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Simplifying the Input of Perceived Exertion in the Mobile Context using Prediction

Janko Timmermann[1], Alexander Schiotka[2], Wilko Heuten[1], Susanne Boll[2]
[1]OFFIS – Institute for Information Technology, Oldenburg, Germany
[2]University of Oldenburg, Germany
firstname.lastname@{offis.de, uni-oldenburg.de}

Abstract. In cardiac rehabilitation, training in the right intensity is important. To find this right intensity, vital parameters can be measured, but also the perceived exertion is an important factor. The perceived exertion is often measured using the Borg-RPE-Scale. It is usually used by trainers in indoor environments, not in a mobile context. In this context, the complexity of the Borg-RPE-Scale is a problem, especially when it should be used on a mobile device. In this paper, we present an approach to predict the perceived exertion using the vital parameters of a user to enable the realization of simple user interfaces. We show that the prediction and therefore the simplification is possible. Our results indicate that the usage of a predicted value seems not to influence users when entering their perceived exertion.

1 Introduction

Cardiovascular diseases are an enormous threat for our modern society, responsible for nearly 25 percent of all deaths in the world [10]. For patients who already suffer from a cardiovascular disease and probably already had a heart attack, the cardiac rehabilitation is a very important mean to achieve the best possible recovery [2,3,4,5].

The core element of cardiac rehabilitation is physical activity, which helps to improve the overall constitution of the patient. However, the right intensity is hard to determine because of many important influencing factors like age, constitution, weight, health, and medication [1].

Measuring the heart rate is the most common way to determine the training intensity. However, such measurements might not be available sometimes or be inaccurate, e.g. due to arrhythmia. Another way to assess the training intensity is to ask the patients about their perceived exertion. It is an important parameter as it reflects the subjective health of a patient. It helps to understand the patient's sense for exertion and further allows adjusting the training intensity in a way the patient is comfortable with. Quantitative scales have been developed to overcome the subjective nature of exertion. In cardiac rehabilitation, the Borg-RPE-Scale is used most frequently. In practice, trainers verbally ask patients about their perceived exertion and enter the value on the actual scale. The training is then adopted appropriately. While this is fine for supervised indoor training, patients in unsupervised outdoor training are asked to record the value on their own without any assistance, which can be quite hard. To stop and enter the required information is not an option, as this potentially changes the perceived exertion and patients might lose their preferred training pace. On mobile phones, which are more and more used to accompany the exercise, existing interaction paradigms, like a drop down menu, often require several corrections until the right exertion value is recorded. Consequently, perceived exertion is hardly recorded in outdoor training, which limits the outdoor trainings' success and puts the patients' well-being at risk.

In this paper, we investigate a system which uses an algorithm to predict the Borg-RPE-Points of the patient using measured heart rate and breathing frequency. This way, the system can generate an estimated value to simplify the entry of the real value for the user. We evaluated the system in a user study, to test for possible influences due to a predicted value. We conclude that our system is able to predict the value with an appropriate accuracy and that influences are unlikely. We also show indications on how a future system should look like and how the mobile usage of the Borg-RPE-Scale can be realized.

2 Background

For patients with a cardiovascular disease it is important to perform physical activities with the right intensity, duration, and frequency. The required intensity strongly varies depending on e.g. age, weight, illness, and medication [1]. One indicator for a good intensity is the perceived exertion. To measure the perceived exertion, the Borg-RPE-Scale (RPE: "Ratings of Perceived Exertion") was developed by Gunnar Borg [1]. The Borg-RPE-Scale is used nowadays to measure the perceived exertion of patients [6]. The Borg-RPE-Scale ranges from 6 to 20, so 6 means no exertion at all and 20 is the maximum exertion a patient can experience. The Scale is depicted in Figure 1. An activity at that level can only be done over a short period of time and is experienced as the highest possible load level.

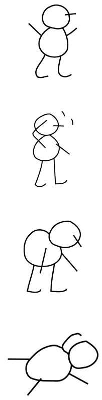
Numerical	Description	Graphical
6		
7	Easy	
8		
9	Very Light	
10		
11	Fairly Light	
12		
13	Somewhat Hard	
14		
15		
16	Hard	
17		
18	Very Hard	
19		
20	Maximum	

Figure 1. Borg-RPE-Scale

Though the perceived exertion as response to physical activity shows an exponential increase [1], the Borg-RPE Scale is linear. Using the Borg-RPE-Scale, patients can report their perceived exertion during their training. This information can then be used for reflecting the training, adjustments regarding the intensity, or even as main parameter for training adaption [11], so the patient can do her or his training in a comfortable way. Technically, the reports can be used to verify the heart rate measurements and allow a support system to adapt to users where the heart rate cannot be measured appropriately or does not normally reflect the intensity due to arrhythmia or medication.

Many parameters can influence the perception of the exertion. Especially patients with cardiovascular diseases sometimes have a deranged perception, but also environmental factors like e.g. temperature, humidity, and noise can influence the rating. Medication can also lead to a deranged perception and to different load limits. Under optimal circumstances, the points on the Borg-RPE-Scale and heart rate show a strong correlation between 0.8 and 0.9 [7]. This correlation is unrelated to the type of the physical activity [3]. For healthy people who are between 30 and 40 years old, the Borg-RPE value can be computed by dividing their heart rate by ten [1]. Patients who are treated with beta blockers have the same perception of exertion as without the medication, though their heart rate is lower [7].

3 Context Analysis

To understand the usage scenarios for the Borg-RPE-Scale during cardiac rehabilitation, we conducted a semi-structured interview with two trainers from a heart clinic and rehabilitation centre. The leading questions for the interview were: "*Which vital parameters correlate with the perceived exertion?*", "*Is the Borg-RPE-Scale already used in outdoor training?*", and "*What is the time interval for measuring a patient's perceived exertion?*" The trainers reported that the Borg-RPE-Scale is successfully used during cardiac rehabilitation to assess exertion and to optimize the training intensity for the patient. The trainers agreed to the fact that medication can strongly influence the perceived exertion and are therefore a problematic factor for its assessment. Another problem we did not see in related work is possible shame of the patient. Some patients do not like to tell their perceived exertion and report a wrong value which seems to be more convenient for them. Especially men sometimes tend to report smaller Borg-RPE values so it seems they have more capacities than they actually have. Since there was no experience with assessing the perceived exertion not through a trainer but through a technical device, it was unclear if that effect is also relevant in a mobile scenario. The trainers were optimistic about the usage of the Borg-RPE-Scale during outdoor activities. The time span between two measurements should be more than 6 minutes to let the cardiovascular system adjust itself to the changed exertion. An interval of 15 minutes was considered practically useful. Additionally, an assessment should be done if a known change of environmental factors, like changing slope, happens because it is very likely that a change in perceived exertion would also happen then.

In preliminary tests, we tested the input of the perceived exertion on the Borg-RPE-Scale with the help of common input methods on mobile devices, i.e. drop down boxes, sliders, and buttons. All variants needed a big and high resolution display to be easily used. Voice input would be an option for entering the perceived exertion and may be the best choice for some users. However, for many users the use of voice input in public is still awkward and the problem of misunderstandings is quite relevant especially in public and loud environments.

The input speed is critically important, since the input distracts users from their activity. Thus, a simple method for entering the value is needed. We propose the usage of a predicted value which requires only small adjustments by the user to ease the user input.

4 Approach

As our approach to simplify the usage of the Borg-RPE-Scale in the mobile context during the cardiac rehabilitation, we created an algorithm which predicts the users perceived exertion as Borg-RPE-Points using the measured heart rate and breathing frequency as the two main input parameters. As explained in the background section, the heart rate shows a very high correlation to the Borg-RPE-Points in an optimal scenario. We used the breathing frequency as a supportive parameter since it can be easily measured alongside the heart rate and is also related to the exertion. As third parameter, the correction to previously computed values the user entered is taken into account to adapt the computation to the specific user.

The outcome of using the algorithm is the possibility to use input methods where only minor corrections have to be entered by the patients. Thus, small wearable devices which can be worn e.g. at the wrist can be used instead of regular and big smartphones, which have to be hold in the hands or need to be pulled out of a pocket to enter the perceived exertion. The algorithm is not intended to convert the Borg-RPE values into a measured value. It is important that such an algorithm helps users to report their perceived exertion, but in no way performs the rating for them.

The algorithm computes the estimated Borg-RPE value using the heart rate and breathing frequency as vital parameters. These parameters have to be measured by sensors the user is wearing. Further, the algorithm needs information about the minimum and maximum heart rate. Because sometimes users do not know these values, we used the popular formula 220 – age. Very high accuracy was not an important factor for the algorithm, because it was not supposed to give recommendations about the load level to the user. The resting breathing frequency is always assumed to be 12 breaths per minute if it's not entered by the user [8]. For trained users, the algorithm assumes at maximum 60 breaths per minute, otherwise 45 breaths per minute [9] are assumed.

The algorithm starts with computing the Borg-RPE value for each vital parameter. As described in the background section, the Borg-RPE value is derived from the heart rate and can be approximately computed by dividing the heart rate by ten. Instead of doing only this simple operation, we took the minimum and maximum heart rate into account and divided this range into 15 sections which represent the 15 values of the Borg-RPE-Scale. If the actual heart rate exceeds or deceeds these limits, the entered or computed maximum or minimum values are used instead. The same method was used to map the breathing frequency onto the Borg-RPE-Scale. To combine them, we calculate the average value of both. Thus, both values have the same weight in the final computed value.

To adjust the computation to a specific user, the algorithm also takes the difference between this computed value and the corrected value of the user into account. The algorithm computes the average of all these corrections and applies this offset to the computed value.

We created an Android application to test our approach and collect user feedback about the Borg-RPE-Scale on mobile devices. The application was kept simple and was planned as throw-away prototype. It was not tested for usability or designed using dedicated guidelines since user interaction with the application was supposed to happen only supervised. It consisted of two views: The start view and the training view. The start view let users enter their gender, training level, and age (Figure 2). An alternate tab let users enter their resting and maximum heart rate and breathing frequency. Both had a button to control whether the application should start the training with computed Borg-RPE value suggestions or not.

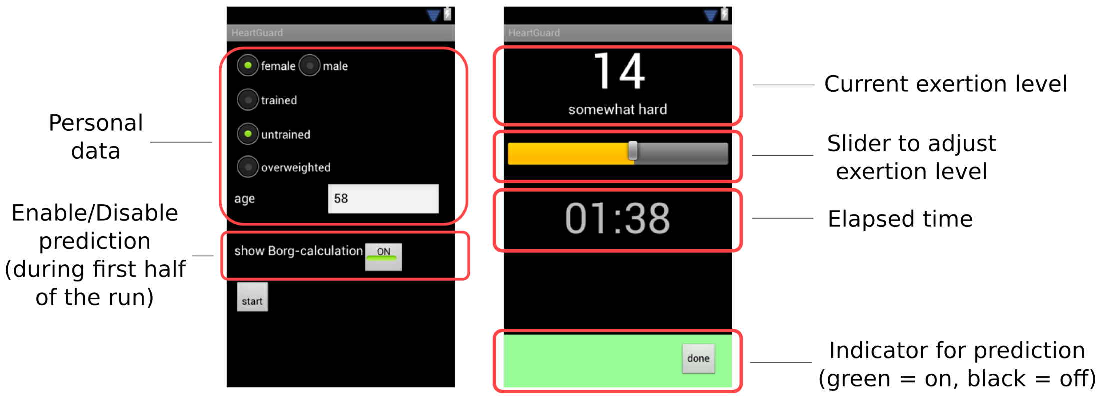


Figure 2. Start & Training View of our application.

The training view was shown after the start view. It is depicted in Figure 2. On top of the view the selected exertion level on the Borg-RPE-Scale as numeric value was shown. A description of that level was printed below in text form. To change this value, a slider was placed below this display. The slider let users enter all possible values from six to 20 by moving it from left to right. It was not only controllable by the users, but also by the algorithm to keep the exertion level display and the slider always consistent. A timer showed the time since the training was started. Near the finish button to end a training, the bottom area of the view was coloured black or green depending on whether the algorithm to suggest values was active or not. Intentionally, the app did not show the measured heart rate and breathing frequency to avoid influencing the users' perceived exertion input.

5 Study

To test the algorithm for predicting the Borg-RPE-Points, to evaluate whether a displayed predicted value influences the users, and to collect qualitative feedback about a mobile usage of the Borg-RPE-Scale, we conducted a field study.

The location for the study were paths dedicated for running. Thus, no distraction by traffic was possible and the participant was able to run continuously. In most cases, the location was a sports field with a running track. We used a Samsung Galaxy Nexus running the application described above in combination with a Zephyr BioHarness 3.0 belt. The BioHarness 3.0 sensor allows measuring the heart rate and the breathing frequency.

We conducted the field study with 14 participants, 4 female and 10 male. The age ranged from 22 to 44 years. The mean age was 26.1 (SD: 5.6). All participants were healthy, despite the fact that the target user group are patients with a heart disease. We did this due to ethical reasons, especially to avoid any risk for the participants. However, the algorithm regards special requirements of cardiac patients like adapting to a lowered heart rate due to medication. As described in the context analysis section, these users have the same perceived exertion compared to healthy users and the algorithm adapts to their lower heart rate over time. The activity levels of the participants were quite mixed and reached from no physical activity to regular intense physical activity. The participants were not paid for their participation in the study.

The study consisted of three parts with different load intensities. The intensities were *low (walk fast), medium (run with moderate pace), and high (run fast)*. The order in which a participant had to reach these load levels was defined using the Latin Square. Every intensity was meant to be maintained for ten minutes. If a participant was not able to maintain a load level for such a long time, she or he should try to keep the highest possible load level. As mentioned above, the application was able to query the load level from the user with or without supposing a predicted value. This behaviour switched in the middle of a run, thus after five minutes. For the first run of the first participant, it was randomly defined that no predicted values were shown in the first five minutes but thereafter. For all following runs of all participants, this order was switched for each run. After one run, a short break for the participants was planned to normalize the heart rate and breathing frequency before starting the next run.

Afterwards we conducted a semi-structured interview with the following leading questions: "*What do you think about the application?*", "*Were you satisfied with the supposed Borg-RPE value and was there a difference between different load levels?*", "*Did you like this type of representation of the exertion?*", and "*Would you like to use such a system?*"

In the beginning of the study, we met each participant at a location communicated beforehand. We explained the study to them and answered their questions. After the participants signed the informed consent, we explained the equipment which we described above. We handed the equipment to the participants and let them attach the chest strap in a private environment. Afterwards, we explained the Borg-RPE-Scale and ensured the participants understood the principle of reporting the perceived exertion with it. Finally, we started the three runs with altering intensity and with pauses in between. The length of a pause was defined by the participants but was encouraged to be only as long as needed to recover from the previous run and normalize the heart rate and breathing frequency. In the end, we conducted the interview, thanked the participant, and ended the study.

6 Results

The quantitative results are based on the data of twelve of the 14 participants. Two recorded data sets contained very high and obviously erroneous recorded heart rates and were therefore eliminated for this evaluation. The following table shows the means of our recorded values during the study at the different load intensities:

	Low Intensity	Medium Intensity	High Intensity
Heart Rate	144 (SD: 17.2)	180 (SD: 10.9)	188 (SD: 11.3)
Breathing Frequency	31 (SD: 5.7)	35 (SD: 6.8)	39 (SD: 4.7)
RPE Ratings	14 (SD: 2.0)	17 (SD: 1.8)	18 (SD: 1.3)

Table 1. Means of values recorded during the study

The correlation coefficient (Bravais-Pearson) between the heart rate and the Borg-RPE-Points was 0.8, as in the related work. The breathing frequency showed a medium correlation of 0.47, which is still good, but clearly shows that the breathing frequency should only be used if the heart rate is not available or inaccurate.

The average ratings of perceived exertion showed no significant difference (t-test, $p = 0.69$), when the suggestions by our algorithm were enabled (13.97, SD: 2.84) or disabled (13.85, SD: 3.47). However, the count of adjustments the users made to the predicted or previously entered value differed significantly (t-test, $p < 0.01$): The displayed Borg-RPE value was corrected on average 8.1 times (SD: 2.68) of 15 when the algorithm was used and 5.28 times (SD: 2.67) of 15 when not. If users corrected the value, it was changed on average by 2.11 Borg-RPE-Points (SD: 1.07) when the algorithm was used and 1.2 Borg-RPE-Points (SD: 1.16) when not. The Shapiro Wilk test showed that this data set was not normally distributed ($p < 0.01$), so we used a Wilcoxon signed rank test as test for significance. The test showed that the difference is not significant with $V = 73$ and $p = 0.06$. These results show, that the quality of the algorithm is not well enough in this iteration. However, it is also an indicator that the algorithm did not influence the users, since they did not simply use the predicted value instead of correcting it. The fact that the average exertion did not significantly differ between both conditions also supports this indication. Under the assumption of no influence we can recommend the usage of the Borg-RPE-Scale with the help of a predicting algorithm in the mobile context, if parameters for assuming values in an accurate way are available. A future version of a prediction algorithm should only propose a predicted value, if the exertion changed heavily, otherwise it may make the input of the Borg-RPE value even more complicated than easier. Naturally, if the predicted value differs not so much from the previously entered value of the user, the proposal of the predicted value instead of the previously entered value would not be beneficial.

During the interview at the end of the study, we found that users would like to use a system to record their perceived exertion if the interface is easy to handle during physical activity. Most users were satisfied with the suggested value given by the app, but reported a higher accuracy at higher load levels, which is supported by the quantitative results.

7 Conclusion

In this paper, we tested the usage of the Borg-RPE-Scale on mobile devices. We created an Android application which queried the Borg-RPE value from the user during training. This application was combined with an algorithm to predict this value using heart rate and breathing frequency to simplify the user input of the perceived exertion. We found that our algorithm was able to predict the perceived exertion within an acceptable range and is therefore able to enable a user input with only small corrections of a predicted value. Our results indicate that users were not influenced by these predictions. We can therefore recommend the use of this technique if the users are intended to record their perceived exertion using the Borg-RPE-Scale. However, it has to be made clear to the users, that a predicted value does not replace entering the perceived exertion but eases the input. We found that users were generally interested in a system which enables the input of perceived exertion. The predicted exertion level of the application was well accepted. When using the

Borg-RPE-Scale in the mobile context, the prediction algorithm needs to be optimized to raise the accuracy. It should only be active when the activity clearly changed and the Borg-RPE value is expected to raise or fall much. Further input methods have to be created and evaluated which are possible with the help of the algorithm. This includes also the usage of small displays like smartwatches or other wearable devices. Since users were interested in using the history of their perceived exertions as observation for their training, this has to be tested against traditional systems, like heart rate recorders.

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