presenting an upright adaptation and an inverted test stimulus.

Further transfer effects were also observed across alterations of the image relations (e.g., stretching the image vertically) and surface reflectance (i.e., albedo; Jiang et al., 2006; Hole, 2011). Moreover, Yamashita et al. (2005) looked at the transferability of adaptation effects to changes in spatial frequency content, contrast, color and size. While they found strong adaptation effects across changes in contrast, color and size, there was only a weak transferability of the effects to changes in contrast polarity and spatial frequency.

In general, the relation of invariant and variant components of the adaptation effect can vary tremendously for the different images or facial dimensions. For adaptation, alterations on dimensions that are known to affect the recognizability of a face (e.g., contrast and spatial frequency) seem to have a greater influence on the magnitude of the adaptation effect compared to alterations that only marginally affect the recognizability of a face (e.g., size or position; Yamashita et al., 2005; Hole, 2011). However, even for dimensions that affect the recognizability, adaptation effects can still be detected, indicating that although a considerable part of these effects appear to be retinotopic, the effects also indicate an involvement of higher, face-specific processing mechanisms (Hole, 2011). The asymmetric pattern regarding the inversion of the adaptation images observed by Watson and Clifford (2003, 2006) and Guo et al. (2009) might have been obtained due to the use of faces that were initially unfamiliar, since Hole (2011) was able to demonstrate adaptation effects inverting the adaptor by using highly familiar faces. However, it is open as to why Rhodes et al. (2004) were able to prove strong adaptation effects applying an inversion of the adaptor, even though they used faces that were initially unfamiliar. It might be the very different test design the authors used (simultaneously induced opposite adaptation effects) that led to these results.

Transfer Within the Priming Paradigm

For priming, Kaiser et al. (2013) and Walther et al. (2013) found effects regarding the recognition of familiar faces, despite differences in the size between the priming and test stimulus. Priming effects could also be generated with a 180-degree rotation (i.e., an inversion) of the prime, using face stimuli with which the participants familiarized themselves in a 1-h training session (Boehm et al., 2006). However, these effects were much weaker compared to the upright prime condition. Similar results could also be observed by Brooks et al. (2002) using familiar face stimuli. They systematically investigated invariances in priming to various metric transformations and found equally strong priming effects when stimuli differed in size, position, and reflectional orientation (mirror reversal). Interestingly, they showed significantly reduced effects when the test stimuli were inverted, pointing to face expert-processing (Schwaninger et al., 2003).

Bruce et al. (1994) were able to demonstrate priming effects from different grayscale images (two levels of gray [black and white] or four levels of gray [black, dark gray, light gray, and white]) on the same colored images (using familiar faces), although these priming effects were much weaker than those that could be detected from one colored image to the next. They also found a similar reduction of priming effects when computer-drawn photographs were presented as the prime and the original photograph as the test stimulus, or vice versa (compared to the condition in which the original images were presented in both phases). By manipulating facial features in the priming phase through blurring, Bourne et al. (2009) were able to show a transfer of identity priming (the task included a popularity rating of the presented famous identities), although here again effects were reduced compared to the unmanipulated condition. Furthermore, identity priming effects seem to be possible even when the test image is trimmed to just the internal features of a familiar (and also initially unfamiliar) face (Ellis et al., 1979).

In general, for priming the pattern seems to be similar to the one seen in the adaptation area: a transfer across manipulations is possible but to some extent the manipulations do affect the magnitude of the priming effect, suggesting invariant and variant components within the priming effect. Whether there is also a similar pattern regarding those dimensions that affect the recognizability of faces more strongly (i.e., dimensions that influence the priming effect more strongly than dimensions that do not have an influence on the recognizability) has not yet been investigated very intensively. The study by Brooks et al. (2002) might suggest a similar pattern to that of adaptation, since an inversion (which is known to impair recognition) generated significantly weaker priming effects than other metric changes (such as size, position, and reflectional orientation).

Implications of the Transfer Between Different Image Versions for the Face Space

Altogether, the listed results on adaptation and priming show that the effects are not entirely retinotopic but that there is a component of face-specific processing. The systematic investigation of these face-specific components provides important information about which factors are generally involved in face representations and thus also which dimensions define the face space. Further research could eventually identify and specify the 15 to 22 dimensions of the face space, determined by Lewis (2004) at some point. The above results on adaptation and priming might indicate that factors that qualitatively change faces (and thus affect face recognition, such as contrast polarity) are more likely to be represented in face space than factors that are of a more quantitative or metric nature and thus do not affect recognition, such as size or position.

However, by applying an inversion of a face (which is known to impair recognition and even might lead to non-expert processing of faces, see Schwaninger et al., 2003), very ambiguous results were obtained. Within the adaptation area, Watson and Clifford (2003, 2006) and Guo et al. (2009) observed reduced adaptation effects, by using face stimuli that were unfamiliar at the beginning of the adaptation phase and by inverting the adaptor. Hole (2011), however, also inverted the adaptor but used familiar faces and found adaptation effects were as equally strong as those in upright face stimuli. Thus, an inversion does not seem to affect the perception and processing of familiar faces as much as the perception and processing of initially unfamiliar faces. The facilitated recognition of familiar faces despite an inversion of the face stimulus might be due to a high flexibility (i.e., for example wide-ranging information about the identity) of the representations stored in memory and face space. The high flexibility could allow the identification of a person (and thus also an adaptation of the representation) despite large alterations of the orientation. Unfamiliar faces, on the other hand, are not yet stored in memory as highly flexible representations, so that large alterations of the orientation can be less easily ignored.

However, applying an inversion within the priming paradigm, weaker effects were also observed using familiar faces (Brooks et al., 2002). This may be explained by the differences between the two paradigms priming and adaptation. Within the priming paradigm the presentation duration of the prime is usually much shorter compared to the presentation duration of the adaptor (see section "Implications of the Transfer Between Different Image Versions for the Face Space"). When applying an inversion, the shorter presentation duration could lead to additional recognition difficulties, since more time might be needed to compensate the inversion of the image and to recognize the presented identity and then activate its representation within the face space. Within the adaptation paradigm, on the other hand, the adaptor is usually presented for longer to achieve the greatest possible effect, so that recognition might be easier despite an inversion of the stimuli.

Transfer on an Identity Level

Transfer Within the Adaptation Paradigm

Most studies investigating the transfer of adaptation effects from one image of a familiar identity to a different image of the same identity (*structural level*) were focused on distortions when manipulating the adaptor (e.g., alterations of the eyes–mouth distance; Carbon and Leder, 2005; Carbon et al., 2007; Carbon and Ditye, 2011, 2012; Strobach et al., 2011). All of them were able to find strong transfer effects even though the transfer on the *structural level* often led to a small decrease of the adaptation effect compared to the adaptation effect on a *pictorial level* (Carbon and Leder, 2005; Carbon and Ditye, 2012). Using face stimuli that were unfamiliar at the beginning of the adaptation phase, Fox and Barton (2007) on the other hand, observed equally robust adaptation effects on the *pictorial* and *structural level*. However, they did not distort the presented stimuli but investigated adaptation effects to different emotional expressions.

The same authors were also able to transfer the demonstrated effects across different identities (*cross-identity level)*, irrespective of the gender of the presented identities (Fox and Barton, 2007). Although these adaptation effects on a *cross-identity level* were significant, they were weaker compared to the effects on the *pictorial* or *structural level*, suggesting that the generated effects are at least partially identity-specific. Fox et al. (2008) reversed this paradigm by investigating adaptation effects on identity alterations and their modulation by congruency of facial expressions (using familiar as well as initially unfamiliar face stimuli). Interestingly, they did not find any impact of expression congruency on the identity effects, which indicates that identity perception is independent of emotional expressions (Fox et al., 2008). However, other authors who also investigated adaptation effects on different emotional expressions found limitations in the transferability of the effects. Using faces that were unfamiliar when starting the adaptation phase, Otten and Banaji (2012) reported a robust transferability of expression effects across images of the same identity and across images of a different identity but significantly weaker effects for images of individuals of a different ethnicity.

For configurally distorted famous faces, several studies were able to demonstrate a robust transfer to other identities, even though the magnitude of the effects decreased compared to the *pictorial* or *structural level* (Carbon et al., 2007; Carbon and Ditye, 2011, 2012; Strobach et al., 2011). However, also for configurally distorted (initially unfamiliar) faces, a limited transferability to other ethnicities could be observed (Jaquet et al., 2008), indicating an ethnic specific component within the effect. Additionally, Jaquet and Rhodes (2008) investigated the transferability of adaptation effects on configural alterations (presenting face stimuli that were initially unfamiliar) across gender and found a partial transfer (i.e., a weaker but still significant effect for the different-gender condition than for the same-gender condition), suggesting both common and gender-specific components within the adaptation effect. A gender adaptation effect (using as well-initially unfamiliar faces), on the other hand, was largely transferable across different identities and thus did not seem to have an identity-specific component (Webster et al., 2004). Moreover, the study also revealed differences in category boundaries selected in the preadaptation assessment (observers categorized images of a gender-morph-continuum to estimate the category boundary of male and female), indicating that observers tended to select a category boundary that was shifted to their own gender. These differences in category boundary were also observed with different ethnicities (Asian and Caucasian), leading to a shift of the observer's boundary toward their own ethnicity. However, this shift was not as intense when observers had already been exposed to the other race for a longer time (e.g., Asians living in the US for at least 1 year). Additionally, other authors have found an impaired identification of the face's gender in other race faces (O'Toole et al., 1996).

A transfer of adaptation effects between other social groups was found by Barrett and O'Toole (2009). They investigated adaptation effects (using face stimuli that were unfamiliar at the beginning of the experiment) on gender and demonstrated a transfer of these effects across different age groups (Barrett and O'Toole, 2009). However, by presenting familiar face stimuli, Lai et al. (2012) investigated adaptation effects on age differences and observed that they were just partly transferable across different identities, suggesting both identity-variant and identity-specific components within the adaptation effect.

Transfer Within the Priming Paradigm

Face priming effects seem to be equally transferable to different images of the same identity (*structural level*) as adaptation effects (Bruce and Valentine, 1985; Ellis et al., 1987, 1993), although the priming effects seem to decrease the more dissimilar the prime and the test images are. Ellis et al. (1987) systematically investigated the transferability of priming (using famous faces) by applying a three-level differentiation regarding the similarity of the presented test stimuli to the prime: identical, similar, and dissimilar (the similarity of the stimuli was rated in advance by an independent jury). The priming effect seemed to be greatest when the prime and the test image were identical, less when they were similar, and least when they were dissimilar (but still representing the same person).

Several studies investigating priming effects on a *cross-identity level* focused on associate priming and thus compared highly associated couples (e.g., Siegfried and Roy) with less associated identities (e.g., Angela Merkel and George Clooney). In these studies, Bruce and Valentine (1986) and Young et al. (1994) observed strong priming effects on famous highly associated identities. While a transfer of the priming effect to a highly associated identity seems to be successful, a transfer to other ethnically related identities apparently does not work. By using face primes that were unfamiliar at the beginning of the experiment, Rostamirad et al. (2009) demonstrated a facilitation effect in recognition when the test face was preceded by the same priming face, an inhibition effect when it was a different face and an even greater inhibition when the face belonged to the same ethnic group as the prime. Zarate and Sanders (1999) also investigated priming effects (using faces that were initially unfamiliar) across different ethnicities and gender. They could not find a relation between the strength of the priming effect and ethnic and gender similarity of the prime and test image, but observed that the magnitude of the priming effect was rather modulated by the general similarity of the stimuli. The authors suggest that the facilitation effect is not generated through the activation of a superordinate abstract concept (e.g., gender or ethnicity), but that the priming effect is rather prime-specific and depends on the inter-item similarity.

In line with these results, Ellis et al. (1990) found that, by systematically investigating the transferability of priming effects (using familiar and initially unfamiliar face stimuli) to different categorization tasks (familiarity, occupation, gender, and expression tasks), priming effects only occur for decisions in the test phase that require an identification of a face and not a classification according to a higher concept. Thus, a priming effect was observed for familiarity and occupation tasks in the test phase but not for gender or expression tasks. On the other hand, any encounter with a face seems to be sufficient to cause priming (meaning that the magnitude of a priming effect does not depend on the task given in the priming phase, but obviously does depend on the task given in the test phase). Nevertheless, the study results of Johnston and Barry (2006) do not seem to fully fit into this picture. As in the study by Ellis et al. (1990), the authors found repetition priming effects for an occupation decision task. However, by using familiar faces, Johnston and Barry (2006) were also able to demonstrate a priming effect for a nationality decision task in the test phase, which, according to the Ellis et al. (1990) argumentation (that only tasks that require an identification of the face show priming effects), should actually not exist. Other authors also disagreed with the argumentation of Ellis and colleagues, since they were able to find priming effects (using face stimuli that were unfamiliar at the beginning of the experiment) for a gender decision task (Goshen-Gottstein and Ganel, 2000). However, Ellis et al. (1990), Goshen-Gottstein and Ganel (2000), and Johnston and Barry (2006) investigated priming effects across different categorization tasks only on a *pictorial level*. They did not consider the transferability of the effects on a *structural* or *cross-identity level*. Hence, in their test design higher concepts (such as gender) could only be addressed by the categorization of the stimuli (in, e.g., female or male). However, since a systematic comparison of the categories on a *cross-identity level* [i.e., comparing the transferability of priming effects of an identity of one category (e.g., female) to either a different identity of the same category or an identity of the opposite category (e.g., male)] was not performed, the results give little assurance as to whether higher concepts were really primed or not.

Implications of Identity Transfer for the Face Space

Both phenomena, adaptation and priming, seem to transfer quite well across different images of the same identity and thus provide further evidence that adaptation as well as priming effects do have an identity-specific component. Furthermore, the results regarding the transferability on a *structural level* suggest a high flexibility of the representations stored in memory and face space, since they seem to be altered and activated despite significant alterations of the images presented in the adaptation and priming paradigms. Thus, they must somehow contain either wide-ranging information about the identity or stable, basic and minimalistic face structures that allow an identification of a person despite large and diverse changes. The basis on which the recognition of a person's face occurs is not clear yet. However, the fact that adaptation effects can be generated through altering very diverse information might indicate that the representations rather contain a wide range of different face information than just a very basic structure.

Regarding transferability on a *cross-identity level*, the reported findings on adaptation provide clear evidence that adaptation effects are transferable to different identities. This suggests a hierarchical processing of faces, where adaptation also affects superordinate face categories, indicating a distinction of different social groups (e.g., different ethnicities, gender, etc.) in facial processing. Referring to the face space, this would mean that adaptation not only alters the representation of the presented identity but also the representation of the social group(s) to which the person belongs. This suggests that either different modules or sub-face spaces must exist (that probably show some overlap between each other) or different prototypes for each social group, which can be altered through adaptation. Thus, adaptation would alter the common underlying face structures and lead to an alteration not just of that identity presented in the adaptation paradigm but also of all other faces located close to the identity or within the same social group. The reported results regarding the category boundary further suggest that there are stronger adaptation effects to the sub-face spaces individuals encounter most and also that these more familiar sub-face spaces are more differentiated.

Furthermore, there seem to be differences in the transferability of adaptation effects depending on the type of adaptation information. Face information that is more transient or more variable (such as facial expression or age) appears to transfer more easily (see the reported results of, Fox and Barton, 2007; Fox et al., 2008; Barrett and O'Toole, 2009; Lai et al., 2012) than information that is invariant (such as configural face information, gender, or ethnicity), suggesting that this information type has a more subordinate role in facial perception and processing and thus also in the face space. However, on a *cross-identity* level (i.e., a transfer to other identities) more variable information also shows slight limitations of the transfer to other identities (Fox and Barton, 2007; Lai et al., 2012), indicating that it cannot be neglected completely when investigating face-specific adaptation effects. Thus, it does have a face-specific component within the adaptation effect and therefore must also be somehow represented in face space. However, the face-specific component of the effect seems to be somehow smaller compared to the level of face specificity within the adaptation effects obtained with more invariant information. This indicates that the representation of more variable information in face space must also be somehow weaker compared to the representation of more invariant information.

For priming, the picture regarding the transferability on a *cross-identity level* seems to be more ambiguous than for adaptation. Many of the reported results indicate transferability to different identities but this transfer rather depends on the similarity of the presented images than on belonging to the same or a different superordinate social group. Thus, referring to the face space, an activation of a representation of an identity might not automatically lead to an activation of a higher-level prototype or a sub-space. The results rather indicate that, within the face space, just those identities that are located very close to the primed identity (due to their similarity on many face dimensions) might also be affected through priming. However, the outcomes regarding the transferability of priming effects to associated individuals suggest that an activation of representations that are more distant to the primed identity within the face space is also possible. Thus, the activation of a representation might automatically lead to an activation of the representation of the associated person, due to the strong associative and exclusive bond between them. Another explanation could be that by activating a representation, a higher concept under which both associated persons are to be classified is activated as well. As a result, not only the representations of the associated persons would be activated, but also representations of possible other persons belonging to this concept. Although this idea would clearly contradict the results of Zarate and Sanders (1999; demonstrating that the priming effects rather depend on the inter-item similarity than on the belonging to the same concept), it would support the results of Goshen-Gottstein and Ganel (2000) and Johnston and Barry (2006), who demonstrated priming effects for nationality and gender tasks. However, the results of these studies should be taken into account with caution, since it is not clear yet whether the implemented categorization tasks can really address higher concepts.

DISCUSSION

Adaptation and priming are two established paradigms in the face literature. Both paradigms and their associated phenomena can assist a better understanding of face recognition and face representation. Regarding the face space framework, up to now the literature has mainly focused on face adaptation while largely neglecting face priming. By reviewing and comparing the literature on face adaptation and face priming within one paper, this work aims to create an overall picture of both phenomena and their contributions to the face space. While face adaptation is a phenomenon that seems to alter a representation, leading to a shift of the representation within the face space, face priming mainly activates such a representation. The reported studies show that these effects can be influenced by modifications of the temporal components of adaptation and priming.

Summary of the Temporal Characteristics of Adaptation and Priming and the Consequences for the Face Space

A longer adaptation duration causes an increasing adaptation effect (Rhodes et al., 2007; Strobach et al., 2011) and therefore a larger position shift of the representation within the face space. A longer prime duration, however, leads to a decrease of the priming effect (Rieth and Huber, 2010) and therefore to an activation reduction of the facial representation within the face space. This activation reduction might be an automatized mechanism to avoid a confusion with other faces presented afterward. However, a longer prime duration can sometimes even cause a negative priming effect (Rieth and Huber, 2010; Barbot and Kouider, 2012). Since negative priming and adaptation seem to be identical regarding their behavioral outcome (they both lead to a slower or more difficult recognition), the negative priming effect could also be that of an adaptation process (evoked due to the lack of fit between the presented facial stimulus and the mental representation). Thus, a longer prime duration might function as an adaptor and might lead to a shift of the facial representation within the face space toward the prime.

Compared to the adaptation duration, a longer presentation of the adaptation test stimulus does not cause a greater adaptation effect but rather decreases it Leopold et al. (2005) and Rhodes et al. (2007), since it leads to a re-adaptation process and thus to a shift of the facial representation within the face space back to the original position. A longer presentation of the prime test stimulus also causes a decrease of the priming effect (Rieth and Huber, 2010), probably because the test stimulus addresses, just like the prime, the mental face space representation and thus leads, as an overstimulation of the representation, to a neuronal habituation and activation reduction.

The effects of both phenomena, however, can be equally robust, since they can last up to a week or (at least priming effects) up to several months (Maylor, 1998; Lewis and Ellis, 1999; Carbon and Ditye, 2011, 2012). Thus, an adaptation can probably lead to a very persistent shift of the mental representation within the face space, whereas priming causes a long-lasting activation or a facilitated reactivation of the facial representation. However, the effects of both phenomena decrease, the more time elapses between the adaptation/priming and the test phase. Within the context of adaptation, a possible explanation for the continuous decrease of the effect might be an increased possibility of exposure to the presented identity (which possibly causes a re-adaptation back to the original representation and thus decreases the effect), during a long delay. Another possible explanation could be that the re-adaptation process is an automatic process due to the robustness of the original facial representation (which presumably is built up over a longer period of time) and which does not integrate transient alterations permanently unless they are presented for longer and/or more frequently. The continuous decrease of priming effects over time, however, might be caused by either a constant decrease of the activation of the representation or a decrease of the reactivation capability of the representation located in face space. Since a longer priming duration seems to lead to an activation reduction to inhibit a confusion with other faces seen subsequently, a long-term maintenance of activation does not seem plausible (also for shorter priming durations). A facilitated reactivation, however, would probably not inhibit the recognition of subsequent faces (since it would only lead to a full reactivation of the representation, if the identity is presented again) and thus might be more likely.

Summary of the Transfer Characteristics of Adaptation and Priming and the Consequences for the Face Space

Not only the temporal components of adaptation and priming give us information about the facial perception, the storage and thus the face space, but also the transferability of adaptation and priming effects contribute to the understanding of it. The listed study results reveal that a transfer of adaptation and priming effects across alterations of specific image dimensions is possible, but to some extent the alterations do affect the magnitude of the effects (meaning that the effects usually decrease when they are transferred; see, e.g., Bruce et al., 1994; Brooks et al., 2002; Yamashita et al., 2005; Kovács et al., 2007). This indicates that although a considerable part of the effects seems to be retinotopic, there does exist some kind of face-specific component too. Nevertheless, the results also show that dimensions that qualitatively change faces and thus affect their recognition (e.g., contrast polarity or spatial frequency) have a greater impact on the adaptation and priming effects than dimensions that are of a more quantitative or metric nature (e.g., size or position) and do not affect the recognition as much (see, e.g., Brooks et al., 2002; Yamashita et al., 2005). Thus, the dimensions that have a greater impact show a greater face specificity and are therefore more likely to be represented in face space than dimensions that do not affect the adaptation and priming effects as much.

Adaptation and priming effects can be observed not only despite changes in specific image dimensions, but also despite a presentation of a completely different image of the identity in the test phase (Bruce and Valentine, 1985; Ellis et al., 1987; Carbon and Leder, 2005; Carbon et al., 2007). Thus, the representations within the face space must somehow be very flexible. They must either contain wide-ranging information about the identity or stable but minimalistic face structures that allow an identification of an identity despite large and diverse changes. Since adaptation effects can be evoked by altering very diverse face information, the latter might be more likely.

Adaptation and priming effects regarding the transferability on a *cross-identity level* reveal that both kinds of effects are (at least partly) transferable to different identities (Bruce and Valentine, 1986; Carbon et al., 2007; Strobach et al., 2011). The reported findings on adaptation indicate a hierarchical processing of faces, where adaptation not only alters the representation of the presented identity but also affects superordinate concepts (see, e.g., Jaquet and Rhodes, 2008; Jaquet et al., 2008). This suggests that there must exist different sub-face spaces or different prototypes for each superordinate concept within the face space. Thus, by altering the representation of a specific identity, underlying face structures of superordinate concepts would be altered toward the adaptor too. The findings further suggest that there are stronger adaptation effects for the sub-face spaces individuals encounter most and that these sub-face spaces are more differentiated than more unfamiliar ones (O'Toole et al., 1996; Webster et al., 2004). The listed results on priming, on the other hand, are ambiguous. Some studies indicate that the transferability of priming effects to other identities rather depends on the similarity of the presented images than on the belonging to (and thus activation of) a common sub-face space (Zarate and Sanders, 1999). Other study results, however, suggest, that priming is able to activate representations of identities that are strongly associated with the primed identity (e.g., Young et al., 1994). However, it is not clear yet whether this activation of other representations occurs due to an activation of a higher sub-face space under which the associated persons are to be classified or due to an associative and exclusive bond between these identities.

Future Adaptation and Priming Studies and the Face Space

The two phenomena adaptation and priming demonstrate that perceived faces can change our facial perception and storage and hence our face space significantly. Adaptation and priming studies manipulating the temporal factors help identify the best temporal structure of both paradigms (in the way of generating the greatest possible effects; e.g., for adaptation a long adaptor and a short test stimulus, for priming both: a short prime and a short test stimulus). A systematic manipulation of temporal parameters may also provide information about the underlying mechanisms of the two phenomena. It seems that the presentation of a stimulus could initially lead to a priming effect. However, prolonging the presentation of the stimulus might possibly induce an adaptation effect (see the results on negative priming). Thus, it could be assumed, that it depends on the presentation duration of the adaptor/prime, which phenomenon occurs.

However, the study by Walther et al. (2013) indicates that the ambiguity of the test stimulus should rather be considered as the decisive factor. The authors were able to demonstrate both phenomena within one paradigm. While adaptation effects were induced by presenting very ambiguous test stimuli, unambiguous test stimuli provoked priming effects. Thus, it still seems unclear which specific parameters (e.g., temporal parameters or the ambiguity of the test stimuli) are crucial for the occurrence of one or the other phenomenon. Future studies should therefore focus more on the investigation of specific parameters using combined (adaption and priming) paradigms to better understand and distinguish both phenomena.

Furthermore, studies on temporal characteristics provide important information about the robustness of the adaptation and priming effects and the hereby-created long-term transformation of the face space (i.e., persistent shifts of representations and sub-face spaces, a permanent facilitation of activation as well as the pattern of decay of those alterations). However, it is still unclear which mechanisms are causing the continuous decrease of the effects over time, at least for adaptation. Future studies should therefore specifically investigate the two possible mechanisms responsible for the re-adaptation (i.e., increased exposure to the original image of the presented identity or automatic re-adaptation process due to the robustness of the original facial representation).

The investigations on the image dimensions of adaptation and priming stimuli reveal that some face information is more important and thus probably more likely represented in the face space than other facial characteristics (e.g., invariant information, such as gender, ethnicity, etc. is more likely included in face space than variant information, such as size or location). However, due to a lack of systematic studies on this topic, the dimensions on which all faces vary within the face space [according to Lewis (2004) there should be from 15 up to 22 dimensions] could not yet be determined. Nevertheless, the view that only an exclusive number of dimensions exist in face space and thus facial information other than those dimensions is not considered in facial perception, should be questioned. The reported studies show that facial information that seems to be less important for facial perception (since it has a weaker impact on adaptation and priming effects) still affects the perception of faces and thus also the face space. Perhaps this categorical view of the face space dimensions should be reconsidered and it should be further investigated whether the very diverse facial information is just represented with a different weighting within the face space. Future research should therefore systematically compare adaptation and priming effects on variant and invariant facial information.

The reported studies investigating the transferability of effects further show that the facial representations located in face space are very flexible (i.e., a recognition is possible despite large alterations of the presented face) and that there must be some kind of sub-face spaces representing higher concepts. While adaptation clearly has an effect on these sub-face spaces, no final conclusion can be drawn yet as to whether priming also activates higher concepts. Thus, future studies should focus on a systematic investigation of priming effects on different superordinate concepts to further clarify this topic.

Finally, it can be stated that priming probably can add as much to the understanding of face space as adaptation. It would therefore be recommendable to consider priming more closely in this still challenging field of face research in the future.

RÉSUMÉ

Face adaptation and priming are two phenomena that seem to differ tremendously. While adaptation leads to a shift of representations within the face space, priming rather activates these representations without shifting them (see **Figure 2**). However, both paradigms alter subsequent face recognition and thus, can be used to gain a better understanding of face recognition, representation and hence the face space. By analyzing the characteristics of the two different effects, both phenomena can give us detailed information about the content, the structure and the flexibility of the face space. The adaptability or priming of specific face information, for example, provide insight into what facial dimensions are stored in face space. The comparison of different facial information may also reveal a different weighting of the information stored in face space (e.g., invariant information seems to be more relevant than variant information). The transferability of effects can reveal information about the structure of the face space (e.g., division into sub-face spaces). The robustness and decay of effects, however, give insight into how flexible or stable representations are within the face space. Furthermore, the specific temporal characteristics of the two paradigms (e.g., adaptor/prime duration) might reveal information about the underlying mechanism of both phenomena. Thus the presentation of a stimulus may initially lead to a priming effect (i.e., a pure activation of the representation). However, if the stimulus is presented for a longer time, an adaptation effect might be induced. The systematic evaluation of the adaptation and priming literature presented here, highlights the valuableness of both paradigms for the investigation of face recognition and representation. It also reveals that priming (although often neglected by face-space literature) is an equally useful tool as adaptation to explore the face space.

AUTHOR CONTRIBUTIONS

C-CC and TS conceived of the conceptual idea. RM wrote the manuscript with input from all coauthors (C-CC, SU, and TS). TS supervised the process of writing. All authors provided critical feedback and helped in shaping the manuscript.

FUNDING

This research was supported by a grant to C-CC and TS from the Deutsche Forschungsgemeinschaft (DFG, CA 917/7-1; STR 1223/4-1).

REFERENCES

Afraz, S. R., and Cavanagh, P. (2008). Retinotopy of the face aftereffect. *Vision Res.* 48, 42–54. doi: 10.1016/j.visres.2007.10.028

Anderson, N. D., and Wilson, H. R. (2005). The nature of synthetic face adaptation. *Vision Res.* 45, 1815–1828. doi: 10.1016/j.visres.2005.01.012

Barbot, A., and Kouider, S. (2012). Longer is not better: nonconscious overstimulation reverses priming influences under interocular suppression. *Atten. Percept. Psychophys.* 74, 174–184. doi: 10.3758/s13414-011-0226-3

Barrett, S. E., and O'Toole, A. J. (2009). Face adaptation to gender: does adaptation transfer across age categories? *Vis. Cogn.* 17, 700–715. doi: 10.1080/13506280802332197

Boehm, S. G., Klostermann, E. C., Sommer, W., and Paller, K. A. (2006). Dissociating perceptual and representation-based contributions to priming of face recognition. *Conscious. Cogn.* 15, 163–174. doi: 10.1016/j.concog.2005.06.001

Bourne, V. J., Vladeanu, M., and Hole, G. J. (2009). Lateralised repetition priming for featurally and configurally manipulated familiar faces: evidence for differentially lateralised processing mechanisms. *Laterality* 14, 287–299. doi: 10.1080/13576500802383709

Brooks, B. E., Rosielle, L. J., and Cooper, E. E. (2002). The priming of face recognition after metric transformations. *Perception* 31, 297–313. doi: 10.1068/p3283

Bruce, V., Burton, A. M., Carson, D., Hanna, E., and Mason, O. (1994). "Repetition priming of face recognition," in *Attention and Performance XV: Conscious and Nonconscious Information Processing*, eds C. Umiltà, and M. Moscovitch (London: The MIT Press), 179–202.

Bruce, V., and Valentine, T. (1985). Identity priming in the recognition of familiar faces. *Br. J. Psychol.* 76, 373–383. doi: 10.1111/j.2044-8295.1985.tb01960.x

Bruce, V., and Valentine, T. (1986). Semantic priming of familiar faces. *Q. J. Exp. Psychol. A* 38, 125–150. doi: 10.1080/14640748608401588

Bruce, V., and Young, A. (1986). Understanding face recognition. *Br. J. Psychol.* 77, 305–327. doi: 10.1111/j.2044-8295.1986.tb02199.x

Carbon, C.-C., and Ditye, T. (2011). Sustained effects of adaptation on the perception of familiar faces. *J. Exp. Psychol. Hum. Percept. Perform.* 37, 615–625. doi: 10.1037/a0019949

Carbon, C.-C., and Ditye, T. (2012). Face adaptation effects show strong and long-lasting transfer from lab to more ecological contexts. *Front. Psychol.* 3:3. doi: 10.3389/fpsyg.2012.00003

Carbon, C.-C., and Leder, H. (2005). Face adaptation: changing stable representations of familiar faces within minutes? *Adv. Cogn. Psychol.* 1, 1–7. doi: 10.2478/v10053-008-0038-8

Carbon, C.-C., and Leder, H. (2006). The Mona Lisa effect: is 'our' Lisa fame or fake? *Perception* 35, 411–414. doi: 10.1068/p5452

Carbon, C.-C., Strobach, T., Langton, S. R. H., Harsányi, G., Leder, H., and Kovács, G. (2007). Adaptation effects of highly familiar faces: immediate and long lasting. *Mem. Cognit.* 35, 1966–1976. doi: 10.3758/bf03192929

Clifford, C. W. G., and Rhodes, G. (2005). *Fitting the Mind to the World: Adaptation and Aftereffects in High Level Vision*. Oxford: Oxford University Press.

Clifford, C. W. G., Wenderoth, P., and Spehar, B. (2000). A functional angle on some aftereffects in cortical vision. *Proc. R. Soc. Lond. B Biol. Sci.* 267, 1705–1710. doi: 10.1098/rspb.2000.1198

Ellis, A. W., Burton, A. M., Young, A., and Flude, B. M. (1997). Repetition priming between parts and wholes: tests of a computational model of familiar face recognition. *Br. J. Psychol.* 88, 579–608. doi: 10.1111/j.2044-8295.1997.tb02659.x

Ellis, A. W., Young, A. W., and Flude, B. M. (1990). Repetition priming and face processing: priming occurs within the system that responds to the identity of a face. *Q. J. Exp. Psychol. A* 42, 495–512. doi: 10.1080/14640749008401234

Ellis, A. W., Young, A. W., Flude, B. M., and Hay, D. C. (1987). Repetition priming of face recognition. *Q. J. Exp. Psychol. A* 39, 193–210. doi: 10.1080/14640748708401784

Ellis, H. D., Ellis, D. M., and Hosie, J. A. (1993). Priming effects in children's face recognition. *Br. J. Psychol.* 84, 101–110. doi: 10.1111/j.2044-8295.1993.tb02465.x

Ellis, H. D., Shepherd, J. W., and Davies, G. M. (1979). Identification of familiar and unfamiliar faces from internal and external features: some implications for theories of face recognition. *Perception* 8, 431–439. doi: 10.1068/p080431

Fox, C. J., and Barton, J. J. S. (2007). What is adapted in face adaptation? The neural representations of expression in the human visual system. *Brain Res.* 1127, 80–89. doi: 10.1016/j.brainres.2006.09.104

Fox, C. J., Oruc, I., and Barton, J. J. (2008). It doesn't matter how you feel. The facial identity aftereffect is invariant to changes in facial expression. *J. Vis.* 8, 11.1–11.13. doi: 10.1167/8.3.11

Goshen-Gottstein, Y., and Ganel, T. (2000). Repetition priming for familiar and unfamiliar faces in a sex-judgment task: evidence for a common route for the processing of sex and identity. *J. Exp. Psychol. Learn. Mem. Cogn.* 26, 1198–1214. doi: 10.1037/0278-7393.26.5.1198

Guo, X. M., Oruç, Ý, and Barton, J. J. S. (2009). Cross-orientation transfer of adaptation for facial identity is asymmetric: a study using contrast-based recognition thresholds. *Vision Res.* 49, 2254–2260. doi: 10.1016/j.visres.2009.06.012

Hole, G. (2011). Identity-specific face adaptation effects: evidence for abstractive face representations. *Cognition* 119, 216–228. doi: 10.1016/j.cognition.2011.01.011

Jaquet, E., and Rhodes, G. (2008). Face aftereffects indicate dissociable, but not distinct, coding of male and female faces. *J. Exp. Psychol. Hum. Percept. Perform.* 34, 101–112. doi: 10.1037/0096-1523.34.1.101

Jaquet, E., Rhodes, G., and Hayward, W. G. (2008). Race-contingent aftereffects suggest distinct perceptual norms for different race faces. *Vis. Cogn.* 16, 734–753. doi: 10.1080/13506280701350647

Jiang, F., Blanz, V., and O'Toole, A. J. (2006). Probing the visual representation of faces with adaptation: a view from the other side of the mean. *Psychol. Sci.* 17, 493–500. doi: 10.1111/j.1467-9280.2006.01734.x

Johnston, R. A., and Barry, C. (2006). Repetition priming of access to biographical information from faces. *Q. J. Exp. Psychol.* 59, 326–339. doi: 10.1080/02724980443000791

Kaiser, D., Walther, C., Schweinberger, S. R., and Kovacs, G. (2013). Dissociating the neural bases of repetition-priming and adaptation in the human brain for faces. *J. Neurophysiol.* 110, 2727–2738. doi: 10.1152/jn.00277.2013

Kloth, N., and Schweinberger, S. R. (2008). The temporal decay of eye gaze adaptation effects. *J. Vis.* 8, 1–11. doi: 10.1167/8.11.4

Kovács, G., Zimmer, M., Harza, I., and Vidnyánszky, Z. (2007). Adaptation duration affects the spatial selectivity of facial aftereffects. *Vision Res.* 47, 3141–3149. doi: 10.1016/j.visres.2007.08.019

Lai, M., Oruc, I., and Barton, J. J. (2012). Facial age after-effects show partial identity invariance and transfer from hands to faces. *Cortex* 48, 477–486. doi: 10.1016/j.cortex.2010.11.014

Lee, K., Byatt, G., and Rhodes, G. (2000). Caricature effects, distinctiveness, and identification: testing the face-space framework. *Psychol. Sci.* 11, 379–385. doi: 10.1111/1467-9280.00274

Leopold, D. A., O'Toole, A. J., Vetter, T., and Blanz, V. (2001). Prototype-referenced shape encoding revealed by high-level aftereffects. *Nat. Neurosci.* 4, 89–94. doi: 10.1038/82947

Leopold, D. A., Rhodes, G., Müller, K. M., and Jeffery, L. (2005). The dynamics of visual adaptation to faces. *Proc. R. Soc. Lond. B Bio. Sci.* 272, 897–904. doi: 10.1098/rspb.2004.3022

Lewis, M. (2004). Face−space−R: towards a unified account of face recognition. *Vis. Cogn.* 11, 29–69. doi: 10.1080/13506280344000194

Lewis, M. B., and Ellis, H. D. (1999). Repeated repetition priming in face recognition. *Q. J. Exp. Psychol. A* 52, 927–955. doi: 10.1080/027249899390873

Maylor, E. A. (1998). Retrivieng names in old age: short- and (very) long-term effects of repetition. *Mem. Cognit.* 26, 309–319. doi: 10.3758/BF03201142

McNamara, T. P. (2005). *Semantic Priming: Perspectives from Memory and Word Recognition*. New York: Psychology Press.

Meytlis, M., and Sirovich, L. (2007). On the dimensionality of face space. *IEEE Trans. Pattern Anal. Mach. Intell.* 29, 1262–1267. doi: 10.1109/TPAMI.2007.1033

O'Toole, A. J., Peterson, J., and Deffenbacher, K. A. (1996). An 'other-race effect' for categorizing faces by sex. *Perception* 25, 669–676. doi: 10.1068/p250669

Otten, M., and Banaji, M. R. (2012). Social categories shape the neural representation of emotion: evidence from a visual face adaptation task. *Front. Integr. Neurosci.* 6:9. doi: 10.3389/fnint.2012.00009

Rhodes, G., Jeffery, L., Clifford, C. W. G., and Leopold, D. A. (2007). The timecourse of higher-level face aftereffects. *Vision Res.* 47, 2291–2296. doi: 10.1016/j.visres.2007.05.012

Rhodes, G., Jeffery, L., Watson, T. L., Clifford, C. W. G., and Nakayama, K. (2003). Fitting the mind to the world: face adaptation and attractiveness aftereffects. *Psychol. Sci.* 14, 558–566. doi: 10.1046/j.0956-7976.2003.psci_1465.x

Rhodes, G., Jeffery, L., Watson, T. L., Jaquet, E., Winkler, C., and Clifford, C. W. (2004). Orientation-contingent face aftereffects and implications for face-coding mechanisms. *Curr. Biol.* 14, 2119–2123. doi: 10.1016/j.cub.2004.11.053

Rieth, C. A., and Huber, D. E. (2010). Priming and habituation for faces: individual differences and inversion effects. *J. Exp. Psychol. Hum. Percept. Perform.* 36, 596–618. doi: 10.1037/a0018737

Rostamirad, S., Barton, J. J. S., and Oruc, I. (2009). Center-surround organization of face-space: evidence from contrast-based face-priming. *Neuroreport* 20, 1177–1182. doi: 10.1097/WNR.0b013e32832f078d

Schwaninger, A., Carbon, C. C., and Leder, H. (2003). "Expert face processing: specialization and constraints," in *The Development of Face Processing*, eds G. Schwarzer, and H. Leder (Göttingen: Hogrefe & Huber), 81–97.

Schweinberger, S. R., Pfütze, E.-M., and Sommer, W. (1995). Repetition priming and associative priming of face recognition: evidence from event-related potentials. *J. Exp. Psychol. Learn. Mem. Cogn.* 21, 722–736. doi: 10.1037//0278-7393.21.3.722

Strobach, T., and Carbon, C. C. (2013). Face adaptation effects: reviewing the impact of adapting information, time, and transfer. *Front. Psychol.* 4:318. doi: 10.3389/fpsyg.2013.00318

Strobach, T., Ditye, T., and Carbon, C.-C. (2011). Long-term adaptation effects of highly familiar faces are modulated by adaptation duration. *Perception* 40, 1000–1004. doi: 10.1068/p6986

Tredoux, C. (2002). A direct measure of facial similarity and its relation to human similarity perceptions. *J. Exp. Psychol. Appl.* 8, 180–193. doi: 10.1037/1076-898x.8.3.180

Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *Q. J. Exp. Psychol. A* 43, 161–204. doi: 10.1080/14640749108400966

Valentine, T. (2001). "Face-space models of face recognition," in *Computational, Geometric, and Process Perspectives on Facial Cognition: Contexts and Challenges*, eds M. J. Wenger, and J. T. Townsend (Mahwah, NJ: Lawrence Erlbaum Associates), 83–113.

Valentine, T., Lewis, M. B., and Hills, P. J. (2016). Face-space: a unifying concept in face recognition research. *Q. J. Exp. Psychol.* 69, 1996–2019. doi: 10.1080/17470218.2014.990392

Walther, C., Schweinberger, S. R., Kaiser, D., and Kovacs, G. (2013). Neural correlates of priming and adaptation in familiar face perception. *Cortex* 49, 1963–1977. doi: 10.1016/j.cortex.2012.08.012

Watson, T. L., and Clifford, C. W. (2003). Pulling faces: an investigation of the face-distortion aftereffect. *Perception* 32, 1109–1116. doi: 10.1068/p5082

Watson, T. L., and Clifford, C. W. (2006). Orientation dependence of the orientation-contingent face aftereffect. *Vision Res.* 46, 3422–3429. doi: 10.1016/j.visres.2006.03.026

Webster, M. A. (2011). Adaptation and visual coding. *J. Vis.* 11, 3. doi: 10.1167/11.5.3

Webster, M. A., Kaping, D., Mizokami, Y., and Duhamel, P. (2004). Adaptation to natural facial categories. *Nature* 428, 557–561. doi: 10.1038/nature02420

Webster, M. A., and MacLeod, D. I. (2011). Visual adaptation and face perception. *Philos. Trans. R. Soc. Lond. Series B Biol. Sci.* 366, 1702–1725. doi: 10.1098/rstb.2010.0360

Webster, M. A., and MacLin, O. H. (1999). Figural aftereffects in the perception of faces. *Psychon. Bull. Rev.* 6, 647–653. doi: 10.3758/BF03212974

Yamashita, J. A., Hardy, J. L., De Valois, K. K., and Webster, M. A. (2005). Stimulus selectivity of figural aftereffects for faces. *J. Exp. Psychol. Hum. Percept. Perform.* 31, 420–437. doi: 10.1037/0096-1523.31.3.420

Young, A. W., Flude, B. M., Hellawell, D. J., and Ellis, A. W. (1994). The nature of semantic priming effects in the recognition of familiar people. *Br. J. Psychol.* 85, 393–411. doi: 10.1111/j.2044-8295.1994.tb02531.x

Zarate, M. A., and Sanders, J. D. (1999). Face categorization, graded priming, and the mediating incfluences of similiarity. *Soc. Cogn.* 17, 367–389. doi: 10.1521/soco.1999.17.4.367

Zhao, L., and Chubb, C. (2001). The size-tuning of the face-distortion after-effect. *Vision Res.* 41, 2979–2994. doi: 10.1016/S0042-6989(01)00202-4

Conflict of Interest: 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.

Copyright © 2020 Mueller, Utz, Carbon and Strobach. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

3 Second manuscript: Face adaptation effects on non-configural face information

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2021). Face adaptation affects on non-configural face information. *Advances in Cognitive Psychology*, *17*(2), 99–106. doi: 10.5709/acp-0325-3

CC BY-NC-ND, © 2022 Advances in Cognitive Psychology (ACP)

Face Adaptation Effects on Non-Configural Face Information

Ronja Mueller[1, 2], *Sandra Utz*[3, 4, 2], *Claus-Christian Carbon*[3, 4, 2], *and Tilo Strobach*[1]

[1] Medical School Hamburg, Hamburg, Germany

[2] Bamberg Graduate School of Affective and Cognitive Sciences (BaGrACS), University of Bamberg, Bamberg, Germany

[3] Department of General Psychology and Methodology, University of Bamberg, Bamberg, Germany

[4] Research Group EPÆG (Ergonomics, Psychological Æsthetics, Gestalt), Bamberg, Germany

ABSTRACT

Inspecting new visual information in a face can affect the perception of subsequently seen faces. In experimental settings for example, previously seen manipulated versions of a face can lead to a clear bias of the participant's perception of subsequent images: Original images are then perceived as manipulated in the opposite direction of the adaptor while images that are more similar to the adaptor are perceived as normal or natural. These so-called face adaptation effects can be a useful tool to provide information about which facial information is processed and stored in facial memory. Most experiments so far used variants of the second-order relationship configural information (e.g., spatial relations between facial features) when investigating these effects. However, non-configural face information (e.g., color) was mainly neglected when focusing on face adaptation, although this type of information plays an important role in face processing. Therefore, we investigated adaptation effects of non-configural face information by employing brightness alterations. Our results provide clear evidence for brightness adaptation effects (Experiment 1). These effects are face-specific to some extent (Experiments 2 and 3) and robust over time (Experiments 4 and 5). They support the assumption that non-configural face information is not only relevant in face perception but also in face retention. Brightness information seems to be stored in memory and thus is even involved in face recognition.

KEYWORDS

face adaptation
face perception
face memory
non-configural face information

INTRODUCTION

Despite ongoing changes in our surrounding world, we perceive the environment as rather stable. This impression arises as our cognitive apparatus continuously adjusts to the changing and dynamic attributes of the environment—a process commonly known as *figural aftereffect* or *adaptation effect* (Carbon & Ditye, 2011). Although adaptation occurs largely automatically and usually remains unnoticed, it works effectively in ensuring reliable object recognition. This recognition process is ensured by continuously integrating the adaptation information into the mental object representation stored in memory. However, this integration mechanism also leads to a strong bias in the perception of subsequently inspected stimuli. For example, adapting to a vertical ellipse would cause a circle to appear as slightly elliptical along its horizontal axis (Clifford, 2002; Köhler & Wallach, 1944; Suzuki, 2005). Moreover, after inspecting a tilted line, a vertical line would be perceived as slightly tilted in the opposite direction (Gibson, 1933). Thus, the integration of new visual information into the mental representation can lead to a contrastive effect: Subsequent stimuli may be perceived as manipulated in the direction opposite to the adaptor.

Over time, adaptation studies have increasingly focused on more complex objects than simple geometric forms. Many studies investigated adaptation effects on human faces. Human faces are a particularly interesting class of visual information due to their dynamic

Corresponding author: Ronja Mueller, Medical School Hamburg, Department of Psychology, Am Kaiserkai 1, 20457 Hamburg, Germany.
Email: ronja.mueller@medicalschool-hamburg.de

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

changes that are based on factors like ageing and different viewing and context conditions. As faces are important for recognizing people and mastering social situations, they seem to be particularly susceptible to adaptation effects that help to update the mental representation. Webster and MacLin (1999) were the first to systematically show visual adaptation effects to alterations in human faces. The authors presented strongly distorted faces in an initial adaptation phase and subsequently observed a strong bias in face perception that was reflected in perceiving the original (i.e., not manipulated) image as being distorted reversely (i.e., in the opposite direction of the adaptor). Since this seminal research, a great number of studies on face adaptation has been performed and various face adaptation effects have been identified. Studies investigating different operational parameters such as the delay between adaptation and test phase revealed that face adaptation effects are highly robust and even transferable to other faces (Carbon & Ditye, 2011; Carbon et al., 2007). These results indicate that face adaptation effects seem to be better explained by changes on a representational memory level than by changes merely on a perceptual or retinal level. Moreover, the robustness and transferability of the effects (i.e., the sustainability and the transfer to face images other than the adaptor) contradict a simple recency effect (i.e., a tendency to remember the most recently perceived information the best). However, most of the studies investigated adaptation effects on configural face information (i.e., second-order relations; for an overview see Strobach & Carbon, 2013), although it was hypothesized and also empirically revealed that face recognition is based on further facial information (e.g., Cabeza & Kato, 2000; Macho & Leder, 1998; Maurer et al., 2002; Mondloch et al., 2002; Rakover & Teucher, 1997). This partial neglect of previous studies inspired us to initiate the present study, where we investigated adaptation effects on non-configural face information.

Face Adaptation Effects

Most face adaptation studies were designed following the same principle: In the initial adaptation phase, a strongly manipulated face is presented. In the subsequent test phase, the participants are asked to choose the veridical (i.e., not manipulated) face out of several face versions displaying the original face along with slightly manipulated versions. The participants usually show a clear bias in their selection toward the previously seen manipulated adaptor. Thus, after adaptation, the original face appears to be manipulated in the opposite direction to the adaptor. Using the example of the so-called *face distortion aftereffect*, participants would—after seeing a strongly stretched face—choose a slightly stretched face to be the veridical face version since the original version appears compressed (e.g., Carbon & Ditye, 2011; Carbon & Leder, 2006; Strobach et al., 2011; Webster & MacLin, 1999).

This contrasting bias seems to be based on a shift of our mental representation or mental norm of a specific face toward the previously presented adaptor. This shift can be explained by using the face space theory proposed by Valentine (1991). Valentine's theory describes an abstract concept in which mental face representations are located in a multidimensional space. Each face representation reflects the average appearance of a specific individual, built from all encounters one had with this individual. When identifying individuals, their faces are matched against the corresponding mental representations stored in face space. These face representations are located in face space depending on their characteristic value on different feature dimensions (e.g., size of the eyes or shape of the mouth). Face representations that are similar are located very close to each other (since they have similar positions on the feature dimensions), whereas representations that are dissimilar are further apart. This way, a face can be classified along various feature dimensions (Webster & MacLeod, 2011). Each new experience with a face reshapes the mental representation since new information is immediately integrated into this representation. Hence, an exposure to an extreme alteration in one feature dimension (e.g., an extremely extended face) would cause the mental representation to shift along the specific dimension toward the alteration (see Figure 1 for an illustration). According to Valentine et al. (2016), this mechanism constitutes the adaptation process. When identifying a face (matching the face against the mental representation in face space) after adaptation to a face manipulation, a face image that is similar to

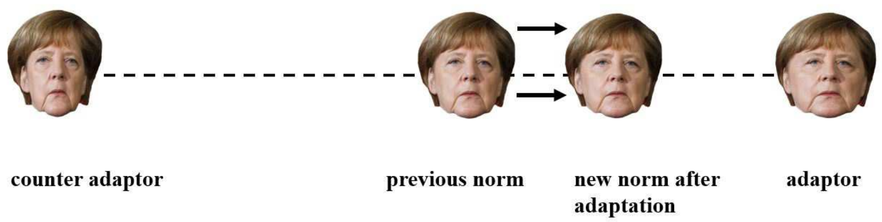

FIGURE 1.

A very basic illustration of a representation shift along a feature dimension within the face space (Valentine, 1991). An image of Angela Merkel is used for illustrative purpose. The feature dimension represents a continuum of a specific facial characteristic on which a face can vary (in this case the head's width). The two faces located at the end of the continuum are extreme versions of the feature dimension. The face in the middle represents the initial norm/representation. After adaptation to the right extreme (stretched version of Angela Merkel), the norm is shifted toward the adaptor. The initial norm, however, is perceived as being slightly compressed and appears closer to the left extreme (extremely compressed version). Adapted from Mueller et al. (2020). Permissions and image licenses have been obtained from the copyright holders [Source: © Drop of Light/Shutterstock.com].

the adaptor would then be perceived as more normal or natural. In contrast, a face image that is similar to the initial mental representation appears as being slightly manipulated in the opposite direction to the adaptor (Mueller et al., 2020).

Adaptation effects have been reported for various types of face information such as ethnicity, identity, gender, expression, or age (Fox & Barton, 2007; Lai et al., 2012; Leopold et al., 2001; for a review, see Strobach & Carbon, 2013; Webster et al., 2004). However, these studies investigating face adaptation have one component in common: They used adaptors that were manipulated in terms of configural face information. Configural information refers to the second-order spatial relations between specific facial features (e.g., eye-mouth distance; Maurer et al., 2002). For example, by investigating the aforementioned face distortion aftereffect, Carbon et al. (2007) manipulated the eye-mouth distance and thus created configurally stretched as well as compressed versions of different celebrity faces. A configural manipulation is also performed when investigating face information related to ethnicity, identity, or gender. Studies investigating these types of information often merge different faces or face pairs or create computer generated anti-faces (that reverse the characteristics of the original image, e.g., a female head shape becomes a male head shape, narrow lips become full lips) to generate different levels of ethnicity, identity, gender, and so forth (Fox & Barton, 2007; Lai et al., 2012; Webster et al., 2004). All these manipulations involve structural and spatial alterations of facial characteristics and thus affect configural aspects.

However, configural face information does not seem to be the only information that is relevant in face processing (although it was most focused on when investigating adaptation effects; see Strobach & Carbon, 2013, for a review). Non-configural face information that does not affect any relational aspect of the face seems to be involved as well. For example, several studies were able to demonstrate the relevance of feature information (e.g., eyes, nose or mouth; Cabeza & Kato, 2000; Macho & Leder, 1998), texture (e.g., Liu et al., 2005; Meinhardt-Injac et al., 2013; O'Neil & Webster, 2011) or color (e.g., Lee & Perrett, 1997; Nestor & Tarr, 2008) in face processing. For instance, Rakover and Teucher (1997) conducted one of the rare studies on the relevance of different facial information by investigating the face inversion effect (i.e., recognition of an inverted face is more difficult than the recognition of an upright face) for either featural or configural face information. They found strong inversion effects for isolated facial features and concluded that these features contribute considerably to face recognition. They assumed that even 91% of the recognition of an upright human face is actually based on its features.

Liu et al. (2005) presented different grayscale faces that were only defined by texture gradients (the distortion in size or the change in density when objects extend into depth). However, face specific texture information other than texture gradients was no longer accessible since it was manipulated by mapping a fractal-noise pattern onto the face. In a subsequent eight-alternative forced choice test, participants had to identify the previously seen face. The test stimuli were also grayscale faces defined by texture gradients and/or grayscale faces without any fractal-noise patterns that altered the texture of the face. Participants correctly identified the faces above chance but performed poorer than in another experiment where only faces without the fractal-noise pattern were used as targets. The authors concluded that texture gradient information might have been used to recover surface geometry. Thus, texture gradient is probably involved in face processing. Lee and Perrett (1997) investigated the perception of color in faces. They were able to show that participants' accuracy in recognizing celebrity faces was improved when presenting them as caricatures in color space (the results were compared with two other conditions in which either the veridical image or an image with an increased contrast was presented). However, grayscale images decreased participants' accuracy, which indicates that color is an important dimension in facial perception and identification. Taken together, these results clearly show that face perception does not rely solely on configural information, but also involves non-configural face characteristics.

Although many studies show the relevance of non-configural face information in face perception, this type of face information was mainly neglected when investigating adaptation effects. Yamashita et al. (2005) conducted one of the few adaptation studies that implemented an adaptation condition where non-configural face information was used. The authors primarily investigated face adaptation effects to distortions but were also interested in exploring the selectivity of these effects to changes in different facial information. They presented strongly distorted adaptors in the adaptation phase and original and slightly distorted images in the test phase. In addition to the distortions, the authors altered other facial information (configural as well as non-configural information, such as color) of the test images. They found weaker adaptation effects when implementing changes in spatial frequency and contrast polarity (positive vs. negative/inverted contrast) as compared to changes in size, contrast (high vs. low contrast), and color (i.e., red and green chromaticity). Although some dimensions seem to have a greater impact on adaptation effects than others, all facial dimensions actually lead to weaker adaptation effects when altered. This indicates that all implemented dimensions (including non-configural color information) seem to be somehow involved in face processing. However, since these dimensions were only assessed indirectly and in combination with configural distortions, the results cannot clarify whether non-configural face information also contributes to mental representation and long-term retention of faces. Therefore, as to the authors' knowledge, no study directly investigating adaptation effects on non-configural face information exists as of yet.

Processing Levels of Adaptation Effects

For configural face information, various studies were able to show that adaptation effects are not just processed on a purely sensory level, but they also affect a rather representational memory basis. For example, Carbon et al. (2007) and Carbon and Ditye (2011) showed strong adaptation effects on configurally distorted celebrity faces lasting for one day and even up to one week. These long-term effects cannot be explained by purely perceptual models of adaptation, but indicate sustained modifications of the facial memory. Moreover, they also cannot be explained by simple recency effects since recency effects are based on processes of short-term memory and thus would not last a day or even a whole week (especially if distracting stimuli are perceived in the meantime, see e.g., Glanzer & Cunitz, 1966; Tan & Ward, 2000). Additionally, in adaptation paradigms where a series of several face versions are presented in the test phase that also includes the strongly manipulated adaptor image, only slightly manipulated face versions are selected (Carbon et al., 2007). This also contradicts a recency effect since a recency effect would lead to a selection of the previous seen adaptor.

Further evidence that adaptation does not operate on a purely sensory processing level is provided by studies investigating different kinds of transfer dimensions. Various authors (e.g, Carbon & Ditye, 2011, 2012; Carbon et al., 2007; Fox & Barton, 2007; Strobach et al., 2011; Webster et al., 2004) have found that face adaptation effects not only occur using the identical images as adaptors and test stimuli, but they also transfer across different images of the same identity, as well as across images of different identities (although these effects are usually attenuated). Ghuman et al. (2010) were even able to transfer adaptation effects from bodies onto faces. The authors presented either female or male bodies as adaptors and detected adaptation effects in the perception of gender in subsequent face stimuli. These findings indicate a processing of faces where adaptation affects different hierarchical levels of face representation. Hence, adaptation does not seem to alter only the representation of the presented face, but also representations of specific subpopulations of faces (e.g., faces of the same gender or ethnicity) or a generic norm that represents faces as an object class (Carbon & Ditye, 2011; Mueller et al., 2020). Thus, durability and transferability seem to be important indicators of the processing level of adaptation effects. Both parameters have been investigated intensively for configural face information but not for non-configural information (e.g., Carbon & Ditye, 2011, 2012; Carbon & Leder, 2005; Carbon et al., 2007; Fox & Barton, 2007; Lai et al., 2012; Otten & Banaji, 2012; Strobach et al., 2011; Webster et al., 2004). The following study aims to close this gap in the literature.

The Current Study

Until now, the literature on adaptation appears to have mainly focused on configural face information. In the current study, both the robustness and the transferability of effects were investigated intensively, leading to a relatively profound understanding of how configural face information is represented in memory. However, non-configural face information was mainly neglected when investigating adaptation effects. To the authors' knowledge, previous studies focusing on non-configural face information were able to demonstrate the role of non-configural information in face perception, but were not able to clarify whether this type of information is also stored in memory. Adaptation paradigms enable the investigation and identification of the information stored in memory. By applying different temporal parameters and transfer levels, the current study investigated the processing level of adaptation effects to non-configural face information. We hereby focused on brightness alterations since it represents more natural changes as compared to, for example, changes in texture or featural information. Moreover, alterations to featural information are confronted with a specific problem: Alterations of features with the methods used so far (i.e., mainly distortions or replacements) also lead to an alteration of configural aspects of the face. By distorting or replacing only one specific unit within a face, the relation to other units is affected too. However, an alteration of facial brightness does not lead to spatial changes and is thus defined as non-configural.

Five experiments are reported in which participants were exposed to celebrity faces that were manipulated in brightness. The manipulation of brightness differed depending on which group the participants belonged to (decreased, no manipulation, or increased brightness). Subsequently, participants were asked to respond to a two-alternative forced choice test in which they were supposed to choose the veridical face out of two alternative faces (the original face and a slightly manipulated version). Following adaptation to strongly manipulated faces, we expected an alteration of the participants' representations of the respective faces toward the adaptor. Thus, after adaptation, the original face would appear manipulated in a direction opposite to the adaptor (e.g., the original would seem to be decreased in brightness after adaptation to a face with increased brightness, and vice versa). Consequently, we expected the participants to select a slightly manipulated face version (e.g., with a slightly increased brightness) to be the veridical face when presented with the two options (original and slightly manipulated face version).

In Experiment 1, we investigated whether face adaptation effects fundamentally exist for non-configural color (i.e., brightness) alterations in celebrity faces. Experiments 2 and 3 attempted to clarify whether possible adaptation effects for brightness alterations are face-specific or whether they also occur to the same extent using non-facial stimuli (or facial stimuli with impaired recognizability, such as inverted faces). Experiments 4 and 5 focused on the durability of possible adaptation effects and thus aimed to determine whether the effects that may have been observed are based on recency effects, addressing a purely sensory level, or if they are based on a representational memory basis (e.g., Carbon & Ditye, 2011; Carbon et al., 2007). We did so by increasing the interval between adaptation and test stimuli from a relatively short to a longer interval (longer-term adaptation effects are probably processed cognitively higher and might affect the representational memory). In all experiments, we applied different transfer levels (see Figure 2). In the first transfer level (*pictorial*), the identical images were presented in both the adaptation and test phases. The second transfer level (*structural*) reflected an experimental condition where the adaptor and test stimulus differ but still represent the same identity (following the study by Carbon & Leder, 2005 famous faces are used as stimuli). However, in the third transfer level (*cross-identity*), even different identities were presented in the adaptation and test phase. A comparison of the results of these three conditions can clarify whether the adaptation effects are image- or identity-specific or if they even address higher face concepts (such as the generic norm of faces).

EXPERIMENT 1

To find out whether adaptation effects exist for non-configural color information, the first experiment presented celebrity faces manipulated in brightness as adaptation stimuli. In a subsequent test phase, we expected the participants to show a clear bias toward the previously seen manipulated adaptor. The interval between adaptation and test stimuli was 300 ms and thus rather short.

Method

PARTICIPANTS

Forty-eight undergraduate students from the Medical School Hamburg (47 females, 1 male, M_{age} = 22.7 years, range = 18 to 44 years) were tested individually. The needed minimal sample size of N = 45 was calculated a priori via power analysis (Faul et al., 2007) based on a mixed-design analysis of variance (ANOVA) with a 3 (between-subjects) × 3 (within-subjects) factor design being able to detect a medium-large effect size f of 0.25 (Cohen, 1988) given an α = .05 and a test power (1−β) = 0.90. The effective N was 48, resulting in an increased test power of 0.93. Study participation was rewarded with either money (€12) or credit points (as part of course requirements). All participants were naïve to the purpose of the experiment. To test for anomalies in color perception, we employed a short version of the Ishihara color test (Ishihara, 1917). Vision was further assessed with the Freiburg Visual Acuity and Contrast Test (FrACT; Bach, 1996). Only participants with normal or corrected-to-normal vision were included in the subsequent testing. The participants were randomly assigned to one of the three participant groups (adaptation stimuli decreased in brightness, original images, or stimuli increased in brightness). The study was conducted according to the guidelines of the Declaration of Helsinki. All participants provided written informed consent. The study was approved by the ethics board of the Medical School Hamburg (date of application: March 09, 2017).

APPARATUS AND STIMULI

A list of 70 celebrity names was generated by studying articles of tabloid journalism and interviewing colleagues. A color photograph of each celebrity from the list was collected and displayed in a subsequent survey in which we asked the participants (92 participants; 66 females, 26 males, M_{age} = 21.7 years, range = 18 to 30 years) to write down the name of the celebrities (as far as they knew it) and judge their familiarity on a 5-point Likert scale (1 = *unfamiliar*; 5 = *very familiar*). People who participated in the survey were excluded from further experiments. On the basis of the survey data, we selected 30 celebrities[1] who were named most frequently and rated highest in terms of familiarity. Two color photographs (A and B) of each of these 30 "most famous" celebrities were collected and selected according to the following criteria: The photographs should present a full face in a frontal view, in high resolution, and with a straight gaze. Furthermore, it was ensured that hair did not cover any facial features (such as eyes, nose, or mouth) and that celebrities did not wear glasses. These images served as the basic stimulus material for the conducted experiments. All selected celebrity photos were randomly divided into three groups. Since there were two photos of each celebrity (A and B), there were a total of six different stimulus sets. These sets served to investigate the possible transfer of adaptation effects by forming the three different transfer levels that varied in terms of the overlapping information between images seen in the adaptation and test phase. On the first transfer level (pictorial), the stimuli of the adaptation and test phase were pictorially identical (e.g., presenting Image A of George Clooney as an adaptor and the identical image as the test stimulus). On the second transfer level (structural), the adaptation and test image differed from each other but still showed the same identity (e.g., displaying Image A of Heidi Klum as an adaptor and Image B of Heidi Klum as a test stimulus). On the third transfer level (cross-identity), different identities were shown in the adaptation and test phases (e.g., presenting Image A of Angela Merkel as an adaptor and Image A of Brad Pitt as test stimuli). The three different transfer levels that were employed as a within-subjects factor are illustrated in Figure 2.

The brightness of all images was manipulated (using Adobe Photoshop CC, Version 19.0), resulting in five different image versions, as illustrated in Figure 3. Either the original image (ORIGINAL, representing the control group), an image with a strongly decreased brightness (−75%, MINUS EXTREME), or an image with a strongly increased brightness (+75%, PLUS EXTREME) were presented as adaptors, depending on which adaptation group the participant belonged to (between-subjects factor). The adaptation images (PLUS EXTREME and MINUS EXTREME) were to be clearly recognized as manipulations.

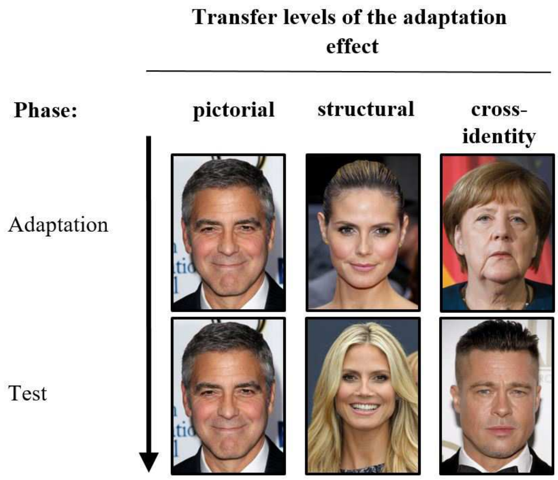

FIGURE 2.
Illustration of the different transfer levels. Each column represents one trial with a different transfer condition being applied. The left column represents a trial of the pictorial transfer level, the column in the middle represents a trial of the structural transfer level, and the right column represents a trial of the cross-identity transfer level. The presented images are used for illustrative purpose only and were not used in the original study. Permissions and image licenses have been obtained from the copyright holders [Sources: © Drop of Light/Shutterstock.com, Tinseltown/Shutterstock.com, s_bukley/Shutterstock.com].

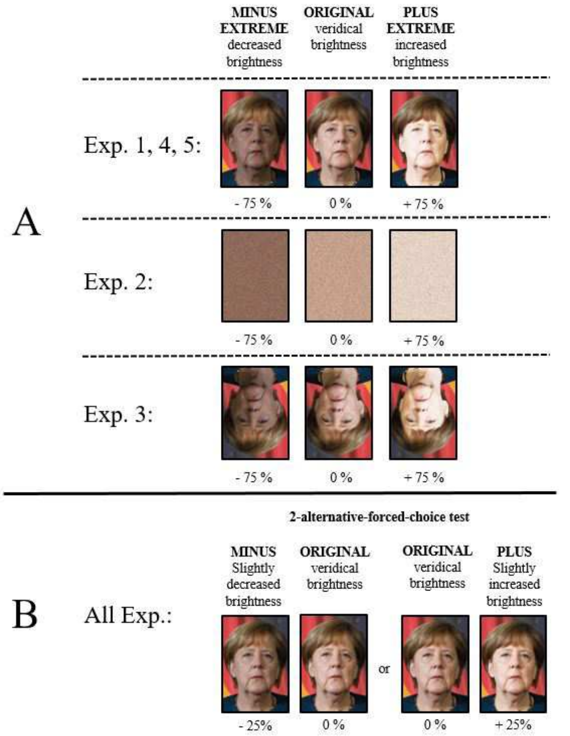

FIGURE 3.

Illustration of the different image versions. Panel (A): Illustration of the different image versions during the adaptation phase. Experiments 1, 4 and 5 used the same stimulus material in the adaptation phase. Experiment 2 displays scrambled face stimuli, and Experiment 3 displays inverted face stimuli as adaptors. Panel (B): Illustration of the different image versions within the test phase. Within the two-alternative-forced-choice test, two images are presented (either an image with decreased brightness or an image with increased brightness, together with the original image). All experiments use the same stimulus material in the test phase. Angela Merkel is used here as an example. Permissions and image licenses have been obtained from the copyright holders [Sources: © Drop of Light/Shutterstock.com].

The test stimuli were the ORIGINAL images and a version with either a slightly decreased brightness (−25%, MINUS) or slightly increased brightness (+25%, PLUS). Since the images could have already been, for example, manipulated by the photographer, it cannot be guaranteed that the images were completely unedited when selected. Consequently, the term "ORIGINAL image" should be used with caution, since it might not represent the original (unedited) identity. Instead, the term refers mainly to the fact that the ORIGINAL image was not manipulated in brightness. Moreover, since the selected images showed no obvious prior manipulations, they should be able to sufficiently reflect the accumulated experience with the depicted identities. The size of the images for adaptation and test phase was approximately 330 × 412 pixels. The experiment was created with Experiment Builder 2.2.1 (SR Research) and ran on a Lenovo PC with a 23-inch monitor and a resolution of 1920 × 1080 pixels.

PROCEDURE

Experiment 1 presented the adaptation and test phase within one trial, separated by a 300 ms interstimulus interval. As illustrated in Figure 4, each trial started with a fixation cross (displayed for 500 ms and placed in the center of the subsequent stimulus position) before presenting the adaptor. Depending on which group they belonged to, participants then either inspected an ORIGINAL image or one of the two extreme versions of this image (MINUS EXTREME or PLUS EXTREME, see Figure 3 for an illustration). In each participant group, all 30 celebrity images were presented. Moreover, the celebrity images were displayed with the same frequency. To increase the inspection time of the adaptation stimuli while avoiding fatigue effects, the variability of the task was increased by presenting the adaptors for either 2, 3 or 4 s—a technique that was already successfully employed by Carbon et al. (2007). To control for retinal effects, the adaptor was placed in one of six different screen positions (top-left, top-center, top-right, bottom-left, bottom-center, or bottom-right). The different presentation times and screen positions of the adaptor were balanced throughout the experiment. Each adaptor was shown twice on each screen position and four times at each presentation time. Hence, a single adaptor was shown 12 times (i.e., in 12 different trials) during the whole experiment. Participants adapted to two sets of celebrity faces (i.e., one image set [A or B] of two [out of three] different celebrity groups). Celebrities assigned to the third group were not shown during adaptation. The image sets that were used for the adaptation phase (and also their order) were determined in advance for each participant and balanced across participants throughout the entire experiment. After the exposure to the adaptor, a backward mask appeared in order to eliminate possible afterimages (Turvey, 1973) and a blank screen was presented. The mask and the blank screen were shown for 150 ms each, resulting in an interstimulus interval (between adaptor and test stimuli) of 300 ms.

After the blank screen, a two-alternative forced-choice test was presented, showing two different image versions of the same picture: either a MINUS image (−25% brightness) or a PLUS image (+25% brightness), together with an ORIGINAL image. Stimulus position was randomized and balanced across trials (ORIGINAL left/MINUS right; MINUS left/ORIGINAL right; ORIGINAL left/PLUS right; PLUS left/ORIGINAL right). While in the adaptation phase only two sets of celebrity faces were presented, three sets were displayed in the test phase, belonging to the three celebrity groups. To apply the three different transfer levels, either the same or the corresponding image set (A or B) of each celebrity group (1, 2, or 3) was presented, depending on the image sets presented in the adaptation phase. For the first transfer level (pictorial), the image set was identical to the first image set of the adaptation phase (e.g., presenting Image Set A of Celebrity Group 1 in both the adaptation and test phase). For the second transfer level (structural), the second image set of the corresponding celebrity group was presented (e.g., presenting Image Set A of Celebrity Group 2 in the adaptation phase and Image Set B of the same celebrity group in the test phase). To apply the third transfer level (cross-identity), images of the celebrity group that was not shown during adaptation were used as test targets, and images presented in the adaptation phase of the other transfer conditions were used as adaptors (e.g., presenting Image Set A of Celebrity Group 1 in the adaptation phase and Image Set A of Group 3 in the test phase). The two adaptor sets that were used to apply the pictorial and structural transfer level (e.g., Image Sets 1A and 2A) also served to apply the cross-identity transfer level. Half of the image set that served to apply the pictorial transfer level (e.g., 15 out of 30 images of Image Set 1A) and half of the image set that served to apply the structural level (e.g., 15 out of 30 images of Image Set 2A) was used for the cross-identity transfer level (e.g., half of the Image Set 1A and half of the Image Set 2A were presented in the adaptation phase and Image Set 3A was displayed in the test phase). The other halves of the image sets used for the pictorial and structural transfer level were not presented in the cross-identity transfer level (i.e., they were not presented a second time). Hence, each adaptor was either presented just in one or two (either pictorial, pictorial and cross-identity, structural or structural and cross-identity) transfer conditions. This imbalance was corrected by balancing the frequency of adaptor presentation across the experiment.

The image sets used for the test phase were balanced across participants throughout the entire experiment. Within each participant group and across all three transfer levels, the brightness of the adaptors was kept constant. While the selection of the presented image sets was determined in advance for each participant, the trial and stimulus order were randomized. In each trial, the test images were presented for 1.500 ms. Backward masks appeared (for 300 ms) after each test-stimulus presentation in order to avoid afterimages and thus an extended exposure to the test stimuli. After the masking, participants were asked to select the veridical image (i.e., the image that most accurately represents the identity) from the two previously presented images. Instructions were: "Which is the original face?" (in German). The selection was indicated by pressing a specific button on a keyboard ("A" and "L"). Participants were explicitly instructed at the beginning of the experiment to base their selection on the memory about the celebrity (e.g., images seen in the media) and not on what they had experienced within the experiment. This way, participants were encouraged to access the representation stored in memory when making their selection. Since the adaptation images were obviously manipulated and thus did not represent the original identity, it was clear to the participants that they were not supposed to base their response on the adaptors seen before. Altogether, the experiment included 360 trials and lasted about 40 minutes. Halfway through the experiment (i.e., after 180 trials), participants were presented with a text informing them that they had completed the first half of the experiment. Participants were allowed to take a short break and were free to decide when to start the second half of the experiment.

After the adaptation and test phases, participants were given the task of judging the celebrities to which they were exposed according to their familiarity (whether they have seen the celebrities before in the media). Instructions regarding the familiarity were: "Are you familiar with this celebrity from the media?" (in German). Participants responded with either "yes" ("A") or "no" ("L"). The aim of this task was to ensure that the participants based their selection about the veridicality of the identities in the task before (i.e., the test phase of

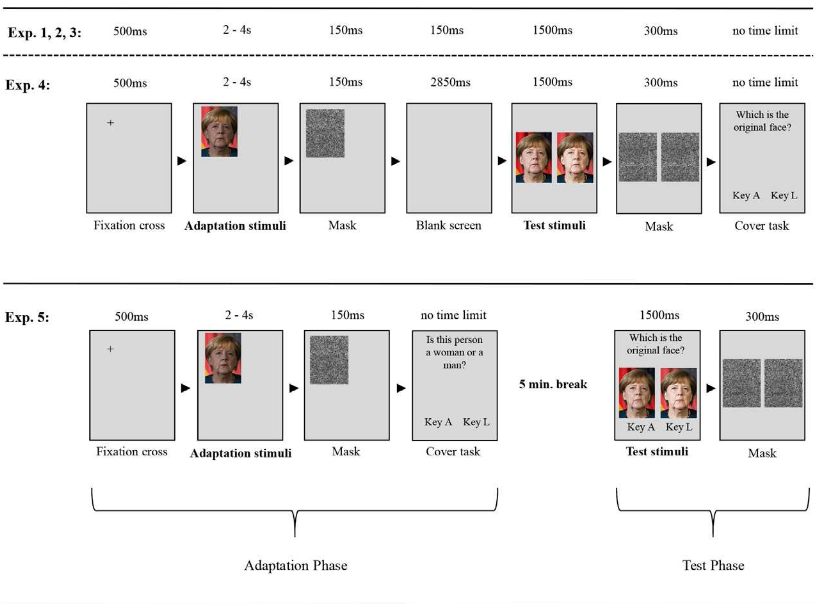

FIGURE 4.

Schematic illustration of the trial structure of Experiments 1 to 5. Experiments 1 to 3 are similar in their timing (but differ in their stimulus material, see Figure 3). Experiments 1 to 3 and Experiment 4 differ only in their interstimulus interval (a blank screen is presented either for 150 ms or 2850 ms, resulting in an interstimulus interval of either 300 ms or 3000 ms). In Experiment 5, the adaptation and test phases are presented separately (with a 5 min. break in between). An image of Angela Merkel is used here as an example. Permissions and image licenses have been obtained from the copyright holders [Sources: © Drop of Light/Shutterstock.com].

the adaptation paradigm) on an internal mental representation. Since the memory probably contains stable mental representations of only familiar identities, the rating was used to exclude trials displaying celebrities that were unfamiliar to the participants.

Results and Discussion

On average, 96.7% of the celebrity faces presented in the experiment were considered to be familiar (individually ranging from 73.3% to 100%). Trials that displayed a celebrity who was not recognized by the participant were excluded from further analysis. Furthermore, all trials with a reaction time (RT) faster than 200 ms, as well as all individual outliers (i.e., RT slower than 3 *SD*s above the individual mean RT) of each participant, were excluded. The average selection of test faces for each participant was used as the dependent variable (later referred to as target selection). The selection was scored according to the alteration of the selected image: A score of −25 was used for MINUS images; a score of 0 was used for ORIGINAL images; and a score of +25 was used for PLUS images[2].

A two-way, mixed-design analysis of variance (ANOVA) was conducted with the between-subjects factor of adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-subjects factor of transfer level (pictorial, structural, and cross-identity). There was a significant main effect of adaptation group, $F(2, 45) = 13.781$, $p < .001$, $\eta_p^2 = .380$ (MINUS EXTREME: $M = −8.84$, $SD = 2.58$; ORIGINAL: $M = −3.78$, $SD = 4.87$; PLUS EXTREME: $M = 1.12$, $SD = 7.51$). Bonferroni adjusted comparisons revealed significant differences between all possible pairs (between MINUS EXTREME and ORIGINAL: $p = .032$; between ORIGINAL and PLUS EXTREME: $p = .040$; and between MINUS EXTREME and PLUS EXTREME: $p < .001$). Since the results revealed the expected pattern in the participants' target selection (i.e., bias of the participants' selection toward images with a reduced brightness, i.e., numerically small values, after inspecting images with a strongly reduced brightness, and a contrasting bias, i.e., numerically higher values, after inspecting images with a strongly increased brightness), a general adaptation effect on brightness is indicated. There was no main effect of transfer level, $F(2, 90) < 1$, $p = .581$, but there was a significant interaction of adaptation group and transfer level, $F(4, 90) = 4.102$, $p = .004$, $\eta_p^2 = .154$, see Figure 5A for an illustration. Hence, the transfer levels differed statistically significantly in their average values (reflecting the average selection of the test faces). Moreover, these significant differences between transfer levels seemed to vary within a different range for each participant group.

Univariate ANOVAs of the factor adaptation group showed large effects for all transfer levels: pictorial, $F(2, 45) = 18.873$, $p < .001$, $\eta_p^2 = .456$; structural, $F(2, 45) = 10.589$, $p < .001$, $\eta_p^2 = .320$; and cross-identity, $F(2, 45) = 9.138$, $p < .001$, $\eta_p^2 = .288$. Within the MINUS EXTREME adaptation group, a greater effect was observed for the pictorial compared to the cross-identity transfer level, $p = .013$. There was no difference between the pictorial and structural, nor between the structural and cross-identity transfer levels, $ps > .188$. Within the PLUS EXTREME adaptation group, a greater effect was observed for the pictorial compared to the cross-identity transfer level, $p = .001$, and also for the pictorial compared to the structural transfer level, $p = .048$. There was no difference between the structural and cross-identity transfer levels, $p = .409$. As expected, the control group (ORIGINAL) did not show any differences between the transfer levels, $ps > .153$. Thus, it seems that although all transfer levels showed a large adaptation effect across the experimental groups, the pictorial transfer level showed the largest effect. This indicates that the observed adaptation effect operates to a certain extent only on an image-specific level. However, the effect is also transferable to other images or even to other identities, although it is attenuated. Thus, faces strongly altered in brightness can bias the subsequent perception of identical images, different image versions, and also the perception of other identities. Since Figure 5A indicates that there could be a shift in the average selection of all participant groups toward the negative pole, a one-sample *t*-test was conducted comparing the average selection across all groups. Since we expected a value around zero for the average selection of the control group and positive or negative values of similar magnitude for the two adaptation groups, a total average value (across all groups) around zero would be anticipated (as the values of the adaptation groups would abrogate each other). Thus, a significant negative deviation from zero would indicate a bias of the overall results into the negative range. The one-sample *t*-test indeed showed a negative bias: $M = −3.83$; $t(47) =$

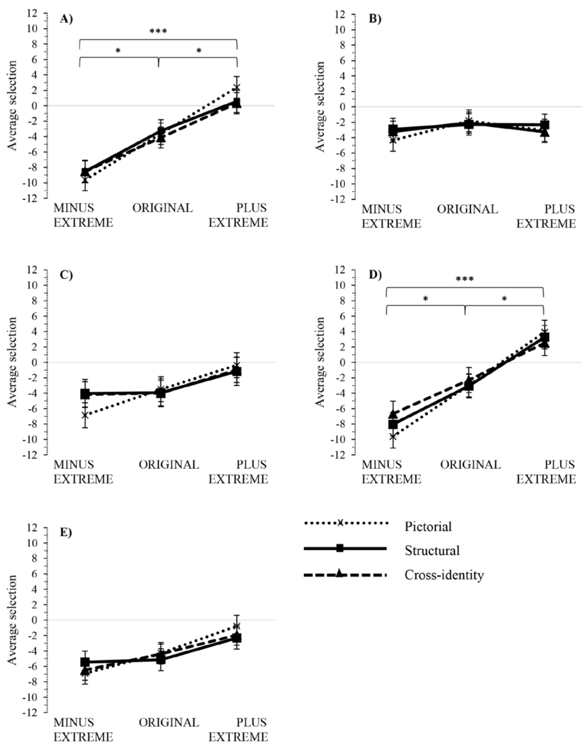

FIGURE 5.

Illustration of the interaction between adaptation group and transfer level for all experiments. Panel (A): Experiment 1. Panel (B): Experiment 2. Panel (C): Experiment 3. Panel (D): Experiment 4. Panel (E): Experiment 5. The "average selection" axis represents the mean brightness of the selected test stimuli (in %). Error bars represent ± 1 standard error of the mean.

−3.981; $p < .001$ (one-tailed); $d = -0.575$. Thus, overall, the participants selected images with a lower brightness than expected.

EXPERIMENT 2

Since the results of Experiment 1 suggested that face adaptation effects also exist for non-configural color (i.e., brightness) information, we wanted to clarify in the following experiment whether the detected brightness adaptation effects are selective for faces or whether they are instead general color aftereffects that can be provoked by other stimulus material than faces. Therefore, Experiment 2 used non-face stimuli in the adaptation phase that were manipulated in brightness. However, test stimuli did not differ from Experiment 1 and thus presented celebrity faces. The non-face adaptation stimuli were created by scrambling beyond recognition the faces initially presented in the adaptation phase in Experiment 1 (see Figure 3A). Each image was divided into very small pieces and randomly assembled so that one homogeneous color area was created, representing the average color of the respective adaptation image from Experiment 1 (a so-called scrambled face). Since the scrambled-face stimuli did not display any face, adaptation effects in this experiment should be reduced compared to the effects of Experiment 1 if the reported adaptation effects of Experiment 1 are indeed face-specific. As the adaptor stimuli no longer displayed the celebrities presented in the test phase, the pictorial and structural transfer levels no longer applied. Nevertheless, for the sake of consistency between experiments, the conditions shall be listed in this experiment.

Method

PARTICIPANTS

Forty-eight undergraduate students from the University of Bamberg (38 females, 10 males, M_{age} = 24.5 years, range = 19 to 41 years) were tested individually. The sample size was the same as in Experiment 1. Study participation was rewarded with either money (€12) or credit points (as part of course requirements). All study requirements and conditions were the same as in Experiment 1. None of the participants had taken part in Experiment 1.

APPARATUS, STIMULI, AND PROCEDURE

Experiment 2 was identical to Experiment 1 except the following: The adaptation stimuli (but not the test stimuli) used in this experiment were scrambled versions of the stimuli presented in Experiment 1 (see Figure 3). The images were scrambled in such a way that face recognition was no longer possible.

RESULTS AND DISCUSSION

On average, 94.9% of the celebrity faces presented in the experiment were considered to be familiar (individually ranging from 46.7% to 100%). As in Experiment 1, all trials that displayed a celebrity who was not recognized by the participant were excluded from further analysis, as well as trials with an RT faster than 200 ms and the individual outliers (i.e., RT slower than 3 *SD*s above the mean of each participant). The target selection was used as the dependent variable. The selection was scored according to the alteration of the selected image (a score of −25 was used for MINUS images; 0 for ORIGINAL images; and +25 for PLUS images).

A two-way, mixed-design ANOVA was conducted with the between-subjects factor of adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-subjects factor of transfer level (pictorial, structural, and cross-identity). There was no significant main effect of adaptation group, $F(2, 45) < 1$, $p = .730$ (MINUS EXTREME: $M = -3.48$, $SD = 5.48$; ORIGINAL: $M = -2.06$, $SD = 4.47$; and PLUS EXTREME: $M = -2.88$, $SD = 5.18$). Furthermore, there was neither a main effect for transfer level, $F(2, 90) < 1$, $p = .619$, nor an interaction between adaptation group and transfer level, $F(4, 90) < 1$, $p = .633$, see Figure 5B for an illustration. Thus, we were not able to detect an adaptation effect regarding brightness alterations of scrambled faces in Experiment 2. Although no adaptation effect was observed, the graph indicates that there could have been a shift in the average selection of all participant groups into the negative range (see Figure 5B). A one sample *t*-test indeed revealed a significant negative bias of the overall results, $M = -2.83$; $t(47) = -3.927$; $p < .001$ (one-tailed); $d = -0.567$. Thus, although no adaptation effects were revealed, the participants showed a tendency of selecting celebrity faces decreased in brightness as the veridical images.

EXPERIMENT 3

Since the scrambled faces differed significantly in contrast and complexity in comparison to the adaptation images presented in Experiment 1, the results of Experiment 2 cannot completely clarify whether the results obtained from Experiment 1 are face-specific or not. The absence of adaptation effects could just as well be explained by the great difference of the adaptation and test stimuli. Thus, the following experiment was carried out using adaptation images that were more similar (e.g., in color composition and complexity) to the adaptor images used in Experiment 1 and to the test images. Experiment 3 used the adaptation images of Experiment 1 as inverted images (see Figure 3A). Inverted face stimuli do not differ from upright images except in orientation. Hence, they are much more comparable to the images of Experiment 1 than the scrambled face stimuli implemented in Experiment 2. Moreover, inverted face stimuli are even more comparable than, for example, images of other object classes (e.g., houses, cars, etc.), since they still display the same faces as used in Experiment 1. Nevertheless, face inversion causes strong recognition impairments and thus can serve as a kind of "non-face stimulus" (for a review see Valentine, 1988; e.g., Yin, 1969). If adaptation effects are revealed in Experiment 3, the results of Experiment 1 can be interpreted as being specific for upright faces. As the adaptor stimuli differed from the test images in their orientation, the use of the term "pictorial" might be misleading. Nevertheless, the term will be used for the sake of consistency with the descriptions of the other experiments. However, in the context of Experiment 3, the term "pictorial" means the pictorial congruence of the basic image, without inversion or brightness alterations

.Method

PARTICIPANTS

Forty-eight undergraduate students from the Medical School Hamburg (33 females, 15 males, M_{age} = 23.0 years, range = 18 to 31 years) were tested individually. The sample size was the same as in Experiments 1 and 2. Study participation was rewarded with either money (€12) or credit points (as part of course requirements). All study requirements and conditions were the same as in the previous experiments. None of the participants had taken part in Experiments 1 or 2.

APPARATUS, STIMULI, AND PROCEDURE

This experiment was identical to Experiment 1 except the following: The adaptation stimuli (but not the test stimuli) used in this experiment were inverted versions of the stimuli presented in Experiment 1 (see Figure 3).

RESULTS AND DISCUSSION

On average, 97.3% of the celebrity faces presented in the experiment were considered to be familiar (individually ranging from 63.3% to 100%). As in Experiments 1 and 2, all trials that displayed a celebrity who was not recognized by the participant were excluded from further analysis, as well as trials with an RT faster than 200 ms and the individual outliers (i.e., RT slower than 3 *SD*s above the mean of each participant). The target selection was used as the dependent variable. The selection was scored according to the alteration of the selected image (a score of −25 was used for MINUS images; 0 for ORIGINAL images; and +25 for PLUS images).

A two-way, mixed-design ANOVA was conducted with the between-subjects factor of adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-subjects factor of transfer level (pictorial, structural, and cross-identity). There was no significant main effect of adaptation group, $F(2, 45) = 1.182$, $p = .316$ (MINUS EXTREME: $M = -4.72$, $SD = 4.96$; ORIGINAL: $M = -4.46$, $SD = 4.40$; and PLUS EXTREME: $M = -1.96$, $SD = 7.15$). Furthermore, there was no main effect of transfer level, $F(2, 90) < 1$, $p = .689$, nor an interaction of adaptation group and transfer level, $F(4 ,90) = 1.863$, $p = .124$ (see Figure 5C for an illustration). Thus, we were not able to detect an adaptation effect regarding brightness alterations of inverted faces in Experiment 3. As in Experiment 2, the graph indicates that there could have been a shift in the average selection of all participant groups into the negative range (see Figure 5C). A one-sample *t*-test indeed revealed a significant negative bias of the overall results, $M = -3.74$; $t(47) = -4.585$; $p < .001$ (one-tailed); $d = -0.662$. Thus, although no adaptation effects were revealed, the participants showed a tendency of selecting celebrity faces decreased in brightness as the veridical images.

EXPERIMENT 4

Experiments 1, 2, and 3 were able to demonstrate that face adaptation effects also exist for non-configural color (i.e., brightness) information and that these effects are somehow face-specific. In the following experiments, we wanted to clarify the processing level of the adaptation effects. Since temporal factors of the adaptation paradigm seem to be a key variable for investigating the level of face processing, timing was relevant in the following two experiments. An extension of the interstimulus interval enables an identification of sensory-based (retinotopic) effects versus more robust and thus cognitively higher processed effects. Experiment 4 only slightly increased the interstimulus interval from milliseconds (300 ms in Experiments 1 to 3) to seconds (3 s).

Method

PARTICIPANTS

Forty-eight undergraduate students from the Medical School Hamburg (39 females, 9 males, M_{age} = 23.9 years, range = 19 to 31 years) were tested individually. The sample size as well as all study requirements and conditions were the same as in the previous experiments. None of the participants had taken part in the previous experiments.

APPARATUS AND STIMULI

The apparatus and stimuli were the same as those used in Experiment 1 (see Figure 3).

PROCEDURE

The procedure was identical to that of Experiment 1, except that the interstimulus interval was extended to 3 s. Thus, following the adaptor and preceding the presentation of the test stimuli, a backward mask appeared for 150 ms, and a subsequent blank screen appeared for 2850 ms (see Figure 4).

RESULTS AND DISCUSSION

All trials with an RT faster than 200 ms were excluded, as well as all individual outliers (i.e., RT slower than 3 *SD*s above the mean of each participant). The target selection was used as the dependent variable. The selection was scored according to the alteration of the selected image (a score of −25 was used for MINUS images; 0 for ORIGINAL images; and +25 for PLUS images). Besides this outlier analysis, we included all trials in this experiment. A two-way, mixed-design ANOVA was conducted with the between-subjects factor of adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-subjects factor of transfer level (pictorial, structural, and cross-identity). There was a significant main effect of adaptation group, $F(2, 45) = 14.539$, $p < .001$, $\eta_p^2 = .393$ (MINUS EXTREME: $M = -8.10$, $SD = 3.77$; ORIGINAL: $M = -2.77$, $SD = 4.90$; and PLUS EXTREME: $M = 3.25$, $SD = 8.27$). Bonferroni adjusted comparisons revealed significant differences between all possible pairs (between MINUS EXTREME and ORIGINAL: $p = .045$; between ORIGINAL and PLUS EXTREME: $p = .019$; and between MINUS EXTREME and PLUS EXTREME: $p < .001$). Since the results revealed the expected pattern in the participants' target selection (i.e., bias of the participants' selection toward images with a reduced brightness after inspecting images with a strongly reduced brightness, and a contrasting bias after inspecting images with a strongly increased brightness), a general adaptation effect on brightness is indicated. There was no main effect of transfer level, $F(2, 90) = 1.460$, $p = .238$, but there was a significant interaction of adaptation group and transfer level, $F(4, 90) = 4.351$, $p = .003$, $\eta_p^2 = .162$ (see Figure 5D for an illustration).

Univariate ANOVAs of adaptation group showed large effects for all transfer levels: pictorial, $F(2, 45) = 20.488$, $p < .001$, $\eta_p^2 = .477$; structural, $F(2, 45) = 13.902$, $p < .001$, $\eta_p^2 = .381$; and cross-identity, $F(2, 45) = 7.929$, $p = .001$, $\eta_p^2 = .261$. Within the MINUS EXTREME adaptation group, a greater effect was observed for the pictorial compared to the cross-identity transfer level, $p < .001$. There was also a significant difference between the pictorial and structural transfer levels, $p = .050$, but not between the structural and cross-identity transfer levels, $p = .096$. Within the PLUS EXTREME adaptation group, a greater effect was observed for the pictorial compared to the cross-identity transfer level, $p = .034$. There was no significant difference between the pictorial and structural transfer levels, $p = .386$, nor between the structural and cross-identity transfer levels, $p = .357$. As expected, the control group (ORIGINAL) did not show any differences between the transfer levels, *ps* > .303. Thus, we observed the same pattern as in Experiment 1: Although all transfer conditions showed a large adaptation effect across the experimental groups, the pictorial transfer condition showed the largest effects, indicating an image-specific component within the adaptation effect. However, since the effect was also transferable to other images or even to other identities, it cannot be entirely image-specific, but must somehow bias the perception of the other presented identities. As in Experiment 1, there was a shift in the average selection of all participant groups toward the negative pole (see Figure 5D), $M = -2.55$; one sample *t*-test: $t(47) = -2.362$ (one-tailed); $p = .011$; $d = -0.341$. Thus, the total average value across all groups deviated significantly from the anticipated value of zero (see Experiment 1 for further explanation). This implies that, overall, the participants selected images with a lower brightness than expected. Moreover, the adaptation effect observed in this experiment seems to have been similarly large as the effects of the first experiment. Thus, the observed adaptation effect seems to clearly resist an interval of 3 s.

EXPERIMENT 5

Since the detected adaptation effects seem to be robust, lasting at least several seconds, it was determined in a further experiment whether the effects also persist for several minutes. Therefore, in Experiment 5, we separated the adaptation and test phases, and the time interval between both phases was increased to five minutes (adopted from the study of Carbon et al., 2007). If adaptation effects still occur after five minutes, it seems plausible that the effects are not just on a sensory level, but that higher cognitive processing mechanisms are involved.

Method

PARTICIPANTS

Forty-eight undergraduate students from the Medical School Hamburg (32 females, 16 males, $M_{age} = 23.7$ years, range 19 to 32 years) were tested individually. The sample size as well as all study requirements and conditions were the same as in the previous experiments. None of the participants had taken part in the previous experiments.

APPARATUS AND STIMULI

The apparatus and stimuli were the same as those used in Experiments 1 and 4.

PROCEDURE

In contrast to the previous experiments, the adaptation and test phases were separated in this experiment. As illustrated in Figure 4, the trials of the adaptation phase started, as in the previous experiments, with a fixation cross (displayed for 500 ms and placed in the center of the subsequent stimulus position) before presenting the adaptor. Depending on which group they belonged to, participants then either inspected an ORIGINAL image or one of the two extreme versions of this image (MINUS EXTREME or PLUS EXTREME) for 2-4 s. The adaptor was placed in one of six different screen positions. The different parameters (i.e., presentation time and position) were balanced across trials. After the exposure to the adaptor, a backward mask appeared for 150 ms, followed by a screen displaying a gender cover task (saying in German: "Is this person a woman or a man?"). The selection was indicated by pressing the "A" (man) or "L" (woman) keys. As in the previous experiments, the image sets presented in the adaptation phase were balanced across participants. After the adaptation phase, there was a 5 minutes break in which a geographical text was presented to the participants to prevent the previously seen images from being mentally recalled.

Following this break, the two-alternative forced-choice test from the previous experiments was presented. Stimulus position was again randomized and balanced across trials. As in the prior experiments, all three celebrity groups were displayed in the test phase to apply all three transfer levels (pictorial, structural, and cross-identity). The image sets used for the test phase were balanced across participants. The test stimuli were presented for 1.500 ms. Backward masks appeared (for 300 ms) after each test-stimulus presentation. Afterwards, participants were asked to select the veridical image from the two previously presented images. The selection was indicated by pressing a specific key ("A" and "L"). The experiment included 360 adaptation and 120 test trials and lasted about 50 minutes. As in all previous experiments, the participants were given a familiarity rating task after the adaptation and test phases.

RESULTS AND DISCUSSION

On average, 98.6% of the celebrity faces presented in the experiment were considered to be familiar (individually ranging from 70% to 100%). As in the previous experiments, all trials that displayed a celebrity that was not recognized by the participant were excluded from further analysis, as well as trials with an RT faster than 200 ms and the individual outliers (i.e., RT slower than 3 *SD*s above the mean of each participant). The target selection was used as the dependent variable. The selection was scored according to the alteration of the selected image (a score of −25 was used for MINUS images; 0 for ORIGINAL images; and +25 for PLUS images). In the following results description, effect sizes for nonsignificant values are reported where relevant if p was < .1.

A two-way, mixed-design ANOVA was conducted with the between-subjects factor of adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-subjects factor of transfer level (pictorial, structural, and cross-identity). There was no significant main effect of adaptation group, $F(2, 45) = 30.553$, $p = .053$, $\eta_p^2 = .122$ (MINUS EXTREME: $M = -6.29$, $SD = 4.82$; ORIGINAL: $M = -4.61$, $SD = 5.67$; PLUS EXTREME: $M = -1.69$, $SD = 5.25$). Furthermore, there was no main effect of transfer level, $F(2, 90) < 1$, $p = .700$, but there was a significant interaction of adaptation group and transfer level, $F(4, 90) = 2.803$, $p = .038$, $\eta_p^2 = .111$ (see Figure 5E for an illustration).

Univariate ANOVAs of adaptation group showed a large effect for the pictorial transfer level, $F(2, 45) = 4.904$, $p = .012$, $\eta_p^2 = .179$, but did not show a large effect either for the structural, $F(2, 45) = 1.451$, $p = .245$, or cross-identity transfer level, $F(2, 45) = 3.044$, $p = .058$, $\eta_p^2 = .119$. However, multiple comparisons revealed a significant difference between the MINUS EXTREME and PLUS EXTREME groups for the cross-identity transfer level, $p = .018$. Accordingly, an adaptation effect can be assumed (although mitigated) for both the pictorial and the cross-identity transfer level. Only within the PLUS EXTREME adaptation group, a greater effect was observed for the pictorial compared to the cross-identity transfer level, $p = .042$. Other pairwise comparisons of the transfer levels within the three groups showed no significant differences, $ps > .60$. Thus, the results indicate that faces strongly altered in brightness can bias the subsequent perception of identical images and other identities over a period of at least 5 minutes. As in Experiments 1 and 4, the pictorial transfer level showed the largest effects, indicating an image-specific component within the revealed adaptation effect. However, since there was also an effect for the cross-identity transfer level, the adaptation effect cannot be entirely image-specific, but must somehow affect also higher concepts of faces. As in the previous experiments, there was a shift in the average selection of all participant groups toward the negative pole (see Figure 5E), $M = -4.20$; one sample t-test: $t(47) = -5.303$ (one-tailed); $p < .001$; $d = -0.765$. Thus, the total average value across all groups deviated significantly from the anticipated value of zero (see Experiment 1 for further explanation). This implies that, overall, the participants selected images with a lower brightness than expected.

GENERAL DISCUSSION

Studies investigating face adaptation effects can contribute to the understanding of how faces are perceived and how they are mentally represented in memory. However, up to now, the literature on face adaptation has mainly focused on configural face information, neglecting the role of non-configural information such as color or brightness. Thus, the experiments reported here tried to provide an elaborated insight into the role of non-configural face information in the perception and retention of faces.

Existence of Non-configural Adaptation Effects and Their Face Specificity

The results of the reported experiments indicate that adaptation effects occur for non-configural (i.e., brightness) face information. The exposure to the applied alterations in brightness caused a clear bias (Experiments 1, 4, and eventually 5) in the perception of subsequent faces. Original faces were subsequently perceived as shifted away from the adaptor, while the likelihood increased that slightly manipulated faces (in the direction of the adaptor) would be perceived as the veridical version. Experiments 2 and 3 revealed that the reported effects seem to be rather face-specific. Indeed, we were unable to detect any adaptation effects when using non-face stimuli (unrecognizable, scrambled faces) altered in brightness as adaptors. This suggests that alterations in brightness as such are not able to provoke a shift in the perception of brightness in faces. We interpret this as contextual-dependent face adaptation effects—specifically, that adaptation to a manipulated dimension (e.g., brightness) is linked to the specific context (e.g., faces) in which the manipulation is applied. Thus, adaptation effects on brightness alterations in faces might be provoked only by adaptors showing faces. Experiment 3 used inverted face stimuli as adaptors in order to investigate whether this face-specificity is only superficially available as a certain Gestalt factor of being a face or whether it is based on the expertise-based processing modes of (upright) faces (Schwaninger et al., 2003). As Experiment 3 did not show any adaptation effect, we furthermore agreed on the hypothesis that the adaptation effects found in Experiment 1 are face-specific, or at least specifically face-sensitively operating.

Experiments 1, 4, and 5 revealed a shift in the average selection of all participants toward the negative pole. Thus, on average, participants tended to select celebrity faces with a reduced brightness as the original images. This could be caused by a very strong adaptation effect of the MINUS EXTREME adaptation group and/or by a relatively weaker adaptation effect of the PLUS EXTREME adaptation group. Also, a shift of the control (ORIGINAL) group toward the negative range could account for this overall bias toward the negative range. Moreover, the participants in Experiments 2 and 3 also showed an overall bias toward the negative range, although no adaptation effects were revealed in these experiments. Thus, in sum, these results indicate that participants somehow tended to choose images decreased in brightness when asked to select the veridical images. The underlying factors for this bias are not clear yet. It could be that participants perceive brighter images to be slightly manipulated (since, on average, they were not selected as often as darker images). This impression might arise due to the darkened test cabins. The darkening of the test cabins could cause brighter

TABLE 1.
Overview of the Effects and Effect Sizes of the Individual Studies

Experiment 1	p	Effect size
Adaptation group	.001	$\eta_p^2 = .380$
Pictorial	.001	$\eta_p^2 = .456$
Structural	.001	$\eta_p^2 = .320$
Cross-identity	.001	$\eta_p^2 = .288$
Experiment 2		
Adaptation group	.730	-
Pictorial	.460	-
Structural	.944	-
Cross-identity	.782	-
Experiment 3		
Adaptation group	.316	-
Pictorial	.110	-
Structural	.493	-
Cross-identity	.481	-
Experiment 4		
Adaptation group	.001	$\eta_p^2 = .393$
Pictorial	.001	$\eta_p^2 = .477$
Structural	.001	$\eta_p^2 = .381$
Cross-identity	.001	$\eta_p^2 = .261$
Experiment 5		
Adaptation group	.053	$\eta_p^2 = .112$
Pictorial	.012	$\eta_p^2 = .179$
Structural	.245	-
Cross-identity	.058	$\eta_p^2 = .119$

Note. Adaptation group = main effect of the between factor *adaptation group* (all transfer levels included); pictorial = effect of the between factor *adaptation group* on the transfer level pictorial; structural = effect of the between factor *adaptation group* on the transfer level structural; cross-identity = effect of the between factor *adaptation group* on the transfer level cross-identity. Effects are only shown if the respective p value was below the preset alpha threshold of .05.

images to be perceived as too bright (this impression should be familiar, e.g., when we reduce the illumination of our cell phone displays in a poorly lit environment), so that participants might have tended to choose darker images as the original image. Another reason could be that an increase in brightness is more obvious as an image manipulation. Hence, participants would clearly identify brighter images as manipulated and would reject them when asked to choose the veridical one. However, the difference between the ORIGINAL image and the slightly decreased version (MINUS) may not be as easy to identify, so that participants might have selected the decreased version in some trials (while rejecting all PLUS versions), resulting in an overall bias into the slightly negative range. Future studies should investigate possible anomalies in the perception of different brightness levels in order to clarify the underlying factors for the bias identified in our experiments.

Processing Levels of Non-configural Adaptation Effects

Experiment 4 showed that the reported adaptation effects are still present after a delay of 3 s. Experiment 5 also demonstrated effects after a delay of 5 min. Since the brightness of the adaptor stimuli was held constant throughout all experiments, the adaptation effects in Experiment 1 could probably also be considered to be "long-term" (however, boosted by short-term adaptation effects within trials). Thus, adaptation effects on brightness alterations might even last 40 minutes (across the entire experiment) when intensified by trialwise adaptation effects. However, the results of Experiment 5 indicated adaptation effects that are even more robust without any intensification by trialwise adaptation procedures. By implementing a blockwise procedure (i.e., separated adaptation and test phase), Experiment 5 revealed adaptation effects up to 50 minutes. These results indicate that the adaptation effects are not just on a sensory basis or based on simple iconic traces (see, Carbon et al., 2007), but that they affect at least the short-term memory or might even involve long-term memory components (Atkinson & Shiffrin, 1971; Peterson & Peterson, 1959; Sperling, 1960). Also, recency effects cannot be considered as the decisive factor for the observed adaptation effects. Previous studies were able to demonstrate that distracting tasks eliminate the recency effects (Glanzer & Cunitz, 1966). Thus, at least in Experiment 5, recency effects could not be effective since in this experiment, a distractor task was introduced that required the reading of a geographical text. Furthermore, the effects on the cross-identity level (and to some extend also on the structural level) rather contradict a recency effect, since the adaptation and test stimuli differed tremendously.

Based on these results on facial brightness adaptation, it seems that brightness probably is part of the facial representation in memory, and thus of the mental face space. By adapting to brightness alterations, the manipulations are integrated into the mental representation or mental norm of the presented celebrities. This integration mechanism causes a shift of the representations along the brightness dimension toward the adaptor (e.g., after seeing the extremely decreased brightness version, the mental representation shifts along the continuum representing the brightness dimension toward the more decreased brightness pole). Subsequently, stimuli that are more similar to the adaptor are then perceived as more normal or natural, so that participants tend to choose the slightly manipulated versions as the veridical images. Stimuli that are similar to the initial mental representation (i.e., the ORIGINAL image) appear as being slightly manipulated in the opposite direction to the adaptor (Mueller et al., 2020).

Storing brightness alterations in facial memory might not appear very plausible at first glance. Since brightness information is very variable and transient (e.g., changes in illumination alter the brightness of a face), it does not seem to be a stable and characteristic property of a face. Moreover, brightness alterations caused by illumination are often perceptually deducted in order to decode the basic and characteristic color of a persons' face. However, the basic color of a face appears to be a relevant information to store in memory because it can provide valuable information about, for example, an individual's state of health or their ethnic background. In our adaptation paradigm, we altered the brightness of faces independent of the context. Thus, it could be assumed that the alterations in brightness are perceived as inherent in the face when taking into account the unchanging context conditions. This could explain a longer-term retention of brightness alterations.

Future studies could investigate this issue even further by altering the brightness of the entire image and thus also of the context. Moreover, an extension of the time interval between the adaptation and test phases could clarify whether brightness information is stored even for a longer period of time than just 50 minutes (see e.g., Carbon & Ditye, 2011; Carbon & Leder, 2006; Carbon et al., 2007).

An extension of the time interval could also reveal whether the effects are of a temporary or permanent nature. Experiment 5 indicated that the adaptation effects might not be very permanent, since they seem to have been attenuated compared to Experiment 1 (see also Table 1). This might reflect some kind of "resetting" mechanism, which can also be observed in adaptation studies applying configural alterations (see e.g., Carbon & Ditye, 2011; Carbon & Leder, 2005; Carbon et al., 2007; Strobach et al., 2011). There are two explanations for this decay of effect. It could either occur as an automatic (passive) process due to the robustness of the original representation of a face (i.e., the preadaptation version). Alternatively, the delay between the adaptation and test phases might provide an opportunity for a re-encounter with the original image (whether mental or real). This could then lead to a readaptation mechanism back to the original (preadaptation) image (see e.g., Carbon & Ditye, 2011; Mueller et al., 2020). To the authors' knowledge, the nature of the recalibration process is not yet fully understood. Hence, future studies systematically investigating the link between temporal aspects and recalibration mechanisms would be of great benefit. Moreover, future studies should also compare the robustness of adaptation effects on configural versus non-configural face information. Studies of this kind could reveal possible differences in the valence of facial information for face perception and/ or representation. It could be possible, for instance, that adaptation to color alterations is less robust than adaptation to configural face information since color alterations are naturally very transient (e.g., due to different lightning conditions). Thus, it could be assumed that more transient information would probably not be processed on a very high level and hence would also have a less important role in storing (for a discussion on the valence of different face information see e.g., Mueller et al., 2020; Yamashita et al., 2005).

Experiments 1, 4, and 5 indicated not only a general adaptation effect, but also revealed different transfer effects. For Experiments 1 and 4, adaptation effects could be demonstrated for all transfer levels (pictorial, structural, and cross-identity). The results revealed a specific pattern: The pictorial transfer level shows numerically a larger effect compared to the structural and the cross-identity levels (see Table 1). This pattern could also be found in adaptation studies altering configural face information (e.g., Carbon & Ditye, 2011; Strobach et al., 2011). Although the adaptation effect seems to transfer across images of the same and different identities, there must be an image-specific component within this effect. Thus, when presenting images that differ from the adaptor, the image-specific component would be absent, leading to a lower effect on the structural and cross-identity levels.

The results on the structural level indicate that adaptation transfers well across different images of the same identity. Thus, the adaptation effects are not just image-specific, but must also have some kind of identity-specific component. Furthermore, these results support the view that the face representations stored in memory must be quite flexible, since adaptation occurs despite great differences between the stimuli (i.e., adaptation and test stimuli). The facial representations must either contain a large variety of facial information or a basic and minimalistic facial structure, allowing a face to be recognized despite various changes. However, the nature of facial representations is not yet clear. Since adaptation effects occur by altering very diverse face information, a face representation containing a large variety of information seems to be more likely (see, Mueller et al., 2020).

While the results on the structural transfer level support the assumption that the observed adaptation effects are somehow identity-specific, the results on the cross-identity level indicate that the effects also transfer between identities. This suggests some kind of hierarchical processing where adaptation affects not only a specific face representation, but also superordinate category representations (e.g., prototype representations of different ethnicities, genders, etc.) or a generic face norm (i.e., a prototype for faces in general) that also leads to alterations in other face representations belonging to a given subpopulation. Hence, adaptation must somehow alter underlying face structures, common face information, or face dimensions, leading to an adaptation effect in faces other than the observed one (Carbon & Ditye, 2011; Jaquet & Rhodes, 2008; Jaquet, Rhodes, & Hayward, 2008; Rhodes et al., 2005). With regard to the results of Experiments 2 (i.e., no adaptation effect when presenting scrambled faces) and 3 (i.e., no adaptation effect when presenting inverted faces), the adaptation effects on the different transfer levels clearly underline the face specificity of the observed effects. For example, adaptation effects occur across identical images (pictorial level) and despite extreme differences of the adaptation and test stimuli (structural and cross-identity levels) as long as the images display faces. However, identical images also showing faces but being rotated by 180 ° do not provoke adaptation effects because the face processing is disrupted.

While in Experiments 1 and 4, adaptation effects could be observed for all transfer levels, adaptation effects in Experiment 5 only occurred on a pictorial and (probably) on a cross-identity level (see Table 1). It remains unclear why a structural transfer did not occur. It is not reasonable that the adaptation has an impact on the generic face norm or a category representation (e.g., gender), but not on the representation of the observed identity. If a superordinate representation is altered through adaptation, then the representation of the specific identity belonging to this superordinate category should be altered, too. A more detailed analysis of the data revealed an irregularity within the MINUS EXTREME adaptation group. From a descriptive perspective, one participant of this group scored very high compared to the mean of the group (M_{group} = −6.28; $M_{participant}$ = +5.98) and was the only one showing a value within the positive range. When excluding the participant from the data analysis, an effect for the main factor of adaptation group was revealed which was absent before, $F(2, 45) = 4.622$; $p = .015$; $\eta_p^2 = .174$. When analyzing the interaction, $F(4, 42) = 2.528$; $p = .050$; $\eta_p^2 = .103$, more specific, univariate ANOVAs of the factor adaptation group showed an effect of the pictorial, $F(2, 45) = 6.639$, $p = .003$, $\eta_p^2 = .232$, and cross-identity transfer levels, $F(2, 45) = 4.501$, $p = .017$, $\eta_p^2 = .170$, but no effect for the structural transfer level, $F(2, 45) = 2.242$, $p = .118$. However, multiple comparisons also revealed an adaptation effect on the structural level between the MINUS EXTREME and PLUS EXTREME adaptation groups, $p = .046$. Thus, the non-representative response behavior of the participants might account for the missing adaptation effect on the structural transfer level. However, other reasons cannot be identified by the authors.

The reported experiments clearly show that adaptation also occurs for non-configural face alterations, here operationalized by brightness. The effects probably operate not just on a sensory level, but also affect representational memory. While previous studies investigating non-configural face information mainly emphasized the role of this type of face information in face perception (e.g., Lee & Perrett, 1997; Liu et al., 2005; Rakover & Teucher, 1997; Yamashita et al., 2005), the reported experiments clearly demonstrate that non-configural face information is also stored (probably on a long-term basis) in memory. Thus, non-configural face information most probably plays a significant role in face identification. The constant update of the information enclosed in the mental representations stored in memory probably facilitates the recognition and differentiation of specific faces from other faces. However, an updating of superordinate category representations or generic norms (i.e., on the cross-identity level) most likely results in a more accurate prototype of specific face categories (e.g., ethnicity, gender, etc.), also leading to a better and more efficient differentiation of different face categories and, thus, faces in general. Being equipped with such an ability to adapt our sensory system provides a stable perception of the faces surrounding us despite the ongoing variations to which they are exposed.

Conclusion

We think that the reported experiments give a deeper insight into the theoretical understanding of face perception and the mental representation of faces. While previous studies on non-configural face information were able to demonstrate the relevance of non-configural face information in face perception, our adaptation study also revealed the role of non-configural information in the retention of faces. This was done by addressing adaptation effects on brightness alterations. The reported experiments clearly show very robust face-specific adaptation effects on brightness alterations that probably alter the mental face representations enduringly. Thus, brightness information, although very transient in a natural context, seems to be stored in memory and is most probably involved when identifying familiar faces. However, future studies should investigate even longer time ranges between the adaptation and test phases in order to determine whether adaptation effects on non-configural face information is as robust and sustainable as adaptation effects on configural face information. This also includes adaptation studies on further non-configural face information in order to understand the qualities and amounts of information responsible for fast, flexible and accurate recognition of faces. This might help to define which face information is generally stored in memory and whether these different types of information have the same valence and longevity in storage.

ACKNOWLEDGEMENTS

This research was kindly supported by a grant to Claus-Christian Carbon and Tilo Strobach from the Deutsche Forschungsgemeinschaft (DFG, CA 917/7-1; STR 1223/4-1). We would like to thank Kim Sievers, Salman Wakilzada, Romy Staedtler and Maximilian Kischkat for their assistance in data collection.

Parts of the data reported here were presented as preliminary data at the following conferences: Annual Meeting of the Psychonomic Society (2018, New Orleans; 2019, Montréal), Annual Meeting of Experimental Psychologists (2019, London), European Conference on Visual Perception (2019, Leuven), Conference of the European Society for Cognitive Psychology (2019, Tenerife)

FOOTNOTES

[1] Musicians (Adele, Amy Winehouse, Ed Sheeran, Justin Bieber, Justin Timberlake, Katy Perry, Pink, Rihanna, Selena Gomez), actors (Cameron Diaz, Daniel Radcliffe, Elyas M'Barek, Emma Watson, George Clooney, Jennifer Aniston, Leonardo DiCaprio, Til Schweiger, Will Smith), politicians (Angela Merkel, Barack Obama, Donald Trump, Queen Elizabeth, Vladimir Putin), sport celebrities (Boris Becker, Cristiano Ronaldo, Joachim Löw), models (Heidi Klum, Paris Hilton) and entertainers (Thomas Gottschalk, Dieter Bohlen).

[2] Thus, the greatest possible adaptation effect toward a reduced brightness would be reflected by always selecting a MINUS image (score of -25) in trials displaying a MINUS image and an ORIGINAL in the test phase and an ORIGINAL image (score of 0) in trials displaying an ORIGINAL and a PLUS image in the test phase. The greatest possible adaptation effect toward an increased brightness would be reflected by always selecting a PLUS image (score of +25) in trials displaying a PLUS image and an ORIGINAL in the test phase and an ORIGINAL image (score of 0) in trials displaying an ORIGINAL and a MINUS image in the test phase. Since the test trial versions are balanced across the experiment, the dependent variable can range from -12.5 to +12.5 maximum.

REFERENCES

Atkinson, R. C., & Shiffrin, R. M. (1971). *The control processes of short-term memory*. Retrieved from Stanford, California.

Bach, M. (1996). The Freiburg Visual Acuity Test - Automatic measurement of visual acuity. *Optometry and Vision Science, 73*(1), 49–53. doi:10.1097/00006324-199601000-00008

Cabeza, R., & Kato, T. (2000). Features are also important: Contributions of featural and configural processing to face recognition. *Psychological Science, 11*(5), 429–433. doi:10.1111/1467-9280.00283

Carbon, C. C., & Ditye, T. (2011). Sustained effects of adaptation on the perception of familiar faces. *Journal of Experimental Psychology: Human Perception and Performance, 37*(3), 615–625. doi:10.1037/

a0019949

Carbon, C. C., & Ditye, T. (2012). Face adaptation effects show strong and long-lasting transfer from lab to more ecological contexts. *Frontiers in Psychology, 3*(2), 1–6. doi:10.3389/fpsyg.2012.00003

Carbon, C. C., & Leder, H. (2005). Face adaptation: Changing stable representations of familiar faces within minutes? *Advances in Cognitive Psychology, 1*(1), 1–7. doi:10.2478/v10053-008-0038-8

Carbon, C. C., & Leder, H. (2006). The Mona Lisa effect: Is 'our' Lisa fame or fake? *Perception, 35*(3), 411–414. doi:10.1068/p5452

Carbon, C. C., Strobach, T., Langton, S. R. H., Harsányi, G., Leder, H., & Kovács, G. (2007). Adaptation effects of highly familiar faces: Immediate and long lasting. *Memory & Cognition, 35*(8), 1966–1976. doi:10.3758/bf03192929

Clifford, C. W. G. (2002). Perceptial adaptation: motion parallels orientation. *Trends in Cognitive Sciences, 6*, 136–143. doi:10.1016/S1364-6613(00)01856-8

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175–191. doi:10.3758/BF03193146

Fox, C. J., & Barton, J. J. S. (2007). What is adapted in face adaptation? The neural representations of expression in the human visual system. *Brain Research, 1127*(1), 80–89. doi:10.1016/j.brainres.2006.09.104

Ghuman, A. S., McDaniel, J. R., & Martin, A. (2010). Face adaptation without a face. *Current Biology, 20*(1), 32–36. doi:10.1016/j.cub.2009.10.077

Gibson, J. J. (1933). Adaptation, after-effect and contrast in the perception of curved lines. *Journal of Experimental Psychology, 16*, 1–31. doi:10.1037/h0074626

Glanzer, M., & Cunitz, A. R. (1966). Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behaviour, 5*(4), 351–360. doi:10.1016/S0022-5371(66)80044-0

Ishihara, S. (1917). *Tests for Colour Blindness*. Tokyo: Handaya Hongo Harukuch.

Jaquet, E., & Rhodes, G. (2008). Face aftereffects indicate dissociable, but not distinct, coding of male and female faces. *Journal of Experimental Psychology: Human Perception and Performance, 34*(1), 101–112. doi:10.1037/0096-1523.34.1.101

Jaquet, E., Rhodes, G., & Hayward, W. G. (2008). Race-contingent aftereffects suggest distinct perceptual norms for different race faces. *Visual Cognition, 16*(6), 734–753. doi:10.1080/13506280701350647

Köhler, W., & Wallach, H. (1944). Figural aftereffects: An investigation of visual processes. *Proceedings of the American Philosophical Society, 88*, 269–357.

Lai, M., Oruc, I., & Barton, J. J. (2012). Facial age after-effects show partial identity invariance and transfer from hands to faces. *Cortex, 48*(4), 477–486. doi:10.1016/j.cortex.2010.11.014

Lee, K. J., & Perrett, D. (1997). Presentation-time measures of the effects of manipulations in colour space on discrimination of famous faces. *Perception, 26*(6), 733–752. doi:10.1068/p260733

Leopold, D. A., O'Toole, A. J., Vetter, T., & Blanz, V. (2001). Prototype-referenced shape encoding revealed by high-level aftereffects. *Nature Neuroscience, 4*(1), 89–94. doi:10.1038/82947

Liu, C. H., Collin, C. A., Farivar, R., & Chaudhuri, A. (2005). Recognizing faces defined by texture gradients. *Perception & Psychophysics, 67*(1), 158–167. doi:10.3758/BF03195019

Macho, S., & Leder, H. (1998). Your eyes only? A test of interactive influence in the processing of facial features. *Journal of Experimental Psychology: Human Perception and Performance, 24*(5), 1486–1500. doi:10.1037/0096-1523.24.5.1486

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences, 6*(6), 255–260. doi:10.1016/S1364-6613(02)01903-4

Meinhardt-Injac, B., Persike, M., & Meinhardt, G. (2013). Holistic face processing is induced by shape and texture. *Perception, 42*(7), 716–732. doi:10.1068/p7462

Mondloch, C. J., Le Grand, R., & Maurer, D. (2002). Configural face processing develops more slowly than featural face processing. *Perception, 31*(5), 553–566. doi:10.1068/p3339

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2020). Face adaptation and face priming as tools for getting insights into the quality of face space. *Frontiers in Psychology, 11*(166), 1–17. doi:10.3389/fpsyg.2020.00166

Nestor, A., & Tarr, M. J. (2008). Gender recognition of human faces using color. *Psychological Science, 19*(12), 1242–1246. doi:10.1111/j.1467-9280.2008.02232.x

O'Neil, S. F., & Webster, M. A. (2011). Adaptation and the perception of facial age. *Visual Cognition, 19*(4), 534–550. doi:10.1080/13506285.2011.561262

Otten, M., & Banaji, M. R. (2012). Social categories shape the neural representation of emotion: Evidence from a visual face adaptation task. *Frontiers in Integrative Neuroscience, 6*, 9. doi:10.3389/fnint.2012.00009

Peterson, L., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58*(3), 193–198. doi:https://doi.org/10.1037/h0049234

Rakover, S. S., & Teucher, B. (1997). Facial inversion effects: Parts and whole relationship. *Perception & Psychophysics, 59*(5), 752–761. doi:10.3758/BF03206021

Rhodes, G., Robbins, R., Jaquet, E., McKone, E., Jeffery, L., & Clifford, C. W. G. (2005). Adaptation and face perception – How aftereffects implicate norm-based coding of faces. In C. W. G. Clifford & G. Rhodes (Eds.), *Fitting the mind to the world – Adaptation and after-effects in high-level vision* (1st ed., pp. 213–240). Oxford University Press.

Schwaninger, A., Carbon, C. C., & Leder, H. (2003). Expert face processing: Specialization and constraints. In G. Schwarzer & H. Leder (Eds.), *The development of fac processing* (pp. 81–97). Göttingen: Hogrefe & Huber.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs: General and Applied, 74*(11), 1–29. doi:10.1037/h0093759

Strobach, T., & Carbon, C. C. (2013). Face adaptation effects: reviewing the impact of adapting information, time, and transfer. *Frontiers in Psychology, 4*, 318. doi:10.3389/fpsyg.2013.00318

Strobach, T., Ditye, T., & Carbon, C.-C. (2011). Long-term adaptation effects of highly familiar faces are modulated by adaptation duration. *Perception, 40*(8), 1000–1004. doi:10.1068/p6986

Suzuki, S. (2005). High-level pattern coding revealed by brief shape aftereffects. In C. W. G. Clifford & G. Rhodes (Eds.), *Fitting the mind to the world: Adaptation and after-effects in high-level vision* (pp. 135–172). Oxford University Press Inc.

Tan, L., & Ward, G. (2000). A recency-based account of the primacy effect in free recall. *Journal of Experimental Psychology, 26*(6), 1589–1625. doi:10.1037//0278-7393.26.6.1589

Turvey, M. T. (1973). On peripheral and central processes in vision: Inferences from an information-processing analysis of masking with patterned stimuli. *Psychological Review, 80*(1), 1–52. doi:10.1037/h0033872

Valentine, T. (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *British Journal of Psychology, 79*(4), 471–491. doi:10.1111/j.2044-8295.1988.tb02747.x

Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *The Quarterly Journal of Experimental Psychology Section A, 43*(2), 161–204. doi:10.1080/14640749108400966

Valentine, T., Lewis, M. B., & Hills, P. J. (2016). Face-space: A unifying concept in face recognition research. *The Quarterly Journal of Experimental Psychology, 69*(10), 1996–2019. doi:10.1080/17470218.2014.990392

Webster, M. A., Kaping, D., Mizokami, Y., & Duhamel, P. (2004). Adaptation to natural facial categories. *Nature, 428*, 557–561. doi:10.1038/nature02420

Webster, M. A., & MacLeod, D. I. (2011). Visual adaptation and face perception. *Philosophical transactions of the Royal Society of London. Series B, Biological Sciences, 366*(1571), 1702–1725. doi:10.1098/rstb.2010.0360

Webster, M. A., & MacLin, O. H. (1999). Figural aftereffects in the perception of faces. *Psychonomic Bulletin & Review, 6*(4), 647–653. doi:10.3758/BF03212974

Yamashita, J. A., Hardy, J. L., De Valois, K. K., & Webster, M. A. (2005). Stimulus selectivity of figural aftereffects for faces. *Journal of Experimental Psychology: Human Perception and Performance, 31*(3), 420–437. doi:10.1037/0096-1523.31.3.420

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology, 81*(1), 141–145. doi:10.1037/h0027474

RECEIVED 18.05.2020 | ACCEPTED 27.04.2021

4 Third manuscript: Face adaptation – Investigating non-configural saturation alterations

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2021). Face adaptation – Investigating nonconfigural saturation alterations. *i-Perception*. 12(6), 1-24. doi: 10.1177/20416695211056362

Open Access (CC BY 3.0), © 2022 SAGE Publications

Check for updates

Standard Article

i-PERCEPTION

i-Perception
2021, Vol. 12(6), 1–24
© The Author(s) 2021
DOI: 10.1177/20416695211056362
journals.sagepub.com/home/ipe
SAGE

Face Adaptation—Investigating Nonconfigural Saturation Alterations

Ronja Mueller [1,2], **Sandra Utz** [2,3,4], **Claus-Christian Carbon** [2,3,4], **and Tilo Strobach** [1]

[1]Department of Psychology, Medical School Hamburg, Hamburg, Germany
[2]Bamberg Graduate School of Affective and Cognitive Sciences (BaGrACS), University of Bamberg, Bamberg, Germany
[3]Department of General Psychology and Methodology, University of Bamberg, Bamberg, Germany
[4]Research Group EPÆG (Ergonomics, Psychological Æsthetics, Gestalt), Bamberg, Germany

Abstract

Recognizing familiar faces requires a comparison of the incoming perceptual information with mental face representations stored in memory. Mounting evidence indicates that these representations adapt quickly to recently perceived facial changes. This becomes apparent in face adaptation studies where exposure to a strongly manipulated face alters the perception of subsequent face stimuli: original, non-manipulated face images then appear to be manipulated, while images similar to the adaptor are perceived as "normal." The face adaptation paradigm serves as a good tool for investigating the information stored in facial memory. So far, most of the face adaptation studies focused on configural (second-order relationship) face information, mainly neglecting non-configural face information (i.e., that does not affect spatial face relations), such as color, although several (non-adaptation) studies were able to demonstrate the importance of color information in face perception and identification. The present study therefore focuses on adaptation effects on saturation color information and compares the results with previous findings on brightness. The study reveals differences in the effect pattern and robustness, indicating that adaptation effects vary considerably even within the same class of non-configural face information.

Keywords

face adaptation, face perception, face memory, non-configural face information, color information, saturation information

Date received: 26 February 2021; accepted: 12 October 2021

Corresponding author:
Ronja Mueller, Department of Psychology, Medical School Hamburg, Am Kaiserkai 1, 20457 Hamburg, Germany; Bamberg Graduate School of Affective and Cognitive Sciences (BaGrACS), University of Bamberg, Bamberg, Germany.
Email: ronja.mueller@medicalschool-hamburg.de

Creative Commons CC BY: This article is distributed under the terms of the Creative Commons Attribution 4.0 License (https://creativecommons.org/licenses/by/4.0/) which permits any use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (https://us.sagepub.com/en-us/nam/open-access-at-sage).

Introduction

Major theories propose that humans identify faces by matching them against mental representations stored and categorized in long-term memory (Bruce & Young, 1986). Different lighting conditions, perspectives, and fluctuant variations of faces often cause them to appear differently than their mental representations stored in memory. However, despite these ongoing changes, we perceive our environment as stable, and we can reliably identify faces, especially if they are personally familiar (Carbon, 2008). This performance is ensured by continuously adjusting our mental representations to the dynamics of the environment. This adjusting process, which is commonly referred to as adaptation, can lead to a strong misperception in subsequently perceived faces. By integrating face alterations into our face representations, we perceive unaltered faces as being manipulated (since they do not match anymore with our updated representations; e.g., Carbon et al., 2007). Specifically, these items are perceived as being manipulated in the opposite direction to the adaptor. Face images slightly manipulated in the direction of the adaptor, however, would be perceived as "normal" or "natural" since the images correspond with the updated representation (e.g., Webster & MacLin, 1999).

Unlike the related phenomenon of afterimages (e.g., the color inverted image that continues to appear after the exposure to a visual stimulus) that is supposed to rely on retinal sensitivity adjustments, adaptation effects most probably address also later stages of the visual pathway (e.g., Carbon & Ditye, 2011; Webster & MacLeod, 2011). These high-level contributions are indicated by a significant number of face adaptation studies, revealing effects that are highly robust over time (e.g., Carbon et al., 2007; Carbon & Ditye, 2011, 2012; Strobach et al., 2011) and also transferable from one person's face to another person's face (e.g., Carbon et al., 2007). Simple retinal sensitivity adjustments (and also recency effects; see, e.g., Glanzer & Cunitz, 1966; Mueller et al., 2021; Tan & Ward, 2000) cannot explain the robustness and transferability of face adaptation effects but rather suggest a processing on a representational memory basis (e.g., Carbon et al., 2007; Carbon & Ditye, 2011).

Although many different types of face information have already been investigated using the adaptation paradigm (e.g., face information regarding expression, age, ethnicity, or gender; Fox & Barton, 2007; Lai et al., 2012; Little et al., 2008; Webster et al., 2004), most of the face adaptation studies focused on configural face information so far (i.e., second-order spatial relations between facial features; Maurer et al., 2002; Piepers & Robbins, 2012; for a review, see Strobach & Carbon, 2013). Studies investigating adaptation effects on nonconfigural face information (i.e., information that does not affect any relational aspects of the face), such as color, are rather rare. This is remarkable as there is mounting evidence revealing the importance of this type of information in face perception and identification. A loss of color, for example, might lead to recognition impairments, while different color alterations reveal information about the ethnic background or the health and emotional status of a person (e.g., Lee & Perrett, 1997; Levin & Banaji, 2006; Re et al., 2011; Thorstenson et al., 2019). Different color dimensions are, therefore, interpreted and perceived very differently. Due to the lack of adaptation studies on color, it is not yet clear, whether these differences in perception are also reflected in face memory. The current study aims to fill the gap of lacking non-configural color adaptation studies by focusing on face adaptation effects on saturation alterations and comparing these effects with effects of alternative color information (i.e., brightness).

Face Adaptation Effects on Color

One of the few existing face adaptation studies on color information is the study by Little et al. (2012). The authors used so-called color or shape transformed antifaces as adaptors. Antifaces are defined as faces that possess traits opposite to a specific identity in terms of a facial average (i.e., by defining the differences between a specific face and an average face that is created of many different faces, an antiface can be computed that lies on the mirror opposite). Antifaces transformed in color, for example, would be opposite in color composition compared to the original face image (e.g., originally blond hair would be probably darker and dark skin would become brighter in an antiface). The authors were able to show that participants' ability to recognize the corresponding celebrity in the average face was improved when adaptors displaying color or shape transformed antifaces of the celebrities are presented in advance. The revealed effects were stronger for shape than for color-transformed antiface adaptors. This improved recognizability is probably based on a shift of mental representations. When integrating the face traits of the antifaces into mental representations, the representations are altered toward these traits and thus also the representation of the average face. When looking at the image of the (original and unaltered) average face, it would then be perceived as having face traits opposite to the antiface since the original average face image does not correspond to the updated representation of the average face anymore. This way, participants would tend to identify the corresponding celebrity in the average face image (for further theoretical input on face representation see the literature on the so-called "face space"; e.g., Lewis, 2004; Valentine, 1991, 2001; Valentine et al., 2016). The study shows that color information is most likely integrated into mental representations. However, this study does not allow conclusions about specific color dimensions and their adaptation effects.

An adaptation study by Mueller et al. (2021) focused on one specific color dimension when investigating face adaptation effects. We used celebrity faces strongly manipulated in brightness (either strongly decreased or increased) as adaptors and presented slightly manipulated face images (also decreased or increased in brightness) and non-manipulated images in the test phase. When asking participants to choose the original (i.e., non-manipulated) image from the presented test images, participants showed a clear bias in their selection by choosing the test image that was more similar to the adaptor seen before (i.e., participants showed an adaptation effect). Since experiments, using nonface or inverted face stimuli altered in brightness as adaptors, were not able to evoke adaptation effects, the observed adaptation effects on celebrity faces seem to be face-specific. Furthermore, by varying the time interval between adaptation and test phase we investigated the robustness of effects. Since they lasted 300 ms, 3 s, and up to 5 min (maybe even up to 50 min across the entire experiment), the effects appear to be not just based on simple retinal sensitivity adjustments but on short-term or maybe even long-term memory processes. Thus, we assume that the observed adaptation effects also affect the face representations stored in memory. We found further evidence that the adaptation effects on brightness alterations affect rather late stages of the visual pathway and facial memory by applying different transfer dimensions in our adaptation paradigm. Different transfer dimensions are implemented by not only (1) presenting the identical face image in the adaptation and test phase (*pictorial* level), but also (2) presenting either different images of the same identity (*structural* level) or (3) even different identities in the adaptation and test phase (*cross-identity* level; for a review on other studies applying these transfer dimensions see Strobach & Carbon, 2013). Although the adaptation effects on the transfer levels structural and cross-identity were attenuated compared to the pictorial level, we observed an adaptation effect on all three transfer levels to a certain degree. This transferability of effects indicates that representations not just of a specific identity are altered through adaptation but also superordinate concepts that subsume different identities with common underlying structures (for more information on rather abstract face representations, see e.g., Carbon & Ditye, 2011; Leopold et al., 2001; Mueller et al., 2020; Strobach & Carbon, 2013).

To the knowledge of the authors, brightness information was the only type of specific color information investigated in face adaptation studies so far. However, previous findings suggest that different color dimensions are perceived and interpreted very differently. Tan and Stephen (2013), for example, were able to show that facial redness, compared to brightness, must be somehow perceived as more salient. Moreover, different color dimensions seem to be associated with different characteristics. Increased saturation, for example, is most likely associated with a person's emotional or health state (Re et al., 2011; Thorstenson et al., 2019). Brightness information, however, seems to refer to the person's relative skin tone when deducting contextual conditions (Levin & Banaji, 2006; Mueller et al., 2021). The few existing face adaptation studies (i.e., the studies by Little et al., 2012; Mueller et al., 2021) seem to be not yet able to capture this differentiation in the perception of facial color, and thus it is not clear yet whether differences in the perception of specific color dimensions are also reflected in mental face representation. It is, therefore, worth taking a more differentiated look at color information. Consequently, the present study aims to provide a greater variability of color adaptation studies by examining color information in the form of saturation alterations. Next to hue and brightness, saturation is one of the three core dimensions traditionally characterizing a perceived color (e.g., Burns & Shepp, 1988; Indow & Kanazawa, 1960). As the studies by Re et al. (2011) and Thorstenson et al. (2019) revealed (see above), saturation seems to provide essential information about a face. An investigation of the retention of saturation information in face memory and the comparison with brightness could therefore be of interest.

The Aim of the Study

The present study investigates (1) whether adaptation to saturation alterations (increased and decreased saturation) generally occurs, (2) whether adaptation effects are robust over time, (3) whether saturation adaptation effects are face-specific, and (4) whether adaptation effects on saturation alterations differ in their magnitude from effects on brightness alterations. Five experiments were conducted in total. Four of these experiments were based on the study procedure of Mueller et al. (2021), but investigated adaptation effects on saturation alterations. Three of these four experiments used celebrity images as adaptor stimuli. The other experiment was performed using non-face adaptation images (scrambled faces) that were manipulated in saturation. This experiment was conducted to clarify whether possible adaptation effects on saturation are selective for faces or whether they are general color aftereffects that also occur when presenting nonface stimuli. The three experiments using celebrity adaptation images altered in saturation differed in their time interval between adaptation and test phase. By increasing the time interval between the adaptation and test phase from very short to a relatively long time interval, the durability of possible adaptation effects can be investigated. The study outcomes could provide information about the processing level of adaptation effects on saturation information. They could clarify whether possible adaptation effects on saturation are processed on a sensory level only or if they affect also higher levels of the visual pathway and thus potentially also face representations (long-term adaptation affects probably higher levels of the visual pathway and thus more likely also face representations; see, e.g., Carbon et al., 2007; Carbon & Ditye, 2011). In all of these experiments, we implemented three different transfer levels: pictorial, structural, and cross-identity (for more detailed information see the description above of the study by Mueller et al., 2021). The implementation of these transfer dimensions might provide insights into the representational level at which adaptation effects can occur. To compare possible adaptation effects on saturation with adaptation effects on brightness, one further study was conducted using adaptation and test stimulus material manipulated in saturation and brightness. Hereby, the strength of the effects of both color alterations could be directly evaluated. In this experiment, only the pictorial dimension was tested.

The adaptation stimulus manipulation was performed differently depending on the group the participants belonged to: they were exposed to stimuli either (1) strongly decreased in saturation/brightness, (2) without any manipulation, or (3) increased in saturation/brightness. In all experiments, a two-alternative-forced-choice (2AFC) test was presented subsequently, instructing the participants to select the veridical image (i.e., the unaltered image) out of two different image versions, displaying a non-manipulated image and an image version slightly manipulated in saturation/brightness (i.e., decreased or increased saturation/brightness). In case an adaptation would occur, we expect the strong manipulations seen in the adaptation phase to be integrated into the face representations stored in the participants' memory leading to an alteration of the face representations toward the adaptor. Non-manipulated images would then be perceived as being manipulated in the opposite direction to the adaptor (e.g., after adapting to an image increased in saturation, a non-manipulated image would appear decreased in saturation, and vice versa). Hence, it would be expected that the participants select the face version that is more similar to the adaptor when being exposed to the 2AFC test.

Experiment 1

Experiment 1 aims to find out whether adaptation effects occur for nonconfigural saturation alterations. Hence, celebrity images strongly manipulated in saturation were presented as adaptors (i.e., decreased, original, and increased saturation) and we tested adaptation effects on the pictorial, structural, and cross-identity levels. Between the adaptation and test phase, we implemented a short time interval of 300 ms.

Method

Participants. Forty-eight undergraduate students from the Medical School Hamburg (30 females, 18 males, M_{age}: 24.2 years, range 20–38 years) participated in Experiment 1.

An a priori power analysis that was based on a 3 (between participants) by 3 (within participants) factor mixed-design analysis of variance (ANOVA) revealed a minimal sample size of $N = 45$ (Faul et al., 2007). Given an $\alpha = 0.05$ and a test power of $(1 - \beta) = 0.90$ the design was able to detect a medium–large effect size f of 0.25 (Cohen, 1988). Previous studies in our lab context mostly revealed medium–large up to medium-to-large adaptation effects when using similar, familiar (celebrity) faces (e.g., Carbon & Ditye, 2011; Mueller et al., 2021). Typically, we have not found small or very small effects, even if we used longer-termed experimental designs. This was the reason for assuming medium–large effects. To provide a balanced study design, we increased the sample size to $N = 48$, resulting in a test power of 0.93.

Participants were either rewarded with money (12 Euros) or recruited as part of teaching course requirements. All participants were naïve regarding the purpose of the experiment. Participants' vision was assessed with the Freiburg Visual Acuity and Contrast Test (Bach, 1996). Furthermore, a short version of the Ishihara color test (Ishihara, 1917) was employed to test for anomalies in color perception. Participation in the subsequent testing was limited to participants with normal or corrected-to-normal vision, according to these tests. We randomly assigned participants to one of three participant groups (presenting either adaptation stimuli decreased in saturation, nonmanipulated images, or images increased in saturation). All participants provided informed written consent. The study was approved by the ethics board of the Medical School Hamburg (date of application: March 9, 2017) and conducted according to the guidelines of the Declaration of Helsinki.

Apparatus and Stimuli. The apparatus and procedure closely follow Mueller et al. (2021). Seventy celebrity names were randomly collected from newspaper articles and by asking colleagues. For each celebrity, a photograph was selected and presented in a subsequent survey (92 participants; 66 females, mean age: 21.7 years, range: 18–30 years) in which participants were instructed to judge the celebrity's familiarity on a 5-point Likert scale (1 = *unfamiliar*; 5 = *very familiar*) and write down the celebrities' names (if known). The 30 celebrities[1] whose familiarity was rated highest and named most often were included as stimulus material in the subsequent tests. Two photos (A and B; other than the photos in the survey) were selected for each of the 30 celebrities, fulfilling the following criteria: the celebrity's full face was presented in frontal view, with a straight gaze, no glasses, and no hair covering any facial features (e.g., eyes, nose, or mouth). Furthermore, the images were of high resolution. All 30 celebrities were randomly assigned to 1 of 3 celebrity groups. Since two photos (A and B) were selected for each celebrity, there were a total of six different stimulus sets. These sets were used to create the three different transfer levels, pictorial, structural, and cross-identity, that differed in terms of the overlapping information between images presented in the adaptation and test phase (all transfer levels of the within-participants factor *transfer* are illustrated in Figure 1).

All images were manipulated by altering the saturation of the presented faces (without hair) in Adobe Photoshop CC (Version 19.0). Different levels of manipulations were applied resulting in five different image versions (manipulation of the saturation by −75%, −25%, 0%, + 25%, and +75%), as illustrated in Figure 2. The size of the images was ~330 × 412 pixels. Depending on which group the participants belonged to (between-participants factor), they either saw an unaltered image (0%, *ORIGINAL*), an image strongly decreased in saturation (−75%, *MINUS EXTREME*) or an image with a strongly increased saturation (+ 75%, *PLUS EXTREME*) as an adaptor. The adaptation stimuli of the MINUS EXTREME and PLUS EXTREME participant groups could obviously be identified as manipulations. During the test phase, the participants were exposed to two image versions, with one image always displaying the ORIGINAL photo and the other image showing a slightly manipulated version with either −25% saturation (MINUS) or +25% (PLUS). The term

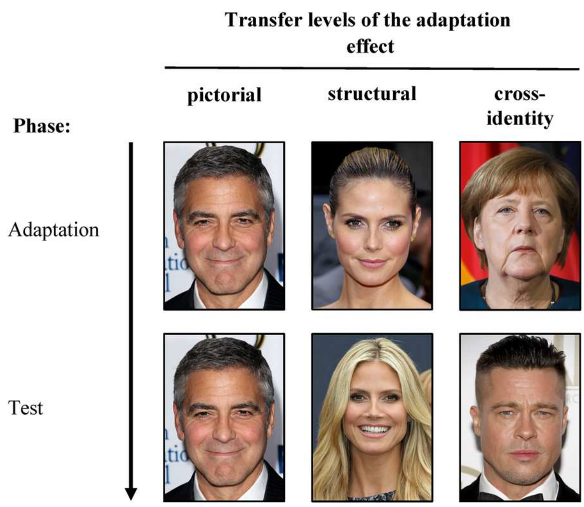

Figure 1. Illustration of the transfer levels pictorial, structural, and cross-identity. Each column represents a different transfer level. The pictorial transfer level describes a test condition where the images of the adaptation and test phase are pictorially identical (e.g., George Clooney as the adaptor and test stimulus). The structural transfer level is characterized by presenting different images of the same identity (e.g., different images of Heidi Klum as the adaptor and test stimulus) and on the transfer level cross-identity, images of the adaptation and test phase even displayed different identities (Angela Merkel as the adaptor and Brad Pitt displayed as the test stimulus). The images were not used in the original study but are displayed here for illustrative purposes only. The figure is taken from Mueller et al. (2021). Permissions and image licenses have been obtained from the copyright holders (Sources: ©Drop of Light/Shutterstock.com, Tinseltown/Shutterstock.com, s_bukley/Shutterstock.com).

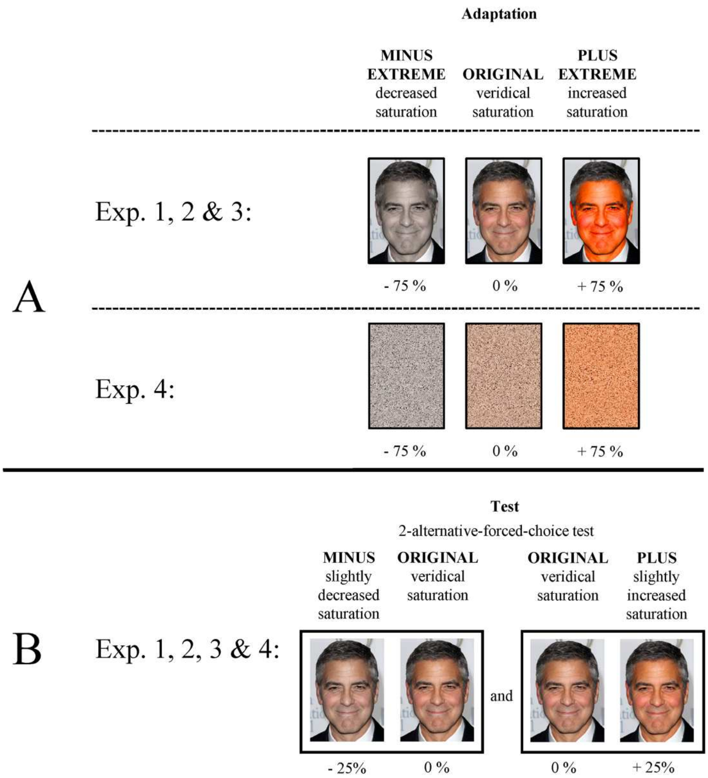

Figure 2. The different image versions are illustrated by the face of George Clooney. (a) Illustration of the different adaptor versions in Experiments 1 to 4. Experiments 1 to 3 use the same adaptation images. Experiment 4 applies scrambled versions of the adaptor images used in Experiments 1 to 3. (b) Illustration of the image versions during the test phase in Experiments 1 to 4. Within the 2-alternative-forced-choice (2AFC) test, two images are displayed (the original image together with an image either decreased or increased in saturation). The position of the images (centered left or centered right) alternated. The illustration is adapted from Mueller et al. (2021). Permissions and image licenses have been obtained from the copyright holders (Sources: ©Drop of Light/Shutterstock.com).

ORIGINAL image should be treated with caution since it might not display a completely unaltered image. Previous manipulations (although not obvious) carried out by the photographer, for example, may have been applied, and thus the identity might be presented in an edited way. Therefore, the term ORIGINAL image rather indicates that the image has not been altered in saturation. Moreover, since possible manipulations are not obvious, the face images should sufficiently reflect our accumulated experience with the presented identities. The experiment was created in Experiment Builder 2.2.1 (SR Research) and run on a Lenovo PC with a 23″ computer screen running at a resolution of 1,920 × 1,080 pixels.

Procedure. As illustrated in Figure 3, each trial included both the adaptation and test phase. All trials started with a fixation cross, presented in the center of the subsequent stimulus position for 500 ms. Subsequently, the adaptor was displayed, showing either the ORIGINAL image or one of the two extreme manipulations (MINUS EXTREME or PLUS EXTREME), depending on which group the participants belonged to (see Figure 2 for an illustration). Following the procedure of Carbon et al. (2007), the adaptor images were presented in one of six different screen positions (top-left, top-

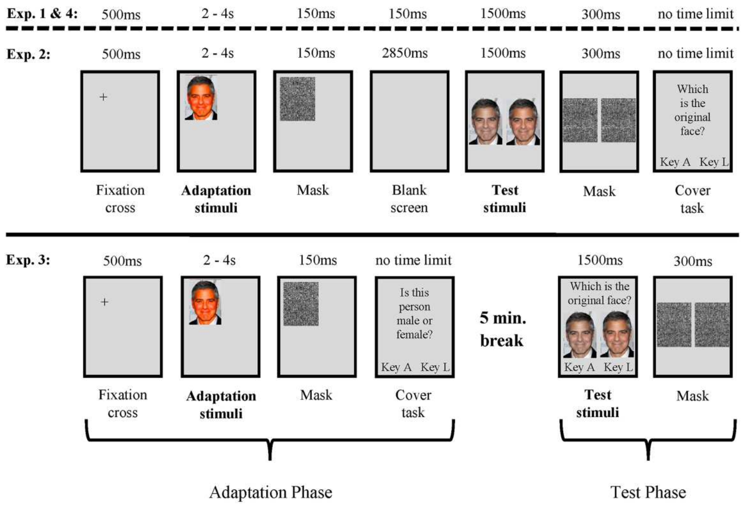

Figure 3. Schematic illustration of the trial structure of Experiments 1 to 4. Trials of Experiments 1 and 4 are identical regarding their timing. Experiments 1 and 4 differ only in their stimulus material (see Figure 5). In Experiment 2, the length of the interstimulus interval was increased from 300 ms (Experiments 1 and 4) to 3,000 ms (Experiment 2), by increasing the presentation duration of the blank screen from 150 ms (Experiments 1 and 4) to 2,850 ms (Experiment 2). In Experiment 3, the adaptation and test phases are presented separately (with a 5 min break in between). An image of George Clooney is used here as an example. Adapted from Mueller et al. (2021); permissions and image licenses have been obtained from the copyright holders (Sources: © Drop of Light/Shutterstock.com).

center, top-right, bottom-left, bottom-center, or bottom-right), to control for retinal adaptation effects. Moreover, by displaying the adaptor images for either 2, 3, or 4 s, we increased the variability of the task with the aim of reducing fatigue effects without decreasing the inspection time of the adaptation stimuli. Each adaptor image was presented four times at each presentation time and twice on each screen position. Thus, each individual adaptor was shown 12 times during the whole experiment. During adaptation, participants encountered only two (out of six) stimulus sets of celebrity faces (e.g., image set A or B of two [out of three] different celebrity groups). The third group of celebrity faces was not displayed during adaptation. For each participant, the displayed stimulus sets were determined in advance, whereby the presentation order of the stimuli was randomized within the experiment. The presented stimulus sets were balanced across participants of one adaptation group. Subsequently to the adaptor, participants were exposed to a backward mask for 150 ms, to eliminate possible afterimages (Turvey, 1973). Following the mask, a blank screen appeared for 150 ms, creating (together with the presented mask) an interstimulus interval of 300 ms between adaptation and test stimuli (i.e., the 2AFC test).

Once the blank screen was presented, the 2AFC was asked for, displaying two image versions of the same photo (that only differed in their saturation) for 1,500 ms (always the ORIGINAL with either a MINUS image version [−25% saturation] or a PLUS image version [+25% saturation]). The position of both presented images (centered left or centered right) was randomized and balanced throughout the experiment. While only two celebrity groups were presented during adaptation, all three groups were shown during the test phase, to implement all three transfer levels. Depending on the transfer level, the test images were either identical to the preceding adaptor (pictorial, e.g., trials presenting images of image set A of celebrity group 1 as adaptors and test stimuli), represented different images of the same identity (structural, e.g., trials where image set A of celebrity group 2 was displayed during adaptation and image set B of the same celebrity group as test stimuli) or displayed identities from the celebrity group not shown during adaptation (cross-identity, e.g., trials where image set A of celebrity group 1 was displayed during adaptation and image set A of celebrity group 3 as test stimuli). The adaptation phase of the cross-identity transfer level was formed out of the two adaptor sets that were used for the pictorial and structural transfer levels (e.g., image sets 1A and 2A). Half of each adaptor set (i.e., half of the pictorial image set [e.g., half of the image set 1A] and half of the structural image set [e.g., half of the image set 2A]) was displayed in the adaptation phase of the cross-identity transfer level (i.e., half of the pictorial and structural image sets [e.g., half of set 1A and 2A] served as adaptor stimuli and the set not shown during adaptation [e.g., image set 3A] was presented in the cross-identity test phase). Across all transfer levels, the saturation of the adaptors was kept constant within each participant group. As for the adaptation phase, the image sets presented in the test phase were determined in advance and balanced across participants. The trial order was randomized within the experiment.

Following the two test images, a backward mask appeared for 300 ms to eliminate any afterimages and thus a prolonged exposure to the test stimuli. Subsequently, participants were required to select the test image they considered to be the veridical one (instructions were saying in German: “Which is the original face?”). To mark their selection, participants pressed a specific button on a keyboard that corresponded to the image position (key “A” for images presented on the left side, key “L” for images presented on the right side). Following the procedure of Carbon et al. (2007), the participants were informed to base their decision on their knowledge about the celebrity (e.g., images that one has encountered in the media) and not on the images inspected in the experiment. This way, participants were encouraged to access the mental representation stored in memory, when finding the “veridical” image in the test phase. Moreover, since the previously displayed adaptation stimuli were obviously strongly manipulated, it should have been clear to the participants that they were not supposed to base their decision on these adaptor images when being asked to select the nonmanipulated image in the test phase. The test phase had a total of 360 trials. After presenting half of the trials (i.e., 180 trials) a break occurred, offering the participants time to relax and informing them that they had completed half of the test. The participants independently started the second half of the test.

After the adaptation and test phases, the participants were again presented with the previously seen celebrity images. This time, they were instructed to judge the celebrities according to their familiarity (instructions were: “Are you familiar with this celebrity from the media?”). Participants responded with “yes” or “no” by pressing again the buttons “A” or “L” on the keyboard, respectively. The ratings were used to exclude trials presenting celebrities that were unknown to the participants since alterations of face representations through adaptation are expected to be more pronounced for faces that are familiar (as familiar faces are already represented in memory; for a comparison of adaptation effects on familiar vs. unfamiliar faces, see Hills & Lewis, 2012). Altogether, the experiment lasted about 60 min.

Results and Discussion

On average, 98.9% of the face stimuli were rated as familiar (individually ranging from 86.7% to 100%) and thus included in further analysis. Moreover, all individual outliers (i.e., response times slower than 3SD above the individual mean response time) of each participant as well as trials with a response time faster than 200 ms, were excluded. The dependent variable of interest was the average test face selection in the 2AFC. The test face selection is an indicator of whether a prior observation of, for example, strongly manipulated images, causes a shift in face perception. The variable was scored according to the degree of manipulation of the selected test images: A score of −25 was assigned to the MINUS images, a score of 0 to the ORIGINAL images, and a score of +25 to the PLUS images.[2]

According to the experimental design, a two-way, mixed-design ANOVA was calculated with the between-participants factor adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-participants factor transfer level (pictorial, structural, and cross-identity). There was a main effect for the adaptation group [$F(2, 45) = 6.39$, $p = .004$, $\eta_p^2 = .221$] with the means: $M_{\text{MINUS EXTREME}} = -2.74$ ($SD = 5.02$), $M_{\text{ORIGINAL}} = -2.42$ ($SD = 3.06$) and $M_{\text{PLUS EXTREME}} = 3.34$ ($SD = 7.26$). Bonferroni-corrected comparisons revealed significant differences between MINUS EXTREME and PLUS EXTREME: $p = .008$, $d = -0.97$ and between ORIGINAL and PLUS EXTREME: $p = .013$, $d = -1.05$. We could not reveal a significant difference between MINUS EXTREME and ORIGINAL: $p = 1.000$, $d = -0.06$. Since the adaptation group PLUS EXTREME reveals a significant bias in the participant's selection toward an increased saturation compared to the other two adaptation groups, an adaptation effect on saturation is indicated at least for the *PLUS EXTREME* adaptation group. The main effect of transfer level was not significant ($F[2, 90] < 1$, $p = .612$, $\eta_p^2 = .011$), neither was there an interaction between transfer level and adaptation group ($F[4, 90] = 1.59$, $p = .184$, $\eta_p^2 = .066$, see Figure 4 (Experiment 1) for an illustration). Thus, it seems that the transfer level has no impact on the obtained adaptation effects.

Experiment 2

Since the results of Experiment 1 indicate face adaptation effects on saturation alterations (at least for the increased saturation condition), we wanted to clarify the processing level of these adaptation effects by varying the temporal factors of the following two experiments (Experiments 2 and 3). While very short time intervals between the adaptation and test phase only allow predictions about more or less sensory-based (retinotopic) effects, adaptation effects using relatively longer time intervals indicate processing on higher cognitive levels. In Experiment 2, the time interval (interstimulus interval) between the adaptation and test phase was consequently extended from 300 ms (in Experiment 1) to 3,000 ms. All other characteristics remained the same from the previous experiment.

Method

Participants. Forty-eight undergraduate students from the Medical School Hamburg participated in Experiment 2. The sample size was the same as in Experiment 1. The requirements and conditions were identical to those in Experiment 1. No participant of this experiment had taken part in Experiment 1.

Apparatus and Stimuli. The apparatus and stimuli were identical to those used in Experiment 1.

Procedure. Experiments 1 and 2 were identical in their procedure except that the length of the interstimulus interval was increased from 300 ms (Experiments 1) to 3,000 ms. This was done by increasing the presentation duration of the blank screen from 150 ms (Experiment 1) to 2,850 ms. Thus, after the presentation of the adaptor, a backward mask was displayed for 150 ms, and subsequently, a blank screen appeared for 2,850 ms, leading to an interstimulus interval of 3,000 ms.

Results and Discussion

On average, 97.0% of the face stimuli were rated as familiar (individually ranging from 66.7% to 100%) and thus included in further analysis. The general outlier analyses, as well as the 2AFC analysis, were similar to Experiment 1.

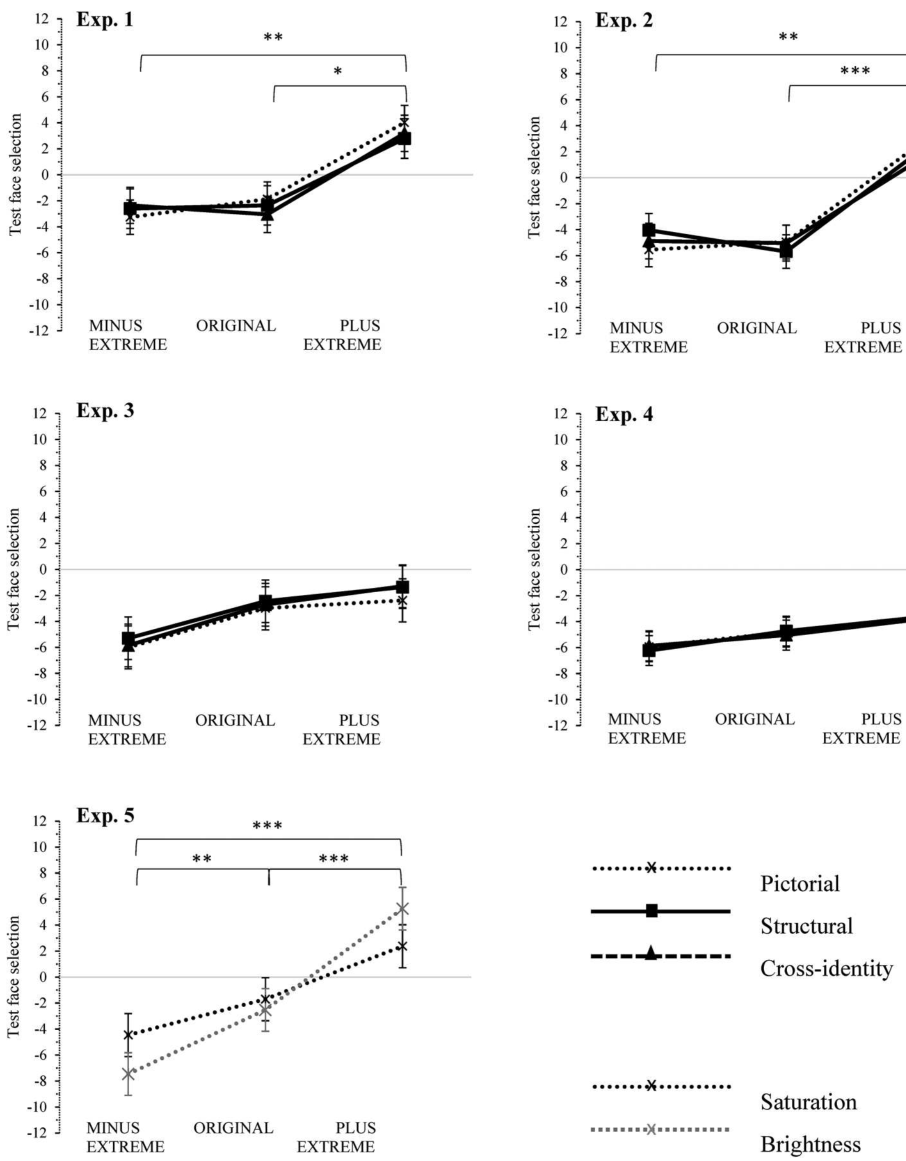

Figure 4. Illustration of the interaction between adaptation group and transfer level for Experiments 1 to 5 and of the interaction between the adaptation group and color type for Experiment 5. The *y*-axis reflects the degree of saturation (and brightness in Experiment 5) of the selected test images in the 2-alternative-forced-choice (2AFC; in %). Error bars represent ± 1 standard error of the mean.

A two-way, mixed-design ANOVA was calculated with the between-participants factor adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-participants factor transfer level (pictorial, structural, and cross-identity). There was a main effect for the adaptation group ($F[2, 45] = 11.19$, $p < .001$, $\eta_p^2 = .332$) with the means: $M_{\text{MINUS EXTREME}} = -4.82$ ($SD = 4.06$), $M_{\text{ORIGINAL}} = -5.22$ ($SD = 3.62$) and $M_{\text{PLUS EXTREME}} = 2.21$ ($SD = 6.69$). Bonferroni-corrected comparisons revealed significant differences between MINUS EXTREME and PLUS EXTREME: $p = .001$, $d = -1.27$ and between ORIGINAL and PLUS EXTREME: $p < .001$, $d = -1.39$. We could not reveal a significant difference between MINUS EXTREME and ORIGINAL: $p = 1.000$, $d = 0.11$. Since the adaptation group PLUS EXTREME reveals a significant bias in the participant's selection toward an increased saturation compared to the other two adaptation groups, an adaptation effect on saturation is indicated at least for the PLUS EXTREME adaptation group. The main effect of transfer level was not significant ($F[2, 90] < 1$, $p = .79$, $\eta_p^2 = .005$), neither was there an interaction between transfer level and adaptation group ($F[4, 90] = 1.75, p = .147, \eta_p^2 = .072$ see Figure 4 [Experiment 2]). Thus, it seems that the transfer level has no impact on the adaptation effects.

Experiment 3

Since the results of Experiment 2 indicate that face adaptation effects on saturation alterations (at least for the increased saturation condition) last several seconds, the following experiment aims to determine whether the effects are even more robust, lasting not only seconds but several minutes. We did so by changing the trial-wise procedure (applied in the previous two experiments) into a block-wise procedure, where the adaptation and test phase are presented in two different blocks, separated by a 5 min break (adopted from Carbon et al., 2007). An occurrence of adaptation effects after five minutes would indicate involvement of higher cognitive processes than just sensory processing.

Method

Participants. Forty-eight undergraduate students from the Medical School Hamburg (36 females, 12 males, M_{age}: 22.9 years, range 19–30 years) participated in Experiment 3 and were tested individually. The sample size was the same as in Experiments 1 and 2. The requirements and conditions were identical to those in Experiments 1 and 2. No participant of this experiment had taken part in Experiment 1 or 2.

Apparatus and Stimuli. The apparatus and stimuli were identical to those used in Experiment 1.

Procedure. Experiment 3 differed from the first two experiments in that the adaptation and test phases were administered in different blocks, separated by a 5 min break. As Figure 3 illustrates, a trial within the adaptation phase started by presenting a fixation cross for 500 ms, followed by the adaptation stimulus. Depending on the group the participants belonged to, they were either exposed to a MINUS EXTREME image, an ORIGINAL image, or a PLUS EXTREME image. As in the two experiments before, the adaptation stimuli were displayed on six different screen positions for either 2, 3, or 4 s. Screen positions and timing conditions were balanced across trials. Subsequently to the adaptor stimulus, a backward mask appeared (150 ms) before a cover task was presented (saying in German: "Is this person a male or female?"). A selection was made by pressing a button on a keyboard (key "A" = male; key "L" = female). The image sets that were used as the adaptation stimuli were determined in advance and balanced across participants. Following the adaptation phase, a 5 min break was given, in which the participant was instructed to read a geographical text. This was intended to prevent a mental recall of the faces seen before.

Subsequently, to the 5 min break, the 2AFC test was presented, displaying either an ORIGINAL and a MINUS image or an ORIGINAL and a PLUS image for 1,500 ms in each trial. As in the experiments before, the stimulus position was randomized and balanced across trials. Image sets used in the test phase represented all three celebrity groups to apply all three transfer levels (pictorial, structural, and cross-identity). The stimulus sets were balanced across participants. Following the stimulus presentation, backward masks were displayed for 300 ms. Subsequently, the participants were asked to choose the veridical image out of the two images presented in the previously seen 2AFC test. The response was indicated by pressing either button A (corresponding to the left image) or button L (corresponding to the right image) on the keyboard. The adaptation phase included 360 trials, while the test phase included 120 trials. As in the two experiments before, a familiarity rating task was conducted following the adaptation and test phase. Altogether, the experiment lasted about 60 min.

Results and Discussion

On average, 98.7% of the face stimuli were rated as familiar (individually ranging from 70% to 100%) and thus included in further analysis. The general outlier criteria, as well as the 2AFC analysis, were similar to the previous experiments.

Based on the between-participants factor adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-participants factor transfer level (pictorial, structural, and cross-identity), a two-way, mixed-design ANOVA was calculated. We did not reveal a main effect for the factor adaptation group ($F[2, 45] = 1.74, p = .187, \eta_p^2 = .072$) nor for the factor transfer level ($F[2, 90] = 1.51$, $p = .226$, $\eta_p^2 = .033$). Also for the combination of transfer level and adaptation group ($F[4, 90] < 1$, $p = .915$, $\eta_p^2 = .011$), no significant interaction could be revealed (see Figure 4 [Experiment 3] for an illustration). Thus, we could not detect an adaptation effect in Experiment 3.

Experiment 4

Although Experiment 3 indicated that adaptation effects on saturations are not detectable after several minutes, we wanted to clarify whether the observed effects in Experiments 1 and 2 are selective for faces or whether they are general color aftereffects, that also occur when presenting nonface stimuli. Thus, in the following experiment, we apply nonface stimuli that were altered in saturation in the adaptation phase. By scrambling the adaptation faces (i.e., the entire images) presented in the previous experiments beyond recognition, the nonface stimulus material was created (Figure 2a). Hence, each adaptation face stimulus presented in the experiments before was divided into tiny little pieces and randomly assembled so that a homogeneous color area was formed (a so-called scrambled face) that reflected the average color of the particular face stimulus. In the test phase, however, we used the same stimuli as in the experiments before (i.e., celebrity faces). In case the observed adaptation effects in Experiment 1 and 2 are face-specific, adaptation effects in the following experiment should be reduced. Since the images displayed in the adaptation phase no longer represent any faces, an application of the transfer levels pictorial and structural is no longer possible. For the sake of consistency between all reported experiments, however, all three transfer levels (i.e., pictorial, structural, and cross-identity) shall be deployed.

Method

Participants. Forty-eight undergraduate students from the University of Bamberg (39 females, 9 males, M_{age}: 23.3 years, range 18–36 years) participated in Experiment 4 and were tested individually. All other requirements and conditions were identical to those in Experiments 1 to 3.

Apparatus, Stimuli, and Procedure. The apparatus and procedure of Experiment 4 were identical to Experiment 1. The experiments only differed in their adaptation stimuli. The adaptation stimuli displayed in Experiment 4 were scrambled versions of the images used in Experiment 1 (Figure 2a). The stimuli were scrambled to such an extent that the faces were no longer recognizable.

Results and Discussion

On average, 96.3% of the face stimuli were rated as familiar (individually ranging from 76.7% to 100%) and thus included in further analysis. The general outlier analyses, as well as the 2AFC analysis, were similar to the previous experiments.

Based on the between-participants factor adaptation group (MINUS EXTREME, ORIGINAL, and PLUS EXTREME) and the within-participants factor transfer level (pictorial, structural, and cross-identity), a two-way, mixed-design ANOVA was calculated. There was neither a main effect for the factor adaptation group ($F[2, 45] = 1.11, p = .338, \eta_p^2 = .047$) nor for the factor transfer level ($F[2, 90] < 1, p = .992, \eta_p^2 < .001$). Also for the combination of transfer level and adaptation group ($F[4, 90] < 1, p = .952, \eta_p^2 = .006$), no significant interaction could be revealed (see Figure 4 [Experiment 4] for an illustration). Thus, we did not obtain any adaptation effect regarding saturation alterations of scrambled faces in Experiment 4 based on our experimental design.

To determine whether adaptation effects are significantly larger after short delays than after longer delays, as well as in faces than in scrambled faces, we further calculated a two-way ANOVA with the between-participants factor experiment (Experiments 1–4) and the within-participants factor transfer level (pictorial, structural, and cross-identity). Since adaptation effects were only apparent in the PLUS EXTREME adaptation group (i.e., the increased saturation condition), only the PLUS EXTREME adaptation groups of all experiments were compared. There was a significant main effect for the factor experiment ($F[3, 60] = 3.96, p = .012, \eta_p^2 = .165$). Bonferroni-corrected comparisons revealed significant differences between Experiments 1 (300 ms interstimulus interval) and 4 (using scrambled faces): $p = .023$, $d = 1.141$. However, although it approached conventional levels of significance, there was neither difference between Experiment 2 (3 s interstimulus interval) and the scrambled face Experiment 4 ($p = .084$) nor between Experiment 3 (5 min interstimulus interval) and the scrambled face Experiment 4 ($p = 1.000$). Furthermore, there was neither a main effect for the factor transfer level ($F[2, 120] < 1, p = .822, \eta_p^2 = .003$) nor for the interaction between transfer level and experiment ($F[6, 120] = 1.40, p = .220, \eta_p^2 = .065$). It should be noted that from an experimental perspective, only the comparison between Experiment 1 and the scrambled face Experiment 4 is reasonable, since these two experiments are the only ones with the same experimental set-up (trial-wise procedure with a 300 ms interstimulus interval). The comparisons of the other experiments should be therefore interpreted with caution.

Experiment 5

Experiment 3 indicated that adaptation effects on saturation alterations are not observable after several minutes. Thus, adaptation effects on saturation seem to be not as robust as adaptation effects on brightness, which still occurred after 5 min (see Mueller et al., 2021). To see if there are also differences in the degree of adaptation effects, the following experiment directly compared adaptation effects on saturation with adaptation effects on brightness alterations. Thus, stimuli altered in saturation and stimuli altered in brightness were presented within one paradigm.

Method

Participants. Forty-eight undergraduate students from the Medical School Hamburg (34 females, 14 males, M_{age}: 23.4 years, range 19–31 years) participated in Experiment 5. All other requirements and conditions were identical to those in Experiments 1 and 2.

Apparatus and Stimuli. The stimulus material of Experiment 5 consisted of the same celebrity images as in Experiment 1 but altered not only in saturation but also in brightness (within-participants factor). Different levels of manipulations were applied, resulting in five different image versions per manipulation type (manipulation of the saturation and brightness by −75%, −25%, 0%, +25%, and +75%), as illustrated in Figure 5. As in Experiment 1, the size of the images was ∼330 × 412 pixels. Depending on which group the participants belonged to (between-participants factor), they either saw an unaltered image (ORIGINAL), an image with a strongly decreased color manipulation (−75% of either saturation or brightness, MINUS EXTREME), or an image with a strongly increased color manipulation (+75% of either saturation or brightness, PLUS EXTREME) as an adaptor. During the test phase, the participants were exposed to two image versions, with one image always displaying the ORIGINAL photo and the other image showing a slightly manipulated version with either a −25% manipulation (MINUS) of saturation or brightness or a +25% manipulation (PLUS) of saturation or brightness. The color manipulation (saturation or brightness) presented in the test phase corresponded to the color manipulation the participants inspected in the previous adaptation phase. The experiment was created in Experiment Builder 2.2.1 (SR Research) and run on a Lenovo PC with a 23″ computer screen running at a resolution of 1,920 × 1,080 pixels.

Procedure. The timing conditions of Experiment 5 were identical to Experiment 1. Adaptation and test phases were again applied within single trials (see Figure 3). Within a trial, stimuli of only one color type (saturation or brightness) were presented (in the adaptation as well as in the test phase). Trials displaying saturation alterations and trials displaying brightness alterations were presented in

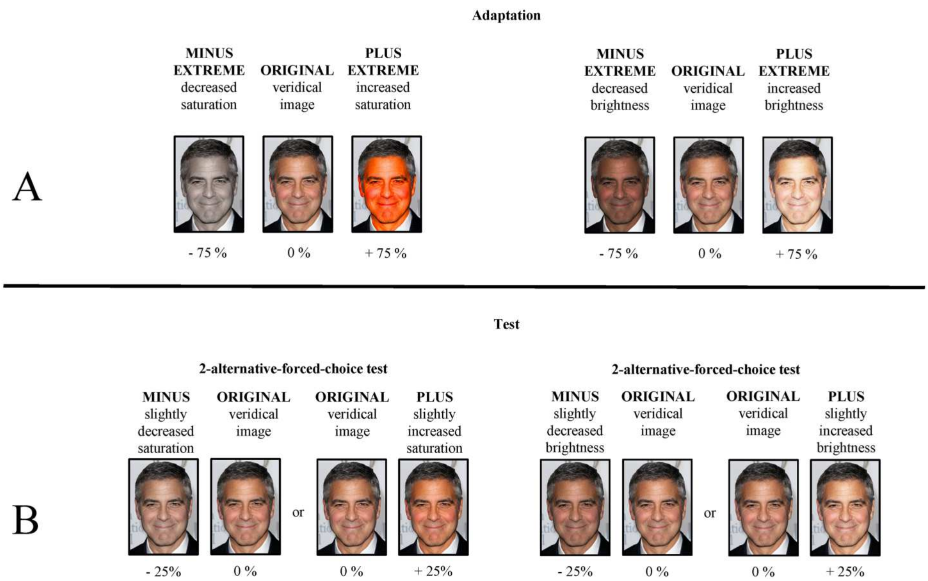

Figure 5. The different image versions in Experiment 5 are illustrated by the face of George Clooney. (a) Illustration of the different adaptor versions. (b) Illustration of the image versions during the test phase. Within the 2-alternative-forced-choice (2AFC) test, two images are displayed (the original image together with either an image with decreased saturation/brightness or an image with increased saturation/brightness). Adapted from Mueller et al. (2021). Permissions and image licenses have been obtained from the copyright holders (Sources: ©Drop of Light/Shutterstock.com).

two different blocks, whereby the presentation order of the stimuli within one block was randomized within the experiment. Each block consisted of 180 trials, so that the whole experiment consisted of 360 trials. Each participant was exposed to only one image set. Thus, only the pictorial transfer level was applied, so that the test images were identical to the adaptation image seen before (except the different color alterations applied to the images). All celebrity groups and all image sets were applied and balanced across participants of one adaptation group. All other conditions were the same as in Experiment 1. Altogether, the experiment lasted about 60 min.

Results and Discussion

On average, 97.4% of the face stimuli were rated as familiar (individually ranging from 76.7% to 100%) and thus included in further analysis. The general outlier analyses and the 2AFC analysis were identical to the previous experiments.

Based on the between-participants factor adaptation group (MINUS EXTREME, ORIGINAL and PLUS EXTREME) and the within-participants factor color type (with factor levels: saturation and brightness), a two-way, mixed-design ANOVA was calculated. There was a main effect for the adaptation group ($F[2, 45] = 29.19$, $p < .001$, $\eta_p^2 = .565$) with the means: $M_{\text{MINUS EXTREME}} = -5.96$ ($SD = 2.72$), $M_{\text{ORIGINAL}} = -2.11$ ($SD = 2.90$), and $M_{\text{PLUS EXTREME}} = 3.82$ ($SD = 5.12$). Bonferroni-corrected comparisons revealed significant differences between MINUS EXTREME and PLUS EXTREME: $p < .001$, $d = -2.43$ and between ORIGINAL and PLUS EXTREME: $p < .001$, $d = -1.37$. There was also a significant difference between MINUS EXTREME and ORIGINAL: $p = 0.014$, $d = -1.52$. The main effect of color type was not significant ($F[1, 90] < 1$, $p = .751$, $\eta_p^2 = .002$), neither was there an interaction between color type and adaptation group (although results approach conventional levels of significance; $F[4, 90] = 3.085$, $p = .056$, $\eta_p^2 = .121$, see Figure 4 [Experiment 5]). Thus, adaptation effects seem to be demonstrated across both alteration conditions (i.e., decreased and increased saturation/brightness alterations).

This finding would make the results on saturation clearly different from those in Experiments 1 and 2. In the first two experiments, adaptation effects could only be demonstrated for the increased saturation condition compared to the other conditions. It should be noted that the interaction approaches conventional levels of significance. When analyzing the interaction more closely (irrespective of the probably lacking interaction) and focusing on saturation only, multiple comparisons reveal a significant difference between the ORIGINAL and PLUS EXTREME groups ($p = .043$, $d = -0.67$), but not between the ORIGINAL and MINUS EXTREME groups ($p = .166$, $d = -0.65$). This indicates that there would be an adaptation effect only for the increased saturation condition but not for the decreased condition, when analyzing the results of saturation and brightness separately. However, when analyzing multiple comparisons even further, adaptation effects did not differ between both color types (MINUS EXTREME adaptation group $p = .084$; ORIGINAL adaptation group $p = .628$; PLUS EXTREME adaptation group $p = .095$). Thus, there seem to be no differences in the adaptation on saturation and brightness.

The fact that the interaction effect and also the direct comparisons of saturation and brightness did not reach conventional levels of significance (although some of the effects are not far from being significant) could be related to the different design of the experiment (e.g., only the pictorial transfer condition was applied). The slightly different design of the study could possibly lead to lower test power. A post hoc power analysis of the interaction of adaptation group and color type indeed revealed a rather low test power of $(1 - \beta) = 0.73$ (3×2 factor design, given an effect size f of 0.37, an α of 0.05, and N of 48). Thus, the missing interaction of adaptation group and color type might be caused by a low test power. Potentially, the adaptation pattern of the first experiments (i.e., adaptation effect for the increased but not the decreased saturation condition) would also emerge in Experiment 5 if the test power had been higher.

General Discussion

Face adaptation seems to be a useful tool to investigate how faces are perceived and stored in memory. Up to now, mainly configural face information has been subject to adaptation studies often neglecting nonconfigural face information, such as color. To the knowledge of the authors, brightness was the only type of specific color information investigated in face adaptation studies so far. The reported experiments, therefore, aim to provide a greater variability in the literature of adaptation studies on color by examining other color information in the form of saturation alterations.

Existence of Adaptation Effects on Saturation Alterations

The results clearly show that adaptation effects exist for at least increased saturation alterations (i.e., the PLUS EXTREME adaptation group shows a significant difference to the ORIGINAL and MINUS EXTREME condition; Experiments 1 and 2). Unlike original or decreased face versions, stimuli strongly increased in saturation lead to a perceptual bias when inspecting subsequent faces. This is reflected in a more frequent selection of images with a slightly increased saturation in the 2AFC for participants belonging to the PLUS EXTREME adaptation group (the average selection of test faces in this group is $M = 3.34$ for Experiment 1 and $M = 2.21$ for Experiment 2). Thus, after being exposed to strongly increased saturation images, participants tend to perceive a slightly increased saturation image as being the nonmanipulated (original) image. The significant main effect of the factor adaptation group of Experiment 5 (saturation and brightness are both included) surprisingly revealed adaptation effects for both alteration conditions (i.e., increased and decreased)—although this result has to be questioned due to the almost significant interaction of color type and adaptation group and the low test power of this experiment. Also, when analyzing the interaction and focusing on saturation only, the same pattern as in the first two experiments (i.e., adaptation effect for the increased but not the decreased saturation condition) can be observed. Hence, unlike effects on brightness adaptation, effects on saturation seem to occur only in one direction (i.e., for increased saturation alterations).

However, this result should also be evaluated regarding the other two adaptation groups (i.e., MINUS EXTREME and ORIGINAL). Graphically, a shift of the ORIGINAL adaptation group in the negative direction can be observed in all studies. One-sample *t*-tests revealed that the shift was also statistically significant in all experiments (one-tailed, $ps < .035$). Thus, participants seeing nonmanipulated faces or even nonmanipulated scrambled images as the adaptor (ORIGINAL) somehow tend to choose images decreased in saturation (and also brightness in Experiment 5) as the veridical image in the test phase. The causes for this bias are not clear yet. It might be that participants that did not adapt to any extreme image version (i.e., MINUS EXTREME or PLUS EXTREME images) somehow perceive an increase in saturation (or brightness) as more evident as a decrease. This way, participants of the ORIGINAL adaptation group would more easily identify slightly increased test images (PLUS) as being manipulated and would therefore reject them when choosing the veridical face. The slightly decreased version (MINUS) and the original image (ORIGINAL), however, are maybe not as easy to distinguish, so that participants would more often select decreased images in test trials where a decreased image and the original image are presented. This response tendency (i.e., rejecting all increased images while selecting decreased images at times) could result in an overall bias of the ORIGINAL adaptation group into the negative range. Moreover, assuming that this perceptual bias is becoming also apparent in the adaptation phase, the difference between ORIGINAL and MINUS EXTREME adaptor images would probably be perceived as being smaller compared to the ORIGINAL and PLUS EXTREME images as well. This, however, could explain the missing adaptation effects in the decreased adaptation group. Future studies should, therefore, investigate possible anomalies in the perception of saturation (and also brightness). Furthermore, studies should adjust the saturation (or brightness) level of the adaptors, so that differences between adaptation groups would be perceptually equal. This way it could be revealed whether the missing adaptation effects on decreased saturation is caused by experimental factors or because adaptation on decreased saturation is generally not possible (for a discussion on the perception of different brightness levels, see Mueller et al., 2021).

Since adaptation effects could not be provoked using nonface stimuli (unrecognizable scrambled face stimuli manipulated in saturation), Experiment 4 indicates that the adaptation effects on saturation are maybe face-specific. Moreover, the direct comparison of Experiment 1 (300 ms interstimulus interval) and Experiment 4 (scrambled faces) also revealed a significant difference in adaptation, supporting the assumption that adaptation to saturation is qualitatively different in faces versus nonface stimuli (the nonsignificant difference for Experiment 2 compared to the scrambled face experiment might be due to the different experimental design). Hence, face adaptation effects on saturation might not just reflect general color aftereffects. Instead, they seem to be contextual dependent, meaning that they are linked to the specific context of faces. Accordingly, face adaptation effects on saturation might occur only when using adaptors displaying faces. It should be noted, however, that also the large variation in adaptation and test images could have led to this result. Moreover, the scrambled faces representing homogeneous color areas might attract less attention than human faces (for comments on how faces specifically attract attention, see, e.g., Palermo & Rhodes, 2007). Less attention on the adaptor stimuli could possibly have resulted in a failure to adapt (previous studies, however, suggest that attention may not be a decisive factor for adaptation; see Stein et al., 2012, revealing adaptation effects when using interocular suppression). It could be possible though that images that are more similar in their composition to the applied face images (e.g., in contrast and complexity) would evoke adaptation effects when altered in saturation. Therefore, future studies should apply other nonface stimuli than scrambled faces (e.g., objects or inverted faces; see, e.g., Mueller et al., 2021).

Experiment 5 did not reveal any differences between adaptation effects on saturation compared to brightness. This result, however, should be questioned, since the interaction almost reached conventional levels of significance, and the test power of the experiment should be considered as rather low. Hence, it might be that there is a difference in the adaptation of saturation and brightness. Brightness would in this case cause stronger adaptation effects than saturation (PLUS EXTREME adaptation group: $M_{\text{Saturation}} = 2.38$, $M_{\text{Brightness}} = 5.27$). Accordingly, the observed differences in the perception of different color dimensions (see, e.g., Re et al., 2011; Tan & Stephen, 2013; Thorstenson et al., 2019; or the "Face Adaptation Effects on Color" section) are maybe even reflected in the retention of these colors in face memory. To validate this assumption further adaptation studies on saturation and brightness and other color dimensions should be conducted.

Processing Level of Adaptation Effects on Saturation

Experiment 2 revealed that the reported adaptation effects in Experiment 1 still occur after a delay of 3,000 ms. However, adaptation effects did not appear when applying a delay of 5 min. Thus, the adaptation effects on saturation alterations do not seem to be very robust. Unlike adaptation effects on brightness alterations, which last up to 5 min (Mueller et al., 2021), effects on saturation seem to be more transient. However, the adaptation effects still seem to be retained for up to 3,000 ms, which might indicate an involvement of the short-term memory. Nevertheless, since the effects do not seem to affect the long-term memory, it is not clear whether adaptation operates on a representational memory or a rather sensory basis. Future studies should investigate how long the adaptation effects on saturation can last precisely (anything between 3,000 ms and 5 min) and whether the effects decrease over time.

Previous adaptation studies revealed a continuous decay of adaptation effects, suggesting some kind of "resetting" mechanism of the mental representation (see, e.g., Carbon et al., 2007; Carbon & Ditye, 2011; Carbon & Leder, 2005; Mueller et al., 2021; Strobach et al., 2011). It could be possible that the resetting of saturation information somehow occurs faster than for other face information. It could be, for example, that saturation information is integrated into the representation but because of an automatic resetting process (e.g., due to the robustness of the original representation) that occurs very quickly, adaptation effects on saturation are relatively transient. A quick resetting of saturation could possibly be related to the lower importance of this kind of information for face identification. The possibly lower importance for face identification could be due to the variant nature of saturation information. Compared to configural face information, which is associated with invariant personal characteristics (such as identity, sex, or ethnicity), saturation information would be rather labeled as a variant type of face information, since it is often associated with a person's emotional or health state (e.g., Re et al., 2011; Thorstenson et al., 2019). Because of its rather variant nature, saturation information might not be stored in long-term memory, since it does not provide very stable information for identifying a face. The presumably higher robustness of brightness adaptation effects compared to saturation (Mueller et al., 2021, found adaptation effects on brightness up to 5 min) might be related to a rather invariant nature of brightness information (facial brightness probably refers to a person's skin tone and thus maybe even to a person's ethnicity). Hence, the robustness of facial color information (and possibly face information in general) might be related to the information's variability.

The different robustness of saturation and brightness could also be interpreted in accordance with a very popular model of face recognition and retention. Bruce and Young (1986) described a functional model which outlines the processes occurring when recognizing and processing a face. The model distinguishes between a *pictorial code,* a *structural code,* and a so-called *face recognition unit* (the model describes further structures for identity processing but since they are not relevant here they shall not be explained further). The pictorial code describes picture-dependent processing and representation of a face (comparable with the pictorial transfer level) while the structural code reflects a more abstract face processing and representation that is based on the specific structure of a face. It enables face recognition despite changes in the depiction of the face (e.g., despite a different head angle, expression) and is thus comparable with a processing on the structural transfer level applied in our study. However, there is one decisive difference between the structural transfer level applied in our study and the structural code proposed by Bruce and Young (1986): adaptation effects occurring on a structural transfer level often serve as an indicator that a representation of a specific identity is accessed (see section "Face Adaptation Effects on Color"). Face processing in terms of the structural code proposed by Bruce and Young (1986), however, does not refer to a specific identity. The facial structure is processed and analyzed with respect to, for example, the age or gender of the person, but an attribution to a specific identity is not made before subsequent processing stages were pursued. In the very next stage, which is labeled the "face recognition unit," the assignment of the specific face structure to a specific identity is performed, although only in terms of a feeling of knowing of the target person. In terms of this model, the different robustness of saturation and brightness could be due to processing at different processing levels. Since saturation information might not be very relevant for face identification (due to its variant nature), it could be possible that saturation information is only processed in terms of the structural code without affecting a specific identity. Since brightness information might be more relevant for face identification due to its more invariant nature, it might be processed even in terms of the face recognition unit and thus in regard to a representation of a specific identity.

Further research is needed, however, to substantiate these assumptions. Thus, upcoming studies should investigate other variant and invariant face information to see if the observed differences between invariant and variant face information also become apparent in other types of information than saturation and brightness. Moreover, paradigms should be developed to investigate the identity–specificity of adaptation effects on a structural level. This could be used to examine whether different types of information are processed differently in the sense of Bruce and Young's (1986) model. Furthermore, upcoming studies should investigate whether this adaptation pattern is similar for facial saturation alterations affecting other color dimensions than redness (e.g., saturation alterations that tend more toward the green or the blue). Since increased saturation leading to a greater redness is often associated with a person's emotional or health state (e.g., blushing; see Re et al., 2011; Thorstenson et al., 2019; or the section "Face Adaptation Effects on Color"), it would be interesting, if saturation alterations also occur for other (maybe nonnatural) color dimensions. The missing adaptation effects on decreased saturation might be an indication that adaptation effects rather occur for "natural" saturation alterations (a decrease in saturation leads to a loss of color which can be considered as nonnatural).

As shown by the results of Experiments 1 and 2, saturation seems to be indeed processed on a structural level (for effects of brightness on different transfer levels, see Mueller et al., 2021). The adaptation effects seem to transfer well across different images of the same identity, suggesting that the effects are not only image-specific but must affect a more abstract face representation that captures the structure of the face. Therefore, it is likely that adaptation alters the represented face structure (independent of its attribution to a specific identity). This way, adaptation effects would also occur when presenting images of the identity that differ from the adaptor. Furthermore, Experiments 1 and 2 showed that adaptation effects also transfer between different identities (cross-identity level). These results suggest that adaptation operates on a hierarchically higher level, affecting not only a specific face representation but probably superordinate category representations, such as a prototype representation or a generic face norm. Hence, by altering a specific face representation through adaptation, superordinate prototype representations would be altered too, leading to an adaptation effect when presenting other identities than the identity presented as the adaptor.

Taking into account the possible face-specificity of the observed adaptation mechanism, effects on increased saturation might be better explained by modifications of face representations than by merely perceptual or retinal processes. Simple recency effects (i.e., tendency to recall the last perceived information the best) are probably not able to account for the reported results, since the stimuli presented in the cross-identity transfer level (and to some extend also in the structural transfer level) differ tremendously (a recency effect could only be considered if the stimuli were identical). Thus, it seems likely that increased saturation information is stored in representations (whether of specific identities or as a more general face norm). Hence, adapting to strongly increased saturation alterations would cause the manipulations to be integrated into a facial representation or mental norm. By integrating the increased saturation alterations into mental representations, the initial face norm would be shifted in the direction of the adaptor (e.g., after adapting to a face increased in saturation, the face representation would be "updated" and thus shifted slightly toward the increased saturation adaptor). Following this adaptation process, images only slightly increased in saturation would then be perceived as "normal" (since the image matches the updated representation), while non-manipulated images would be perceived as being manipulated reversely (i.e., as being decreased in saturation).

Conclusions

The reported experiments clearly revealed adaptation effects for non-configural saturation information, although they can be observed only for increased saturation alterations. Thus, adaptation effects can indeed be demonstrated for non-configural face information other than brightness. The results indicate that the adaptation to increased saturation information might be face-specific. Moreover, it is probably stored in the facial representation but maybe not in the long term. Adaptation effects on saturation, therefore, differ in their robustness (and maybe even in their strength) from adaptation effects on brightness. This difference could be based on the somewhat variant nature of increased saturation information compared to brightness information, which can be considered rather invariant. While brightness might provide information about a person's ethnicity and thus identity, increased saturation probably makes essential contributions in identifying emotional and health states. This way adaptation processes on increased saturation might even facilitate the interpretation of complex social situations by enabling a more efficient differentiation of different emotional and health states in other people. However, due to the great variability of emotional and health status, the retention of new information only for a short amount of time is very reasonable since emotional and health status may have changed already within the next moment. A flexible adaptation of the representation and a resetting to the initial representational norm, therefore, seems to be necessary. The here presented experiments indicate that face representations contain a variety of face information that seems to be stored at least partly independent from each other. Moreover, different types of face information seem to be represented with different valence, depending on the relevance the information type has for face recognition. Research on adaptation effects on different face information can help to find out more about the complex mental representation of faces. Possibly, through face adaptation research, we may one day be able to better understand the seemingly contradictory nature of mental face representations: on the one hand, they seem to be stable, ensuring fast and valid face recognition, on the other hand, they are very flexible and adapt quickly to facial changes.

Authors' Note

This research was supported by a grant to Claus-Christian Carbon and Tilo Strobach from the Deutsche Forschungsgemeinschaft (DFG; CA 917/7-1, STR 1223/4-1).

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Deutsche Forschungsgemeinschaft (grant numbers CA 917/7-1 and STR 1223/4-1).

ORCID iDs

Ronja Mueller https://orcid.org/0000-0001-8071-7623
Sandra Utz https://orcid.org/0000-0002-6577-3560
Claus-Christian Carbon https://orcid.org/0000-0002-3446-9347
Tilo Strobach https://orcid.org/0000-0001-7840-0651

Notes

1. Musicians (Adele, Amy Winehouse, Ed Sheeran, Justin Bieber, Justin Timberlake, Katy Perry, Pink, Rihanna, and Selena Gomez), actors (Cameron Diaz, Daniel Radcliffe, Elyas M'Barek, Emma Watson, George Clooney, Jennifer Aniston, Leonardo DiCaprio, Til Schweiger, and Will Smith), politicians/head of states (Angela Merkel, Barack Obama, Donald Trump, Queen Elizabeth, Vladimir Putin), athletes

(Boris Becker, Cristiano Ronaldo, and Joachim Löw), models (Heidi Klum and Paris Hilton), and entertainers (Thomas Gottschalk and Dieter Bohlen).

2. The largest possible adaptation effect toward a decreased saturation would be attained, when a participant would always select a *MINUS* image (−25), in trials presenting *MINUS* and *ORIGINAL* images in the 2AFC test and an *ORIGINAL* image (0), in trials presenting *ORIGINAL* and *PLUS* images in the 2AFC test. The largest adaptation effect toward an increased saturation would be attained by always choosing a *PLUS* image (+25) to be the veridical one in trials, displaying *PLUS* and *ORIGINAL* images and an *ORIGINAL* image (0), in trials presenting *ORIGINAL* and *MINUS* images. Since the versions of the 2AFC test trials were balanced across the experiment, the dependent variable (test face selection) can vary from −12.5 to +12.5 for each participant.

References

Bach, M. (1996). The Freiburg visual acuity test—automatic measurement of visual acuity. *Optometry and Vision Science*, *73*(1), 49–53. https://doi.org/10.1097/00006324-199601000-00008

Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, *77*(3), 305–327. https://doi.org/10.1111/j.2044-8295.1986.tb02199.x

Burns, B., & Shepp, B. E. (1988). Dimensional interactions and the structure of psychological space: The representation of hue, saturation, and brightness. *Perception & Psychophysics*, *43*(5), 494–507. https://doi.org/10.3758/BF03207885

Carbon, C. C. (2008). Famous faces as icons. The illusion of being an expert in the recognition of famous faces. *Perception*, *37*(5), 801–806. https://doi.org/10.1068/p5789

Carbon, C. C., & Ditye, T. (2011). Sustained effects of adaptation on the perception of familiar faces. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(3), 615–625. https://doi.org/10.1037/a0019949

Carbon, C. C., & Ditye, T. (2012). Face adaptation effects show strong and long-lasting transfer from lab to more ecological contexts. *Frontiers in Psychology*, *3*(2), 1–6. https://doi.org/10.3389/fpsyg.2012.00003

Carbon, C. C., & Leder, H. (2005). When feature information comes first! early processing of inverted faces. *Perception*, *34*(9), 1117–1134. https://doi.org/10.1068/p5192

Carbon, C. C., Strobach, T., Langton, S. R. H., Harsányi, G., Leder, H., & Kovács, G. (2007). Adaptation effects of highly familiar faces: Immediate and long lasting. *Memory & Cognition*, *35*(8), 1966–1976. https://doi.org/10.3758/bf03192929

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd edn). Lawrence Erlbaum Associates.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fox, C. J., & Barton, J. J. S. (2007). What is adapted in face adaptation? The neural representations of expression in the human visual system. *Brain Research*, *1127*(1), 80–89. https://doi.org/10.1016/j.brainres.2006.09.104

Glanzer, M., & Cunitz, A. R. (1966). Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behaviour*, *5*(4), 351–360. https://doi.org/10.1016/S0022-5371(66)80044-0

Hills, P. J., & Lewis, M. B. (2012). FIAEs in famous faces are mediated by type of processing. *Frontiers in Psychology*, *3*(256), 1–13. https://doi.org/10.3389/fpsyg.2012.00256

Indow, T., & Kanazawa, K. (1960). Multidimensional mapping of mumsell colors varying in hue, chroma, and value. *Journal of Experimental Psychology*, *59*(5), 330–336. https://doi.org/10.1037/h0044796

Ishihara, S. (1917). *Tests for colour blindness*. Handaya Hongo Harukuch.

Lai, M., Oruc, I., & Barton, J. J. (2012). Facial age after-effects show partial identity invariance and transfer from hands to faces. *Cortex*, *48*(4), 477–486. https://doi.org/10.1016/j.cortex.2010.11.014

Lee, K. J., & Perrett, D. (1997). Presentation-time measures of the effects of manipulations in colour space on discrimination of famous faces. *Perception*, *26*(6), 733–752. https://doi.org/10.1068/p260733

Leopold, D. A., O'Toole, A. J., Vetter, T., & Blanz, V. (2001). Prototype-referenced shape encoding revealed by high-level aftereffects. *Nature Neuroscience*, *4*(1), 89–94. https://doi.org/10.1038/82947

Levin, D. T., & Banaji, M. R. (2006). Distortions in the perceived lightness of faces: The role of race categories. *Journal of Experimental Psychology*, *135*(4), 501–512. https://doi.org/10.1037/0096-3445.135.4.501

Lewis, M. (2004). Face-space-R: Towards a unified account of face recognition. *Visual Cognition*, *11*(1), 29–69. https://doi.org/10.1080/13506280344000194

Little, A., DeBruine, L. M., Jones, B. C., & Waitt, C. (2008). Category contingent aftereffects for faces of different races, ages and species. *Cognition*, *106*(3), 1537–1547. https://doi.org/10.1016/j.cognition.2007.06.008

Little, A., Hancock, P. J. B., DeBruine, L. M., & Jones, B. C. (2012). Adaptation to antifaces and the perception of correct famous identity in an average face. *Frontiers in Psychology*, *3*(19), 1–9. https://doi.org/10.3389/fpsyg.2012.00019

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences*, *6*(6), 255–260. https://doi.org/10.1016/S1364-6613(02)01903-4

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2020). Face adaptation and face priming as tools for getting insights into the quality of face space. *Frontiers in Psychology*, *11*(166), 1–17. https://doi.org/10.3389/fpsyg.2020.00166

Mueller, R., Utz, S., Carbon, C. C., & Strobach, T. (2021). Face adaptation affects on non-configural face information. *Advances in Cognitive Psychology*, *17*(2), 99–106. https://doi.org/10.5709/acp-0325-3

Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia*, *45*(1), 75–92. https://doi.org/10.1016/j.neuropsychologia.2006.04.025

Piepers, D. W., & Robbins, R. A. (2012). A review and clarification of the terms "holistic," "configural," and "relational" in the face perception literature. *Frontiers in Psychology*, *3*(559), 1–11. https://doi.org/10.3389/fpsyg.2012.00559

Re, D. E., Whitehead, R. D., Xiao, D., & Perrett, D. I. (2011). Oxygenated-blood colour change thresholds for perceived facial redness, health, and attractiveness. *PLoS One*, *6*(3), e17859. https://doi.org/10.1371/journal.pone.0017859

Stein, T., Peelen, M. V., & Sterzer, P. (2012). Eye gaze adaptation under interocular suppression. *Journal of Vision*, *12*(7), 1–17. https://doi.org/10.1167/12.7.1

Strobach, T., & Carbon, C. C. (2013). Face adaptation effects: Reviewing the impact of adapting information, time, and transfer. *Frontiers in Psychology*, *4*(318), 1–12. https://doi.org/10.3389/fpsyg.2013.00318

Strobach, T., Ditye, T., & Carbon, C.-C. (2011). Long-term adaptation effects of highly familiar faces are modulated by adaptation duration. *Perception*, *40*(8), 1000–1004. https://doi.org/10.1068/p6986

Tan, K. W., & Stephen, I. D. (2013). Colour detection thresholds in faces and colour patches. *Perception*, *42*(7), 733–741. https://doi.org/10.1068/p7499

Tan, L., & Ward, G. (2000). A recency-based account of the primacy effect in free recall. *Journal of Experimental Psychology*, *26*(6), 1589–1625. https://doi.org/10.1037//0278-7393.26.6.1589

Thorstenson, C. A., Pazda, A. D., Young, S. G., & Elliot, A. J. (2019). Face color facilitates the disambiguation of confusing emotion expressions: Toward a social functional account of face color in emotion communication. *Emotion*, *19*(5), 799–807. https://doi.org/10.1037/emo0000485

Turvey, M. T. (1973). On peripheral and central processes in vision: Inferences from an information-processing analysis of masking with patterned stimuli. *Psychological Review*, *80*(1), 1–52. https://doi.org/10.1037/h0033872

Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *43*(2), 161–204. https://doi.org/10.1080/14640749108400966

Valentine, T. (2001). Face-space models of face recognition. In M. J. Wenger & J. T. Townsend (Eds.), *Computational, geometric, and process perspectives on facial cognition: Contexts and challenges* (pp. 83–113). Lawrence Erlbaum Associates Publishers.

Valentine, T., Lewis, M. B., & Hills, P. J. (2016). Face-space: A unifying concept in face recognition research. *The Quarterly Journal of Experimental Psychology*, *69*(10), 1996–2019. https://doi.org/10.1080/17470218.2014.990392

Webster, M. A., Kaping, D., Mizokami, Y., & Duhamel, P. (2004). Adaptation to natural facial categories. *Nature*, *428*(6982), 557–561. https://doi.org/10.1038/nature02420

Webster, M. A., & MacLeod, D. I. (2011). Visual adaptation and face perception. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *366*(1571), 1702–1725. https://doi.org/10.1098/rstb.2010.0360

Webster, M. A., & MacLin, O. H. (1999). Figural aftereffects in the perception of faces. *Psychonomic Bulletin & Review*, *6*(4), 647–653. https://doi.org/10.3758/BF03212974

How to cite this article

Mueller, R., Utz, S., Carbon, C.-C., & Strobach, T. (2021). Face adaptation—investigating nonconfigural saturation alterations. *i-Perception*, *12*(): 1–12. https://doi.org/10.1177/20416695211056362