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„Velocity-based training: A comparison of two representation approaches for rating of perceived exertion“

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Abstract

Representation of values in smartphone applications can affect user experience and how actions are decided. How certain information is perceived depends on how information is represented and displayed to the end user. This thesis aims to represent the so-called rate of perceived exertion (RPE) values in a textual and graphical way within an Android smartphone prototype and evaluate the preferences of strength athletes, specifically powerlifters. In powerlifting the velocity-based training method can be used to identify how exerting an athlete's training set is based on the mean velocity of a barbell's movement.

One method for athletes to rate exertion is the RPE scale, which rates the felt exertion from 1 to 10. Since the mean velocity of the last repetition of a training set can be mapped to such an RPE value, a comparison between the expected exertion, the felt exertion and exertion based on the mean velocity can be performed to help athletes estimate and plan their exertion.

Training data was gathered during an evaluation with two powerlifters to identify how representations can improve the RPE values estimations. The evaluation lasted for each participant four weeks. This training information consisted of RPE values, repetitions and weight for each training set of the exercises squat, bench press and deadlift and was tracked by using the self-developed Android prototype application. Additionally, an interview was performed to investigate possible value representation preferences and other perceptions of the test persons.

The analysis of the three powerlifting competition lifts – squat, bench press and deadlift – consisted of 95 training sets. The RPE values of the different training sets were compared to check for possible deviations. According to the observations, no significant difference existed between the two representation approaches. As the athlete who started with the graphical representation had slightly less deviations between the RPE values, it is possible that the graphical representation can improve the RPE ratings already at the beginning. Additionally, it was observed that after two weeks of velocity-based training, the estimation of RPE value has improved independently of the RPE value representation.

Nonetheless, the analysis and the interviews with the powerlifting test persons reveal a preference for the graphical representation of values.

Kurzfassung

Verschiedene Darstellungsformen in Smartphone Applikationen können unterschiedlich auf Anwender wirken. Wie Informationen visualisiert sind kann die Benutzerwahrnehmung oder auch User Experience beeinflussen. Der Fokus dieser Masterarbeit liegt auf der Wirkung zweier Darstellungsmethoden im Kraftsportbereich. Im Detail wird eine textuelle Darstellungsform und eine graphische Darstellungsform miteinander verglichen, welche in einer selbstentwickelten Android Prototypenapplikation visualisiert wurden. Die Datenbasis für die Darstellungsform ist der erwartete Anstrengungsgrad, der gefühlte Anstrengungsgrad und der Anstrengungsgrad basierend auf der Durchschnittsgeschwindigkeit der letzten Wiederholung eines Trainingssatzes.Diese Anstrengungsgrad wird meist durch die *Rate of perceived Exertion (RPE)* Skala ermittelt. Mittels der Durchschnittgeschwindigkeit der letzten Wiederholung eines Trainingssatzen kann auch ein RPE Wert ermittelt werden und somit eine objektive Aussage über den Anstrengungsgrad getroffen werden. Diese Methodik ist ein Anwendungsgebiet des *Velocity-based trainings*.

Mittels der Bewertung der erwarteten Anstrengung, der gefühlten Anstrengung und durch das objektive Feedback anhand der Durchschnittsgeschwindigkeit kann ein Vergleich zwischen den ermittelten RPEs Werten erstellt werden. Diese drei Werte können gegenübergestellt werden um einen Vergleich zu ziehen, wie sehr die eigene Einschätzung mit dem Anstrengungsgrad basierend auf der Durchschnittsgeschwindigkeit übereinstimmt.

Während einer Evaluierungsphase, in der jeweils für zwei Wochen eine Darstellungsform die RPE Werte anzeigte, wurden Trainingsdaten von zwei Kraftdreikämpfern gesammelt. Die Evaluierungsphase dauerte pro Teilnehmer 4 Wochen. Die Trainingsdaten umfassten jegliche Information der drei Kraftdreikampf Übungen: Kniebeugen, Bankdrücken und Kreuzheben. Da sich nach 2 Wochen die Darstellungsform des RPE Vergleichs für die Testpersonen änderte, konnte innerhalb von 4 Wochen RPE Vergleichsdaten für beide Darstellungsformen gesammelt werden. Zusätzlich wurde nach dem Ende der Evaluierungsphase einer Testperson ein Interview mit dieser durchgeführt. Die Interviews hatten die Preferenzen über Darstellungsformen und generelles Feedback zu der Evaluierungsphase im Fokus.

Während der Evaluierungsphase wurden Trainingsdaten von insgesamt 95 Trainingssätzen gesammelt. Um eine Aussage darüber treffen zu können, ob eine der Darstellungsformen anhand der RPE Daten präferiert wird, wurden die RPE Bewertungen auf die Darstellungsformen geteilt und miteinander verglichen. Anhand der Analyse konnte insgesamt kein signifikanter Unterschied zwischen den Beiden RPE Darstellungsformen erkannt werden. Einzig, hatte die Testperson, welche mit der graphischen Darstellung in die Evaluierung startete etwas weniger RPE Abweichungen als die andere Testperson. Abgesehen davon wurde aber beobachtet, dass sich nach 2 Wochen für beide Testpersonen die RBE Einschätzung verbessert hatte, unabhängig von der Darstellungsform.

Nichts desto trotz wurde die graphische Darstellungsform basierend auf den Interviews und der Analyse der RPE Vergleichsdaten präferiert.

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1. Introduction

Powerlifting is a competitive strength sport in which athletes aim to gain maximal strength for three different exercises: squat, bench press and deadlift. Competitors have three attempts in a competition for each lift, which are judged by three referees based on the set rules. Each exercise must be performed according to a set of rules set; for instance, the squat needs to be at least at a certain depth to be accepted. To gain strength, training with certain weight is needed. The process of finding the proper training weight can be very tricky. Training methods like velocity-based training (VBT), which uses the mean velocity of the repetitions of a training sets, or rating ones perceived physical exertion can support this process. Athletes can rate their exertion with the rate of perceived exertion (RPE) scale, which rates the felt exertion from 1 to 10. Also the mean velocity of the last repetition of a training set can be mapped to such a RPE value.

By using both methods a comparison between the expected exertion, the felt exertion and exertion based on the mean velocity of training sets can be performed. This comparison can be represented in different ways. The goal of this thesis is to investigated two comparison representation approaches of the RPE values and to identify how representations help to improve RPE-values estimations and which representations are preferred by powerlifters?

1.1. Powerlifting - a sport to gain maximal strength

The main goal for a powerlifting athlete is to improve their strength. To accomplish this an exercise overload must be reached in training that exceeds the usual level. Such an overload can be achieved in multiple ways, such as training intensiveness, namely the amount of effort an athlete puts in to complete the exercise.

Intensity is relative to an athlete's one-repetition-maximum (1-RM), which is the maximum weight that can be performed for one repetition. If an athlete can squat at one day 100 kg for exactly one repetition with maximal effort, an intensity of 80% would refer to 80 kg. Since 1-RM varies day by day due to daily performance fluctuation, the intensity cannot be identified with precision. In addition to intensity, intensiveness represents how exerting a training set was. A training set which consists of 20 repetitions and is performed with 60% of the 1-RM weight, can be very exerting, but has low intensity as the weight is only 60% of the 1-RM. Therefore, it is possible that a training set has high intensiveness but low intensity. For example repetitions 60% of the 1-RM is performed To know the daily 1-RM, a 1-RM test would be needed, which is usually performed the following way: the athlete increases the weight step by step and performs one or multiple repetitions. This increase goes on until a weight is reached which the athlete can perform only for one repetition with maximal effort. According to Zatsiorsky et al. [ZKF20], training with sub-maximal weights is desired to improve strength, but it is hard to decide with which weight to train. One training method to facilitate these decisions is velocity-based training (VBT).

1.1.1. Velocity-based training

VBT is a training method that uses the velocity of a barbell's concentric movement to track an athlete's performance in strength training. In the concentric phase the muscles shorten and develop force to move the barbell against gravity. VBT can be integrated into a wide series of training approaches. There are different traditional training methods in strength training, such as percentage-based training or rate-of-perceived-exertion (RPE) training, for which VBT can be an accessory. In addition to visual and verbal feedback, VBT can support the prescription of loads and the number of repetitions. To account for the large spectrum in which VBT can be used, one can note that VBT can enhance and support training practice by using velocity, as described by Weakley et al. [WMB+20]. One usage of the mean velocity of a training set would be the identification of an athlete's intensiveness. This information can be used to identify an athlete's everyday performance and the right training weight. Besides form using velocity, also rating one's perceived exertion is one way to rate a set's intensiveness. Both methods result in an exertion value which can be represented beneath each other and compared.

1.2. Problem

In strength training it is not always easy to find the training weight needed to achieve the desired result. Athletes' performance and physical condition can vary immensely from day to day, and so can their 1-RM. Therefore, what might be extraordinarily intensive on one day, can be less intensive on another, as described by Zatsiorsky et al. [ZKF20]. Therefore, a load of 90% of the 1-RM on a 'good' day could become 105% on a 'bad' day. Training on the 'bad' day with the same weight as that of the 'good' day tremendously increases the risk of injuries while most likely not bringing the desired results. To identify what an athlete' 1-RM for a particular exercise is, a 1-RM test would be needed, which is not applicable on a regular basis due to the huge amount of effort needed. Therefore, the 1-RM gets estimated. The training weight can be chosen based on this estimation. Another approach to finding the right weight for training is to rate the perceived exertion of a set.

1.2.1. Rate of perceived exertion

The rate of perceived exertion (RPE) scale is a scale to measure how hard a physical sensation feels, also considering heart rate, breathing rate, sweating and fatigue, as described by Borg [Wil17]. Zamuner et al. [ZMC+11] describe the Borg scale as a demonstration of the general perception of physical exertion. This exertion is integrated by multiple aspects, such as muscle activation, pain and dizziness. The scale ranges from 6 to 20 to rate exertion, where 6 is no exertion at all and 20 is maximal exertion, and is used to rate training sessions, exercise intensities and aerobic activities [ZMC+11]. However, for strength training, a derivation of the Borg RPE scale is used.

Prescribed by Mike Tuchscherer in his book *The Reactive Training System*, [Tuc08] another method of using RPE was presented already in 2008. This scale was scientifically introduced by Zourdos et al. later in 2016 [ZKD+16]. It ranges from 0 to 10 in 0.5 steps and uses an approach in which the repetitions in reserve – namely, the number of repetitions that could still be performed with proper technique – are subtracted from the

Rating	Description
10	Maximum effort - No more repetition possible
9.5	1 repetition might be possible
9	1 repetition is definitely possible
8.5	1-2 repetition might be possible
8	2 repetition are definitely possible
7.5	2-3 repetitions might be possible
7	3 repetitions are definitely possible
1 - 6.5	Low effort - multiple repetitions possible

Table 1.1.: Rate of perceived exertion scale (RPE) as described by Zourdos et al. [ZKD+16].

highest value 10. An example would be an RPE value of 9, indicating that exactly one repetition could still have been performed, whereas 8.5 entails that one or two repetitions could still have been performed, as shown in Table 1.1. The 1-RM can be calculated based on this subjective rating. Hence, the intensiveness of a training set can be rated with the RPE scale to identify an athlete's strength on a particular day and calculate the right weight for the training.

However, RPE is subjective and can be affected by an athlete's mood, motivation, or other emotional conditions, making it complicated to compare different sets and can lead to wrongly assessing the current performance and the 1-RM. Nonetheless, if a set felt harder for an athlete than on a previous day, it does not mean that the performance on that day was worse than on the previous. To achieve an objective view of an athlete's performance, one can use the movement's velocity of the set.

1.3. Motivation

A primary goal of velocity-based training is to provide the athlete with immediate feedback on how fast a set was performed. This information can be used to identify intensity and intensiveness. The higher the velocity of barbell's movement – namely, the faster it moved – the easier the movement was for the athlete, as described by Testa et al. [TND12] and Helms et al. [HSC+17]. If a barbell is loaded with an athlete's 1-RM weight, the barbell will move slowly since the athlete needs to generate a maximal amount of force to move it. For instance, on day 1, an athlete could deadlift 200 kg with a velocity of 0.2 m/s, whereas on another day, they could deadlift the same weight at a velocity of 0.35m/s. Since the velocity on day 2 was higher, they were stronger on day 2 for this particular exercise than on day 1.

1.3.1. Load-Velocity profile

A standard method of velocity-based training is to create a so-called load-velocity profile. Load and velocity share an inverse relationship whereby the heavier the weight, the lower the velocity. The goal of a load-velocity profile is to identify how intense the training set was. This can be achieved by using the measured mean velocity. Since the load-velocity profile is modelled through a linear regression equation, the percentage of the 1-RM can be calculated by knowing the mean velocity with which the barbell was moved.

Based on Zourdos et al. [ZKD+16], the percentage of the 1-RM can be converted into RPE values, and the mean velocity can be used to suggest the RPE value.

Subsequently, each RPE value can be mapped to a specific mean velocity range according to the previously created load-velocity profile. For instance, the RPE value @8 ranges from 0.1571m/s to 0.1703m/s, as shown in Figure 1.1. After a new set is performed, the measured velocity can be used to check into which range it fits for identifying the RPE. This mapping can be used to estimate the RPE value based on the mean velocity.

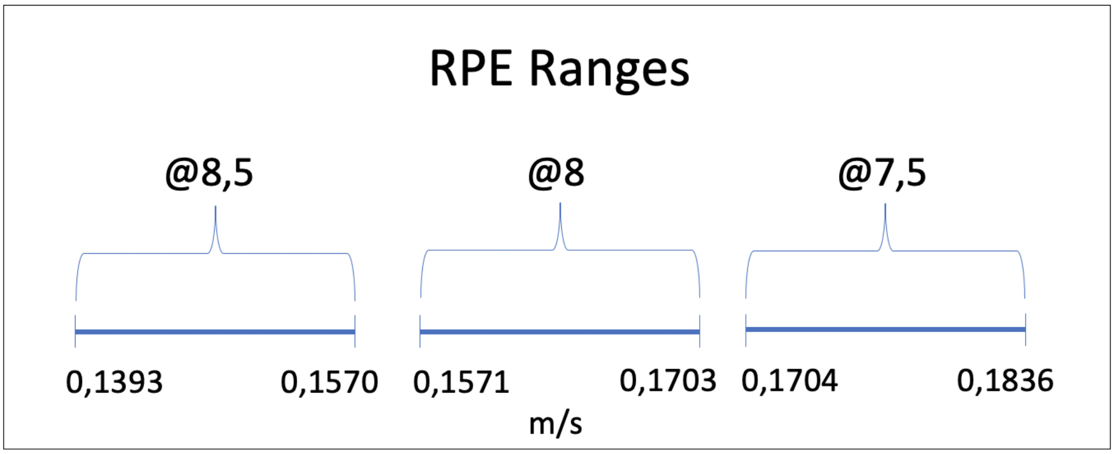


Figure 1.1.: Example of an exertion-load profile with rate-of-perceived-exertion (RPE) values from 8.5 to 7.5.

Subsequently, it is possible to calculate an RPE value out of the measured mean velocity to formulate a more objective statement about a training set's intensiveness than athletes' subjective rating. Comparing an athlete's expected and felt RPE value with the calculated RPE based on the mean velocity helps to correctly state how well the felt exertion fits with the intensiveness suggested by the measured velocity.

Since the mean movement's velocity needed to be measured somehow, an analysis of different inertial measurement units (IMUs) was performed. This analysis consisted of reviewing different papers which evaluated multiple tools (cf. [BNSH17, MHB+21, BFKPOdCV16, WMGR+21]).

To interpret the comparison values, a specific visual representation of these values is needed. Hence, this thesis investigates the following research questions:

1. *Which representations do powerlifters prefer for their RPE-based strength training?*
2. *How can representations help to improve RPE-values estimations?*

1.4. Idea

The approach used to answer the two research questions was to perform an evaluation with two powerlifters, in which each participant collected training data consisting of RPE values and mean velocities for four weeks. Since the information gathered during the evaluation phase needed to be stored and represented, a prototype of an Android application was developed. As measuring the mean velocity was out of scope of this thesis, a commercial tool, the PUSH Band 2.0, was purchased. The measured velocity values measured by the PUSH Band 2.0 were manually entered by the test persons in the Android prototype application. Further, an interview was held with the test persons to gather additional insights on their RPE representation preferences.

At the start of the evaluation, the test persons created their load-velocity profiles for the three exercises. During the evaluation the athletes followed their usual training program and tracked their training sets' mean velocity and perceived exertion. Through the previously created load-velocity profiles, the smartphone application transformed the mean velocity into the calculated RPE value, representing the intensiveness that should be felt according to the movement's velocity. By doing so, the user saw all three RPE values beneath each other for comparison. To know which comparison representation would be preferred, two different approaches were shown to the user during the evaluation phases. In these representations the three RPE values were *RPE Estimated*, *RPE Actual*, *RPE Velocity*.

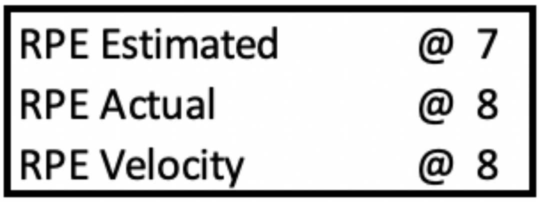


Figure 1.2.: Simple textual representation for the comparison of the three RPE values.

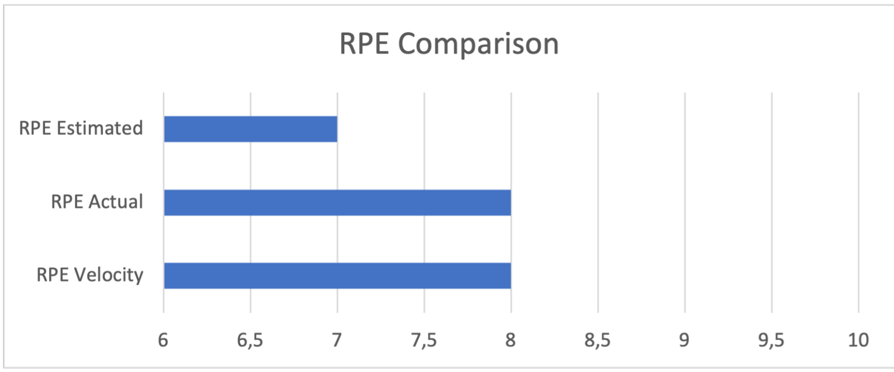


Figure 1.3.: The graphical representation is a bar chart in which each bar represents one RPE value.

- Textual value representation: The textual representation shows the three RPE values and their description below each other in a simple manner. An example of this representation can be seen in Figure 1.2
- Graphical value representation: The graphical representation shows the three RPE values in a horizontal bar chart. In this bar chart each RPE value is represented as a bar. The x-axis of the bar chart shows the RPE value, and the y-axis shows which

RPE value of the three options it is. An example of this representation can be seen in Figure 1.3.

An interview was performed after the four-week evaluation phase to gather qualitative feedback from the test persons on their preference for value representation. Following this interview, the test persons' comparison values were analyzed to check whether their RPE rating improved. As a result of this analysis, a statement on how representations can improve RPE value estimations will be given.

The remaining sections of this thesis are structured as follows: a related work section in which different data representation approaches, activity recognition through accelerometers and existing velocity-based training (VBT) applications are investigated. A design and implementation area of the developed Android application as a realization approach of the described idea. Section 4 covers a preliminary study which is based on the interviews which were performed as part of the *LP Praktikum 2*. In the subsequent section the evaluation of the described approach is described with a discussion about the results. A conclusion and an outlook to possible future work are provided at the end.

2. Related Work

The concept of VBT has existed already for some years. The availability of VBT-tools and applications arose in recent years due to new technologies and sensors. Since there are many possibilities to measure velocity, different types of applications and algorithms can be used. Accelerometer-based activity-recognition systems for the identification of velocity and specific activities are discussed. Additionally, studies that describe the relationship between RPE and velocity are debated to identify how RPE values can be mapped to the mean velocity of a training set.

As the perception of the representation of RPE values in a smartphone application is an important part of this thesis, different value representations in smartphone applications will be discussed. In addition, general design guidelines as well as smartphone specific design guidelines are debated. Especially, the use of UI design patterns and how representations can influence the comprehension of information are investigated.

2.1. Activity recognition through accelerometers

An accelerometer measures acceleration, which is the rate of change of velocity, whereas a tri-axial accelerometer measures the change of velocity in three directions, x, y and z. Since many wearable devices have built-in accelerometers and gyroscopes, using them to detect physical activity has become a current standard, as described by Knight et al. [KBA+07] and Henriksen et al. [HMW+18].

The increase of accelerometers for physical exercise detection is reflected upon by Troiano et al. [TMBC14]. Nearly 600 articles were published in this area between 2012 and 2013. Studies were also conducted in the area of fall detection, and they demonstrated that fall detection occurs through significant changes in acceleration. Thereby, the accelerometer outputs raw acceleration signals which provide an explicit representation of acceleration due to bodily motion in intervals of fractions of a second.

2.1.1. Activity recognition and monitoring of physical activity through mobile phones or fixed accelerometers

In recent years studies on activity recognition and the monitoring of physical activities have increased, aiming to show when the use of wearable sensors is practical.

These studies mostly focus on static or dynamic movements and try to classify and recognize them.

Lugade et al. conducted a study to validate the identification of postural orientation and movement from acceleration data against visual inspection from video recordings [LFMK14]. They used tri-axial accelerometers to collect data from dynamic movements, such as walking and jogging, and data from non-dynamic movements, such as standing and sitting, of 12 adults. One accelerometer was placed at the waist and another at the thigh to obtain greater accuracy. According to the authors, each segment took between

5 seconds, as in the case of jumping, and 60 seconds, as in the case of lying down. For their data collection they used a video camera with a sampling rate of 60Hz and two micro-electrical-mechanical-systems (MEMS) accelerometers with a sampling rate of 100Hz. For data analysis, self-written MATLAB programs were used to remove any high-frequency noise spikes and apply a median filter.

The accelerometer data from the waist was mainly used to differentiate dynamic activities from static postures. By using a threshold-based approach, the authors classified certain data as movements. If the signal-magnitude-area values were above 0.135g, the data was classified as movement. The authors observed that the longer the duration of the movement, the greater the accuracy. While the accuracy for long-lasting movements was high, they could not distinguish between stair climbing and level walking. The usage of the signal magnitude was used to distinguish between walking and other activities with good sensitivity and specificity. Another outcome of their study was that only by using wavelet transforms it was possible to accurately recognize movements from very slow walking adults. However, the study suggests that accelerometers can accurately detect static postures and dynamic movement among the general population.

Another study which was published by Fortune et al. [FLMK14] investigated validating step counts and cadence calculations from acceleration data. The acceleration data was compared with video data and data from two commercial wearable devices (Fitbit and Nike Fuelband) during dynamic activities. Twelve healthy adults participated in the experiment. They performed walking or jogging a straight line over an 8.5 m walkway seven up to 10 times. The data collection phase included several supervised trials, of which the first one was not supervised, and subjects performed the walk with self-selected gait velocity. A total of 105 trials were performed with slower and faster speeds. The threshold of the signal magnitude area indicated by Lugade et al. [LFMK14] was used to identify non-activities.

Four Mayo Clinic custom-built activity monitors consisting of tri-axial MEMS accelerometers with a sampling frequency at 100 Hz for each axis were mounted on each person to monitor activities. Simultaneously, video data at 60Hz was collected with a handheld camera. To eliminate noise, the authors post-processed the data with MATLAB. This processing included a median filter with a window size of 3, which was applied to the orthogonal raw acceleration signals. Further processing was performed by separating the data into its gravitational component to get the bodily motion components. Results revealed that the system could outperform the Fitbits and Nike Fuelband for gait velocities from 0.1 to 4.8 m/s with a higher median agreement.

2.1.2. Accelerometer systems for strength training

Research on the use of accelerometers in strength training started already years ago. In 2007, Change et al. [CCC07] investigated the identification of exercise types and the counting of repetitions of free weight exercises, such as the bent-over row, the bicep curl or the deadlift. The authors used a tri-axial accelerometer which was mounted onto a glove and a posture clip to detect if the person was standing or lying. The sampling rate of the accelerometer was 80Hz, and two machine learning methods – namely, Naïve Bayes classifiers and Hidden Markov models – were used to count repetitions and identify the exercise type. Counting repetitions mainly focused on the acceleration peaks of the exercise sets. The data was collected during an evaluation phase with 10 subjects who performed nine exercises with different weights. In total, they collected acceleration data from 4,925 repetitions. The results revealed an error rate of less than 5% for counting repetitions, implying that out of 100 repetitions less than five were not detected. A good accuracy (i.e. 90%) was also achieved for exercise type recognition. Chang et al.'s [CCC07] study represent a milestone in using accelerometer data for activity recognition in free weight training. A similar study was conducted by Li et al. [LFHQ12] in 2012 in which accelerometer data was also used to count repetitions within sets.

2.1.3. Summary

In summary, it can be seen, that activities like running, walking and counting steps can be well identified as described by Fortune et al. [FLMK14] and Lugade et al. [LFMK14]. Besides from studies on daily activities, also studies on the repetition recognition of strength training exercises like the deadlift and the bent-over row were analyzed.

Since a velocity measurement tool was needed to track the mean velocity of the repetitions and accelerometer-based systems are more affordable than for example linear-position transducers, as it is described in the next section, studies on activity recognition were interesting for this thesis. Especially, studies on the recognition of repetitions of strength training exercises, were relevant as only the mean velocity of recognized repetitions can be measured.

2.2. Velocity-based training applications

Repetition detection is one part that VBT tools need to master. Only repetitions that are correctly detected can be correctly measured. To measure barbell velocity, different technologies, such as accelerometers, video systems or linear transducers (LT), have been used.

2.2.1. Review of existing systems

Today, several commercial products are available to support VBT. Essential tools when it comes to VBT are linear transducers and devices using orientation and acceleration to measure velocity. In most reviewed studies, the wearable tools are compared to linear transducers since they are the gold standard for measuring velocity, as stated by Balsalobre et al. [BFMBV+17] and Banyard et al. [BNSH17].

Linear-position transducer

A linear transducer for VBT consists of a sensor with a cable attached to a barbell. The velocity is measured through the cable displacement or by transducing electrical signals within a certain time. Linear transducers are known for exceptionally high accuracy in measuring velocity. However, their major disadvantage is their cost of up to 2,000 USD, as Balsalobre-Fernadez et al. [BFKPOdCV16] mentioned in their study. One of the most popular linear transducers for VBT might be the *GymAware* tool. Figure 2.1 shows a *GymAware* tool attached to a barbell.

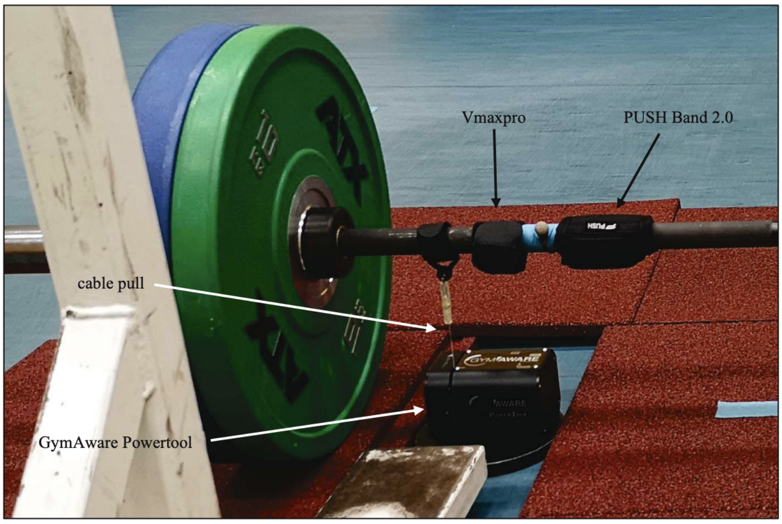


Figure 2.1.: Example of a *GymAware* device, a Vmaxpro device and a PUSH Band 2.0 attached to a barbell, from Menrad and Edelmann-Nusser [MEN21].

Inertial measurement units

Since velocity can be calculated by integrating acceleration over time, tools using acceleration for Velocity-based training were released in the last years. Such inertial measurement units (IMU) for Velocity-based training are technical constructs using orientation, measured through a gyroscope, and acceleration measured through an accelerometer to calculate velocity. Two popular IMU tools for VBT are the PUSH Band (PUSH Inc., Toronto, Canada) and the Beast sensor (Beast sensor, Beast Technologies Srl., Brescia, Italy). Figure 2.1 shows both attached to a barbell.

A validity and reliability study for the PUSH Band 1.0 was conducted done by Balsalobre-Fernadez et al. [BFKPOdCV16]. The systems' measured velocity was compared with the measured velocity of a T-Force linear- velocity transducer (Ergotech, Murcia, Spain) for the back squat exercise, executed on a smith machine.

The authors performed an incremental strength test with 10 students, in which each student performed completed three repetitions during a back squat exercise on a smith machine with five different loads ranging from 25% to 85% of their 1 RM1-RM. The goal of the study's goal was to compare the measured velocity from the linear transducer and the PUSH Band. The used linear transducer measured vertical velocity at a sample rate of 1,000Hz, whereas the PUSH Band 1.0 used a sample rate of 200Hz.

The PUSH Band used a Butterworth filter to smooth the raw acceleration data and integrated the vertical acceleration to calculate the velocity. Unlike the linear transducer, the PUSH Band was not fixed at the barbell but at the forearm, a bit below the elbow. Figure 2.2 shows how the PUSH Band should be fixed at the forearm. To validate the system, the authors took the peak velocity and the mean velocity as comparison values, as well as the resulting load-velocity relationship of the 150 tracked repetitions. Balsalobre-Fernadez et al. [BFKPOdCV16] found higher validity and reliability for the PUSH Band than the linear transducer for both peak and mean velocity. Since the PUSH Band is not a barbell fixed VBT system but is instead fixed at the athlete's forearm, these results encourage one to expect that measuring velocity with systems not fixed at the barbell would also deliver good results. However, the strength test was performed on a smith machine and not with free weights, which would be more interesting.

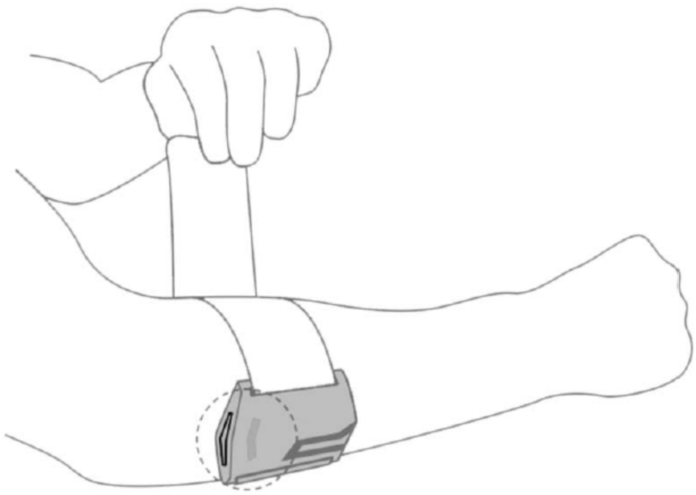


Figure 2.2.: Placement of the PUSH Band at the forearm, as described by Balsalobre-Fernandez et al. [BFKPOdCV16].

In 2017, Balsalobre-Fernadez et al. [BFMBV+17] analyzed the wearable VBT system Beast sensor and the iOS App PowerLift for validity, accuracy and reliability. Similar to their study from 2016, 10 highly trained powerlifters performed a 1-RM test for the following free-weight exercises: back squat, bench press and hip thrust. Since the Beast sensor can be attached either directly on the barbell or at the subject's wrist, both places were tested. Two Beast sensors (one at the barbell and one at the subject's wrist), a linear transducer – specifically, a SmartCoach Power Encoder (SmartCoach Europe, Stockholm, Sweden) and the PowerLift app were compared. The authors achieved results similar to those of their previous study for all three exercises. Compared to the gold-standard linear transducer, all VBT systems had acceptable validity and reliability. Although no significant performance differences were found between the Beast sensor attached to the barbell and that attached to the subject's wrist, Balsalobre-Fernadez et al. [BFMBV+17] mentioned that the Beast sensor had better results than the PUSH Band 1.0 from their previous study. The authors were mainly arguing this due to the different placement of the devices since the PUSH Band 1.0 was placed slightly below the elbow, whereas the Beast sensor was placed at the subjects' wrist. Although Balsalobre-Fernadez et al. [BFKPOdCV16] presented remarkable results for the PUSH Band 1.0, Banyard et al. [BNSH17] questioned its performance based on their validity study. Specifically, they compared the performances of the PUSH Band, a linear position transducer (LPT) of the brand *GymAware* and a laboratory test environment which consisted of four LPT for the back squat with free weights. Comparisons were made for the mean and peak velocity, the mean and peak force and the mean and peak power. Similar to the study of Balsalobre-Fernadez et al. [BFKPOdCV16], a strength test was carried out, with the different weights increased up to 100% of the 1-RM. According to the authors, the study's outcome shows that the

LPT of *GymAware* can accurately measure velocity and estimate force but has problems estimating mean power and peak power for sets with a lighter load. The PUSH Band 1.0 estimated peak force and mean velocity accurately. However, based on their results, the authors question the performance of the PUSH Band 1.0 when measuring anything other than peak force and mean velocity for light to moderate loads of the back squat exercise.

The PUSH Band 1.0 and the Beast sensor were also part of a 2019 study by Perez-Castilla et al. [PCPDG+19], who investigated seven devices, including linear transducers, camera-based optoelectronic system and IMUs (the PUSH Band and the Beast sensor), to measure velocity during the bench press exercise on a smith machine. Data were collected from 14 men with a bench press 1-RM of 86.16 kg plus/minus 11.9 kg who completed two testing sessions. In the first session the authors determined each subject's 1-RM, and in the second one five different loads with three repetitions were performed, and the mean velocity measured. Results for the two IMUs were similar to the ones from Banyard et al. [BNSH17]. For the PUSH Band high accuracy was only found when the data of several sets were combined. According to the authors, the Beast sensors' performance was not convincing. However, the results from Perez-Castilla et al. [PCPDG+19] considered no free-weight bench-press exercise sets and only athletes with a 1-RM below 100 kg. Based on the above studies, both the PUSH Band 1.0 and the Beast sensor were evaluated through different exercises. Among the mentioned studies we also observed different results. Thompson et al. [TRD+20] and Perez-Castilla et al. [PCPDG+19] came to a similar conclusion by stating that both the PUSH Band and especially the Beast sensor are under-investigated. Additionally, one must consider that performance evaluations are always time-specific and might not be valid for newer versions since companies always tend to improve their products. To the same conclusion came Mitter et al. [MHB+21] from the University of Vienna after their study on four different VBT tools, including the PUSH Band 1.0 and the Beast sensor. The authors claim that although different studies used an approved gold-standard criterion for their comparison, the outcomes should be taken with care due to rapidly changing systems, as corroborated by the fact that a major hardware update for the PUSH Band – the PUSH Band 2.0 – has already been released.

A systematic review of VBT tools, including the PUSH Band 2.0 was conducted by Weakley et al. [WMGR+21] in 2021. They stated that accelerometer-based tools are promising, yet their performance cannot be stated as highly valid, which may introduce an additional error in the assessment of accuracy for the device. PUSH Band 1.0, Beast Sensor and PUSH Band 2.0 have been compared to linear transducers for free weight exercises in more than 10 studies for different kinds of exercises. In conclusion the authors argue that the PUSH Band 2.0 may have the best accuracy among them, according to their observations.

2.2.2. Velocity-based training and its practical applications

VBT was introduced to provide accurate and objective data to support the prescription of resistance training. Using velocity for resistance training has multiple advantages, as mentioned by Weakley et al. [WMB+20]. Two crucial facts are the following:

- If an external mass increases, the lifting velocity decreases. The mass can be increased until a 1-RM load is achieved. The velocity which was measured during the 1-RM attempt is called minimum/terminal velocity threshold, which is the smallest velocity at which the most weight can be lifted.

- After creation of the load-velocity profile, it is possible to calculate for each mean velocity value, the percentage value of the 1-RM.

Once the so-called load-velocity profile is established, the velocity of a current set can be compared with the velocities of the profile to assess how intense the set was. An example load-velocity profile is displayed in Table 2.1, which shows different velocity values for different percentages of the athletes 1-RM. For example, at the set with 80% weight of the actual 1-RM, which was identified by the 1-RM test, the athlete had a mean velocity of 0.55 m/s. Using the measured values the full load-velocity relationship can be modelled through a linear regression to estimate the 1-RM, as mentioned by Weakley et al. [WMB+20]. According to González-Badillo and Sánchez-Medina [álBánM10], the velocity for a given percentage of the 1-RM does not change significantly, although the 1-RM value can. Therefore, VBT gives the possibility of estimating strength from the velocity recorded against submaximal loads, as also described by Weakley et al. [WMB+20]. The authors also mention that, for each exercise the load-velocity profile might be different. Therefore, a load-velocity profile of one exercise shall not be used for a different exercise.

Multiple applications exist for VBT, such as 1-RM estimation and creation and usage of a load-velocity profile.

Percentage of 1-RM	Mean Velocity
20	1.41 m/s
40	1.16 m/s
60	0.86 m/s
80	0.55 m/s
90	0.40 m/s

Table 2.1.: Example mapping of the percentage of the one-repetition-maximum (1-RM) to mean velocity.

2.2.3. Rate of perceived exertion scale and velocity

Firstly introduced by Borg [Bor82] in 1982, the RPE scale is a way of rating the exertion of exercising. Originally designed for aerobic exercises, it has been often adapted by multiple authors for different purposes. The RPE scale based on repetitions in reserve is the current standard for powerlifting. Additionally, some studies have observed how this RPE scale and the velocity of a repetition of a particular exercise relate to each other.

RPE scale based on repetitions in reserve

In his book *The Reactive Training System*, Mike Tuchscherer [Tuc08] presented a new idea of how to use RPE that recently became highly popular. The scale reaches from 0 to 10 in 0.5 steps and uses an approach in which the repetitions in reserve (RIR), namely the number of repetitions which could still be performed with proper technique, are subtracted from the highest value 10. For example, an RPE value of 9 means that exactly one repetition could still have been performed, 8.5 means that one or two repetitions could still have been performed, and so on.

This scale was scientifically introduced by Zourdos et al. [ZKD+16] in 2016. Their study had two goals:

- Comparing RPE ratings based on repetitions in reserve at 100%, 60%, 70%, 75%, and 90% of the 1-RM, namely to the maximal weight which can be lifted for one repetition, of experienced and novice athletes for the back squat exercise.
- Determining of an inverse relationship between an RIR-based RPE scale and the mean velocity of the barbell during the back squat exercise.

Twenty-nine athletes, of which 15 were experienced and 14 novice lifters, performed a 1-RM test at the very beginning to determine their maximal weight for one repetition according to the USA Powerlifting (USAPL) specifications. After that, multiple sets with different loads were performed for one repetition. Additionally, one set with eight repetitions and a load of 70% of the previously determined 1-RM was performed. The investigators asked the subjects to provide an RPE value for each set. The *Tendo Weightlifting Analyzer* measured the average velocity of the barbell for each repetition. Zourdos et al. [ZKD+16] show that experienced athletes had a slower average velocity at 100% and 90% of the 1-RM. For 75% and 60% of the 1-RM, no significant difference between experienced and novice lifters could be identified. Hence, only a significant difference was detected at maximum or nearly maximum weight in the average velocity from experienced and novice lifters. The statistics of the rated RPE values showed that novice lifters rated sets with a maximum or nearly maximum weight with a lower value than experienced lifters, as Zourdos et al. [ZKD+16] described. The differences might be explained for both ratings and velocity by the longer training knowledge of experienced lifters. Another interesting observation is the relationship between the mean velocity and the RPE ratings. The higher the RPE rating of a set was, the lower its velocity was – namely, the heavier a set felt, the lower the velocity was since a strong inverse relationship between the average velocity at all intensities and RPE was observed.

Helms et al. [HSC+17] conducted another study on all three competition lifts in powerlifting to investigate the correlation between average velocity and RPE. A 1-RM test was performed for each exercise in the competition order (i.e. squat, bench press and deadlift). The final 1-RM was noted down if the athlete reported an RPE value of 10; if they failed, another attempt with this weight was granted. In case the attempt was failed again, the previously rated highest weight was noted down. The *GymAware* was used to measure velocity. The authors observed a significant difference in velocities at 1-RM for the different exercises. Specifically, the squat had the highest velocity, followed by the deadlift and bench press sets, which had the slowest velocities. Similar to Zourdos et al. [ZKD+16] and Ormsbee et al. [OCK+19], a strong inverse relationship between RPE and velocity was observed in all three exercises. In conclusion, this study from Helms et al. [HSC+17] shows the strong inverse relationships between RPE and velocity for the squat and the bench press again. Therefore, the novel RIR-based RPE scale can be used for 1-RM tests and let one conclude that the lower the measured velocity, the higher the RPE and the intensiveness are. Additionally, Helms et al. [HSC+17] conclude that the daily strength fluctuation can be neglected since the inverse relationship between velocity and RPE will remain the same, which is the main advantage of VBT.

These studies show the validity of a RIR-based RPE scale and its relation to a barbells average concentric velocity for the squat, bench press and deadlift exercise. Furthermore, experienced lifters tend to estimate the RPE value, and therefore intensiveness, better. Since this scale is also a common standard for powerlifting, it was used in this thesis to rate the set RPE values and estimate the 1-RM. In [HCSZ16] Helms et al. describe the applicability of the RIR-based RPE scale for practitioners and how an estimation of the 1-RM from different repetition and RPE value combinations can be made. Additionally, Helms et al. [HCSZ16] prescribed a conversion chart based on the results reported by the experienced athletes for the before mentioned sets published by Zourdos et al. [ZKD+16], which is shown in Figure 2.3.

RPE	Repetitions performed								
	1	2	3	4	5	6	7	8	
10	100,00	95,00	91,00	87,00	85,00	83,00	81,00	79,00	
9,5	97,00	93,00	89,00	86,00	84,00	82,00	80,00	77,50	
9	95,00	91,00	87,00	85,00	83,00	81,00	79,00	76,00	
8,5	93,00	89,00	86,00	84,00	82,00	80,00	77,50	74,50	%
8	91,00	87,00	85,00	83,00	81,00	79,00	76,00	73,00	
7,5	89,00	86,00	84,00	82,00	80,00	77,50	74,50	71,50	
7	87,00	85,00	83,00	81,00	79,00	76,00	73,00	70,00	

Figure 2.3.: Conversion table from percentage of the 1-RM to RPE and repetition combination, based on data from Zourdos et al. [ZKD+16] and Helms et al.[HCSZ16].

Converting mean velocity to RPE

Based on the mentioned studies, a strong inverse relationship was identified between the RPE value and the mean velocity. Similarly, Izquierdo et al. [IGBH+06] observed that the last repetition of a training set to failure has a similar mean velocity to a 1-RM attempt. Additionally, Jovanovic and Flanagan [JF14] investigated the data from Izquierdo et al. and concluded that regardless of the load and the repetitions, the mean velocities at a certain physical exertion or RPE value do not differ significantly. Examples can be seen in Figure 2.4, which shows the evaluated data from the study of Jovanovic and Flanagan [JF14].

By using this information, it can be claimed that the last repetition of a training set with four repetitions at an RPE of @8 will have a mean velocity similar to the last repetition of a training set with one repetition at an RPE of @8.

Since the load-velocity profile is modelled through a linear regression equation, each percentage value of the 1-RM can be calculated by knowing the mean velocity with which the barbell was moved. By doing so, the mean velocities at 89%, 91%, 93%, 95%, 97% and 100% of the 1-RM can be easily identified. The conversion table in Figure 2.3 shows that these values can be exactly mapped to the RPE values of a set with one repetition. Therefore, for example, the mean velocity of 95% of the 1-RM is similar to the mean velocity of the last repetition of a training set with an RPE value of @9.

This method is one part of the so-called exertion-load profile, as argued by Jovanovic and Flanagan [JF14].

Reps in tank	60%	65%	70%	75%	Average	SD	%CV
9	0.54	0.51	0.50	0.49	0.51	0.02	4%
8	0.52	0.51	0.47	0.49	0.49	0.02	4%
7	0.50	0.50	0.48	0.47	0.49	0.02	4%
6	0.48	0.48	0.46	0.45	0.47	0.01	3%
5	0.49	0.47	0.46	0.44	0.46	0.02	5%
4	0.47	0.46	0.45	0.42	0.45	0.02	5%
3	0.47	0.43	0.43	0.41	0.43	0.02	5%
2	0.44	0.44	0.43	0.39	0.42	0.02	6%
1	0.39	0.40	0.44	0.38	0.40	0.02	6%
0	0.34	0.32	0.33	0.31	0.32	0.01	3%

Figure 2.4.: Repetitions in reserve table, which shows the mean velocities at the different exertion levels, from Jovanovic and Flanagan [JF14].

2.2.4. Summary

Multiple VBT systems were analyzed for different validity studies as described by the above mentioned studies. In summary, linear-position transducers are the gold standard when it comes to measuring velocity for strength training, but are also the most expensive ones. Nonetheless, wearable devices like the PUSH Band 2.0 showed also good accuracy. An important note was made by Mitter et al. [MHB+21] saying that the outcomes of their study should be taken with care due to rapidly changing systems. Due to these factors and the affordability of around 400 USD, the PUSH Band 2.0 was chosen as a wearable velocity tracking tool for this thesis.

Besides from the investigation on studies evaluating VBT tools, also the different applications of VBT were analyzed. Especially, studies covering the combination of VBT and the rating of perceived exertion were investigated in depth. The method of converting mean velocity to a RPE value which is in detail described in Subsection 2.2.3, is also used within this thesis. By doing so, the mean velocity, which gets measured by the PUSH Band 2.0, gets converted to a RPE value, which gives an objective feedback on the intensiveness.

2.3. User interfaces in smartphone applications

As the methods of repetition detection with accelerometer based systems and the handling of RPE and Velocity-based training has been investigated, another related subject for this thesis is, how information shall be represented and which UI patterns be kept in mind for modern smartphone applications. According to Chen et al. [CCH+21] provides the user interface the visual bridge between the applications and the users. Through the GUI the interaction between those takes place.

2.3.1. UI Design Guidelines

When it comes to UI design, Shneiderman's eight golden rules for designing a user interface are the basic guidelines one shall follow. Shneiderman [Shn97] described that interactive user interfaces should be well designed and well thought out. He proposed in sum eight different rules. *Permit easy reversal of actions* and *Reduce short-term memory load* are two of them, to name just a few them.

Additionally to Shneiderman's rules also Gong et al.[GT+04] defined some guidelines, especially for mobile device interfaces. They evaluated Shneiderman's eight interface design guidelines and stated which guidelines also apply for handheld devices and which need to be adapted. The authors identified principles which can be neglected but also were identified additional principles. In total Gong et al. [GT+04] stated the following seven additional design principles:

- Design for multiple and dynamic contexts
- Design for small devices
- Design for limited and split attention
- Design for speed and recovery
- Design for "top-down" interaction
- Allow for personalization
- Design for enjoyment

An interesting one is the design principles *Design for "top-down" interaction*. The authors are stating, that it is very important to keep the limitations of small screens in mind and the lack of information which can actually be displayed. One thing to overcome the small screens is scrolling, which goes unfortunately with distraction hand in hand. Therefore, it is very important to use the limited space as optimal as possible. Related to that principle is the rule *Reduce short-term memory load* from Shneiderman [Shn97], saying it is important to not overload the user with a bulk of information as the human information processing is limited.

In addition to those general design principles, the feedback and contribution of the target user group is also very important, as Abras et al. [AMKP+04] are stating in their paper about *Human-centered Design*. According to them, the integration of target user groups can be beneficial for the design of the target application. They mentioning different methods to gather user feedback as for example usability tests, heuristic evaluations or participatory design. Besides from those also so-called quick and dirty evaluations during the first stages of UI design can bring already important feedback.

A similar conclusion was also mentioned by Chen et al. [CCH+21] in their recent paper. According to them, the development of a user interface consists of two phases: the design phase and the implementation phase. Additionally, a third phase, the testing phase, is also crucial for quality assurance and user satisfaction.

Conclusively, we see that lot of guidelines were established already years ago, from which most of them are still valid for today's applications. Especially, for mobile devices also newer methods shall be followed due to decreased display space and newer interaction possibilities like touch actions.

2.3.2. Representation of information

Since the representations of certain data and items in mobile phone applications are an important part of this thesis, ways how to represent information are investigated.

According to Neil [Nei14] the representation of data in a table kind of manner can be challenging in mobile applications. This is mostly caused by the small screens of mobile phones. Therefore, she is mentioning that is crucial to identify which information is exactly needed for the user in the particular view. Depending on the information to be shown, big tables can be represented in certain charts to obtain a better representation of information. Besides from that, displaying the information in a header less table could be a possible way of representation. Especially, for such basic tables, grid lines can be neglected to reduce visual noise. Furthermore, such kind of tables might contain rows which are displaying multiple items of an object, so-called fat items. Similar to Neil, also Tidwell [Tid10] is mentioning such multi-line items for representing multiple data of an item. In addition, Neil is stating that header less tables are similar to simple list views which are meant for fast scanning and fast interactions [Nei14].

Figure 2.5.: Two example screenshots, which show an overloaded screen, as described by Neil [Nei14].

Depending on the amount of information which shall be represented, Neil [Nei14] is suggesting a graphical or chart based representation. One of the tips from Neil is *Keep it simple*. The simpler the chart is, the easier it to understand for the user. Overloaded charts, so-called chart junks which show too much information in different charts shall be avoided. In addition to simplicity, the basic rules for charts is to always provide title, axis descriptions and the actual data. In Figure 2.5 an example from Neil [Nei14] shows two screenshots with multiple charts, which should be avoided. Each screenshot shows 3 different graphical representations of related information. The screens are representing too much information in one screen, which makes it hard to understand and interpret for the viewer.

In conclusion, one can see that the simpler the information is displayed the easier and better it is to understand for the user. Due to small smartphone screens, compared to desktop computers, the amount of space is one of the biggest limitations. This limitation is a key fact, when designing an user interface and might lead to overloaded screens. Anyhow, Neil [Nei14] and Tidwell [Tid10] suggested some simple guidelines how to represent certain information in a proper way. Especially for representing information in a graphical manner, like charts, the simplicity rule is very important.

Effects of text and graphics

Besides from these basic user interface rules, the way how to represent information and how representations can affect users, is an important question.

According to Schnotz [Sch02] text and visual displays fall into two different classes of representations. Text is a descriptive representation, which consists of arbitrary structured symbols. These symbols are associated with the content they represent simply by means of a convention, as mentioned by Schnotz [Sch02]. Depictive representations are consisting of iconic signs, which are associated with the content through common structural features, which can be at a concrete or abstract level. According to the author, although two representations are informationally equivalent their usefulness might differ. How the representation is perceived and processed can be depending on the representation easy or difficult. Besides from these basic definitions, the author also mentioned, that the animation of certain representations is an ideal way to represent change and development.

The human brain processes visuals 60,000 times faster than text, as mentioned by Chibana in her article [Chi], who surveyed over 1400 American adults on two versions of a news article to investigate how infographics affect reading comprehension. Each participant got either a short article or an infographic which contained the same amount of information and could study it without any time limit. Afterwards up to three questions were asked. The participants were not allowed to search the needed information at the original text or graphic. At the end, the author stated, that the results of all differences between the text-only and the infographics were statistically insignificant. Chibana [Chi] concluded the results to be inconclusive if infographics support reading comprehension and recall, but further studies with time limits might be interesting.

Differently to Chibana's research [Chi], Norman [Nor12] performed a study on how students' comprehension of text gets affected by the processing of graphics. 30 students participated in the authors' study, in which the participants studied two informational text and were prompted to share their thoughts whenever they viewed a graphic. Afterwards they needed to retell the text in their own word and answer 8 question about the text. In detail, the verbal protocol was analyzed and the retellings and answers for the comprehension questions were rated. Norman [Nor12], concluded in her study, that the usage of certain processes when reading graphics in informational text can lead to an improved overall understanding of that same text. This statement can be underlined with the conclusion from Hibbing and Erikson [HRE03], who mentioned in their article, that a picture can be worth a thousand words for students who struggle with reading comprehension. Nonetheless, further investigation with larger sample size and additional statistical analysis is suggested by the author.

Another study on the effects of text-only and text-and-visual information was performed by Angeli and Valanides [AV04]. In their study were 65 undergraduates participating which were divided into a text-only and a text-and-visual group. Both groups were assigned to the same description of a certain model. Both materials were being informationally equivalent representations. The text-only group received the information only in a textual format, whereas the other group received the information in a textual and visual format. In addition, were the participants classified in field-independent, field-mixed or field-dependent learners. This classification is based on the visual perceptiveness of persons. According to Angeli and Valanides [AV04] are field-dependent learners often influenced by the prevailing field and therefore, fail to focus on a target information hidden in a complex whole, whereas for field-independent learners it is easier to focus on a target information from a complex whole. The participants were asked to solve a problem about immigration policy. To do so, the students needed to study the structure of the model, which was provided in the two described ways. The results were determined based on the time which was spent to complete the task and the how well the suggested solution was. According to Angeli and Valanides [AV04] were the results from the text-and-visual group better than the results from the text-only group. In addition to the representation style, were the results also depending on the field-dependent and field-independent classification of the participants. Especially, the field-independent participants delivered remarkable better results than field-dependent and field-mixed learners in both groups. Angeli and Valanides [AV04] were concluding their study by stating that visuals added to textual explanations can help to understand the complex whole.

2.3.3. User interfaces of fitness applications

In the recent years many fitness training applications for mobile devices were developed and released. A literature review was performed by Zheng [Zhe], to point out how representations and usability issues are influencing mobile fitness-training applications and to identify potential solutions. Similar to Gong et al. [GT+04], Zheng [Zhe] mentioned also the challenge of smaller screens of mobile devices. Especially, for fitness-tracking applications, there is a large amount of information which is needed to be displayed.

According to Zheng [Zhe], the *Overview+Detail* representation approach, which is in detail described by Burigat and Chittaro [BC13], might be one solution to overcome the space limitation. Basically, this representation approach suggests to split the space into two parts, of which one is covering the context information and the other represents the detail information of the selected context. An exception for using this approach was mentioned by Chittaro [Chi06] when it comes to representing maps at mobile devices. Besides from this approach, the author mentions the importance of gamification approaches and cites Klock and Gasparini [KG15], who evaluated five most popular fitness applications with a ergonomic criteria evaluation technique.

Klock and Gasparini [KG15] performed an usability evaluation on fitness applications based on the *Ergonomic Criteria* from Bastien and Scapin [BS93]. The following 8 criteria are building up the *Ergonomic Criteria*:

1. Guidance: The application should guide the users through the application to achieve their goal. Most important on the quality of guidance is the visual organization, instant feedback, instruction of a system.

2. Workload: The application should only show the necessary information for the specific context.

3. Explicit control: The application should give the users explicit control over certain actions, like start, stop or pause, depending on the context.

4. Adaptability: The application should give the users the possibility to customize the system according to their needs.

5. Error management: The application should avoids errors and help users to recover from them.

6. Consistency: The application should keep consistency of the user interface of similar context.

7. Significance of codes: The application should use easy to understand codes and its references.

8. Compatibility: The application should imitate the real world, using the similar provision of fields.

Klock and Gasparini [KG15] performed their heuristic evaluation based on the mentioned criteria on the following 5 fitness applications: RunKeeper, Nike + Running, Runtastic, Runtastic Pedometer and Endomondo Sports Tracker. In total 15 main activities, like Start walking, Stop walking, Continue walking and Distance measurement, of the applications were evaluated and rated if the tasks were satisfying each criterion. In conclusion, the app Endomondo Sports Tracker performed the best as it satisfied 77.04 % of the mentioned criteria, whereas Runtastic Pedometer performed the worst by satisfying only 61.85 % of the criteria, according to Klock and Gasparini [KG15], which also stated this application be considered as easier to use for initial users.

2.3.4. Summary

In conclusion, multiple user interface design guidelines have been investigated as well as the basic rules for representing information. Besides from the well-known Shneiderman's rules [Shn97], Gong et al.[GT+04] proposed additional guidelines, especially for mobile device interfaces, which were tried to be followed when designing the prototype for this thesis. As suggested by Abras et al. [AMKP+04] and Chen et al.[CCH+21], the target user group can provide useful feedback. This suggestion was followed and usability tests and *quick and dirty* evaluations were performed as part of *LP Praktikum 2*. The results from these user-centered design methods were used in this thesis as part of the preliminary study, which is described in Section 4, for the Android prototype application.

In addition to these design guidelines, studies covering the way how to represent information were important for this thesis, to identify how representations can support the comprehension of information. Sometimes a picture is worth more than a thousand words and sometimes not, as mentioned by Hibbing and Erikson [HRE03]. Hence, 'good' and 'bad' information representation is always depending on the context. Similar to the research from Chibana [Chi], a textual and a graphical representation which are informationally equivalent were compared in this thesis.

Lastly, studies which evaluated the user interface of several fitness applications were analyzed, to identify how and based on which guidelines the fitness information is represented, which were taken into consideration during the design for the Android prototype application.

3. Design and Implementation

A smartphone application was designed and developed to evaluate whether the RPE rating of powerlifters can be improved through different representation approaches. On the one hand, the application acts as a data collection tool; on the other hand, it can be used to visualize the results for the users. The evaluation happens based on the three rates of perceived exertion values: the expected RPE value before a set is performed, the actual felt RPE value after the set has been performed and the RPE value calculated based on the load-velocity profile.

Since measuring and calculating the mean velocity gathered by a wearable device was out of the scope of this thesis, a commercial tool, the PUSH Band 2.0, was used for measurement. The PUSH Band 2.0 consists of a wearable device and a smartphone application. Figure 3.1 shows the device below the elbow for the squat exercise. To use the mean velocity in the self-developed prototype, the user has to enter the measured mean velocity manually.

The used prototype was developed as an Android application. In addition to representing the needed data for the RPE comparison, the application should also provide the user with a decent user experience. Since, the representations of the RPE comparison must be visible to the users, the comparisons are represented in the Android prototype. These representations are crucial to answer the research questions mentioned in Section 1.3.

Figure 3.1.: Push Band 2.0 attached at the elbow for the squat exercise. The green light indicates that the exercise has been started in the PUSH application and the device is measuring the mean velocity for the performed repetitions.

To create the RPE comparison, it must be possible to track the different RPE values and the mean velocity values. The RPE values are defined per training set, as they describe how exerting the training set was. A training set consists of one or multiple repetitions. According to the method described in Subsection 2.2.3, the mean velocity of the last repetition of a training set can be used to calculate also a RPE value. Due to these observations, it must be possible to track training sets, the RPE values of them and the mean velocity of at least the last repetition of such a training set within the prototype.

By designing the data model of the prototype different use cases were identified, which are described in detail in the next section.

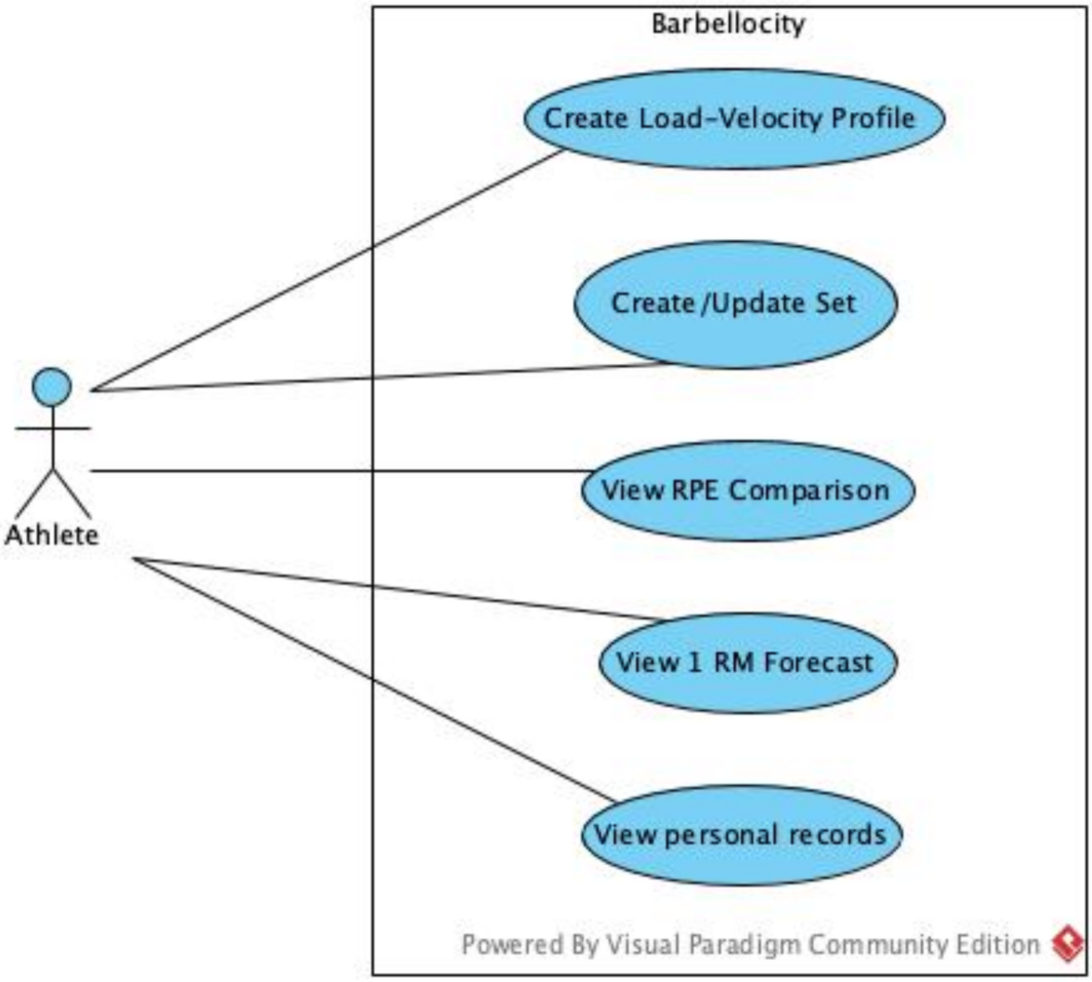


Figure 3.2.: Use case diagram showing the identified use cases.

3.1. Use cases

As a structure is needed to save and track the needed information for the RPE comparison within the prototype, certain activities and workflows like creating and updating data objects, must be supported. By designing the data model to store the training data, multiple use cases were identified. The data model can be seen in Figure 3.5.

Besides from the identified use cases based on the designed data model, additional use cases were found based on the preliminary study, which was performed as part of the *LP Praktikum 2*. The preliminary study is described in detail in Section 4.

Further, the entered RPE and velocity information can be used for additional features, which would make life as an athlete easier. In summary, three primary and two secondary use cases were identified, which are described in detail in the following subsections.

The identified main use cases are visualized in a use case diagram in Figure 3.2. Five different use cases were identified, which were split into primary use cases and secondary use cases. Primary use cases are essential for the application's core functionality and were crucial to answering the research questions.

3.1.1. Primary use cases

Create/Update Set

Training information needs to be tracked to check how an athlete performs and if improvement happens. A training session consists of training sets for specific exercises. Training sets again consists of one or multiples repetitions. The primary use of creating new sets is described in the following way: a user must be able to create sets and to track the amount of performed repetitions, the performed weight and the three different rates of perceived exertion values. During the creation of a new set, the upcoming training weight, the number of repetitions and the expected RPE value must be entered. It must be possible to enter a mean velocity value for each repetition since the velocity is measured for each repetition. A training session needs to be created beforehand to know on which day the exercises were performed and track training sets. Therefore, a session represents a cluster of sets for a specific exercise. After creating one set, the set must be listed within the current training session. The detailed workflow is visualized in Figure 3.3. First, the user logs in and selects the exercise which they are going to perform. Afterwards, a session for the current day must be created. A new set is created within the session by entering the training weight, the number of repetitions and the expected RPE value. After entering all three parameters, the workflow of creating a new set is completed.

As described, the training weight, the amount of repetition, and the expected RPE value are defined during the creation of a set. After the actual execution of the set, the actual felt RPE value and the mean velocity of the last repetition must be updated by the user. Additionally, if any mistakes are made during the creation of the set, it must be possible to correct the already defined data.

View RPE Comparison

The primary use case 'View RPE Comparison' aims to show the user the difference between the three RPE values in the described textual or graphical representation. As the *RPE Velocity* value is only available after entering the mean velocity and locking the training set, this use case is related to the use case 'Create/Update Set'. Therefore, the mean velocity and the expected and actual RPEs are prerequisites for this use case. An additional prerequisite is the load-velocity profile for the specific exercise, which is needed to calculate the *RPE Velocity* value by using the entered mean velocity. Hence, after entering the mean velocity, the *RPE Velocity* must be shown so that all three RPE values are available for review.

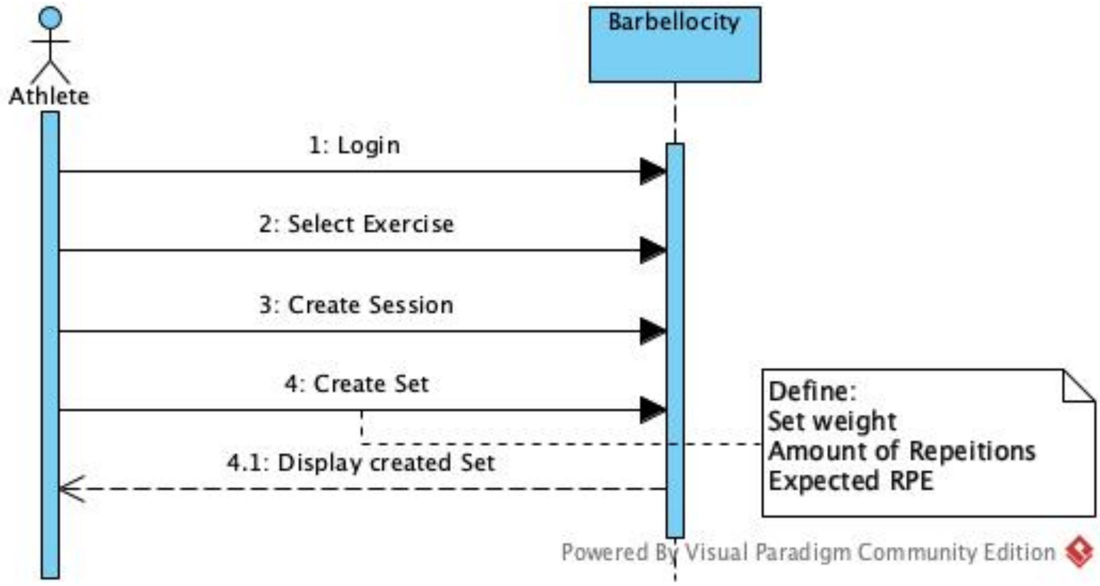


Figure 3.3.: Sequence diagram of the set creation process in which the user, herein called *Athlete*, interacts with the prototype application *Barbellocity*.

Create Load-Velocity Profile

The load-velocity profile builds the basis for VBT. It is individual for each exercise and for each athlete. Weakly et al. [WMB+20] and Jovanovic and Flanagan [JF14] describe two similar approaches on how to create such a profile. Herein, a mixed approach of both is used. Instead of five predefined sets, six training sets are used to define the load-velocity profile. The advantage of Weakly et al.'s [WMB+20] and Jovanovic and Flanagan's [JF14] approaches is that no set with maximal effort is needed, which would make the creation process more unpractical since not every athlete wants to perform a repetition with maximal effort for their load-velocity profile. Additionally, to their described creation process, one last set with 90% of the 1-RM is added. By doing so, one additional data point for the linear regression is added. In total, the workflow consists of seven steps:

1. Estimating the 1-RM of the specific exercise
2. Performing three repetitions with 40% of the 1-RM
3. Performing 2 repetitions with 50% of the 1-RM
4. Performing 1 repetition with 65% of the 1-RM
5. Performing 1 repetition with 75% of the 1-RM
6. Performing 1 repetition with 85% of the 1-RM
7. Performing 1 repetition with 90% of the 1-RM

The load-velocity profile can then be built with this information. Since the load-velocity profile is individual for each exercise, this procedure needs to be performed for all three exercises. The primary use case of establishing the load-velocity profile for an exercise is described the following way: a user must be able to initially estimate the 1-RM for an exercise. Afterwards, six sets need to be created in which the mean velocity for the repetitions is entered. Once all sets are performed and all velocities are entered, the load-velocity profile must be completed and be usable for the upcoming sets.

3.1.2. Secondary use cases

In addition to the described primary use cases, also secondary use cases were identified. Secondary use cases are not mandatory for the basic functionality of the prototype application and were not necessary for answering the research question, but they support the user with different information or gamification features to improve user experience and increase motivation.

View 1-RM forecast

One supportive functionality to find the proper training weight is the 1-RM forecast, which is a translation table that displays the repetitions number from 1 to 8 at the x-axis and the RPE value on the y-axis. In the cell where the x- and y-axes are crossing, the estimated weight is written. How such a 1-RM forecast table could look can be seen in Figure 3.4. With an estimated 1-RM of 200 kg as a basis, five repetitions with 162 kg could be performed at an RPE value of 8. The same weight could be performed for four repetitions at an RPE value of seven, for example. Let us assume an athlete has in the training program written to perform squats for four repetitions at an RPE value of 8 and knows that the approximate one repetition maximum is 200 kg. By looking at such a table, it can be easily observed that a weight around 166 kg would be appropriate. Hence, such a table could help to find the proper training weight easily.

RPE	Repetitions performed						
	1	2	3	4	5	6	
10	200,00	190,00	182,00	174,00	170,00	166,00	kg
9,5	194,00	186,00	178,00	172,00	168,00	164,00	
9	190,00	182,00	174,00	170,00	166,00	162,00	
8,5	186,00	178,00	172,00	168,00	164,00	160,00	
8	182,00	174,00	170,00	166,00	162,00	158,00	
7,5	178,00	172,00	168,00	164,00	160,00	155,00	
7	174,00	170,00	166,00	162,00	158,00	152,00	

Figure 3.4.: Example of RPE-repetitions table for a 1-RM of 200 kg. The table covers the RPE values from 10 to 7 and a repetitions number from 1 to 6 based on the conversion table from Zourdos et al. [ZKD+16] and Helms et al. [HCSZ16].

View Personal Records

Powerlifting is a competitive sport in which athletes aim to continuously improve their strength. Therefore, if an athlete ascertains their improvement, they are pushed to become stronger and stronger. Since 1-RM tests are not regularly performed because they are not useful for strength improvement and increase the risk of injuries, improvement can be measured using the 1-RM estimated by using the conversion table from Zourdos et al. [ZKD+16] and Helms et al. [HCSZ16]. To motivate the user, the highest estimated 1-RM must be shown to them. Once a higher 1-RM is reached, the athlete could be notified to boost motivation.

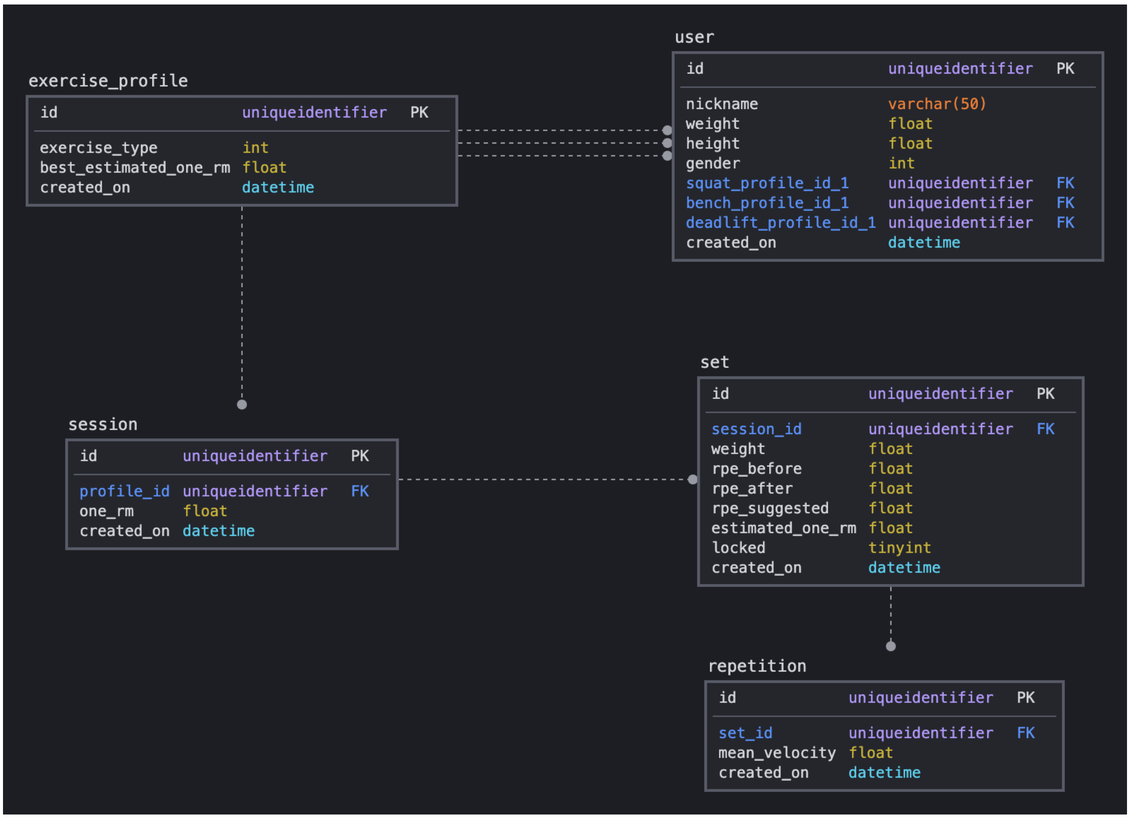


Figure 3.5.: Data model of the prototype application. The five main tables are user, exercise profile, session, set and repetition. The data base is realised through SQLite.

3.2. *Barbellocity* application

A tool was needed to support the described use cases and collect training data. Therefore, an Android smartphone prototype application was developed in which the users could enter their training data and get the comparison between *RPE Estimated*, *RPE Actual* and *RPE Velocity* value visualized.

The smartphone application was designed for the three competition lifts in powerlifting. The prototype contains login and registration views for creating a user profile in which values such as height, weight and gender are entered. Since the topic of VBT can be complex, a tutorial view, which explains the different views, is shown after registration.

To support the described use cases, the application consists of different main views reachable through a bottom navigation bar. The navigation bar was designed to have five different views: the home view, three exercise views and the profile view. Since only five areas were identified, a bottom navigation bar was preferred to a navigation sidebar. The Google material design guidelines were considered for the basic design. Registration with name, weight, height and gender is needed when starting the application for the first time. Afterwards, the tutorial view with embedded GIFs shows how to use the application. Once the tutorial slides are closed, the athlete enters the home view. A data model was designed to store the objects representing different kinds of information. A cutout showing the main tables is presented in Figure 3.5. The diagram shows five different tables: user, exercise profile, session, set and repetition. A user has three different exercise profiles: the squat profile, the bench profile and the deadlift profile. The best 1-RM is held in an exercise profile, and it documents the corresponding training sessions for the specific exercise. A session acts as a cluster of multiple set. By that, it contains one or many sets. Each set is always clustered to exactly one session. Sets and repetitions have a similar relationship. Each repetition is contained by one set, and each set contains one or many repetitions. Since a session and the underlying sets are of a specific exercise type, the session belongs to exactly one exercise profile clustering all sessions. Each user has a unique id, nickname, weight, height and gender. A set is identified by a unique ID and consists of a weight, an *RPE Estimated* value, an *RPE Actual* value, an *RPE Velocity* value and an exercise type.

3.2.1. Home view

The home view is the default view that shows up once the user logs into the application. The view is separated into two sections. The upper section provides information about the user's current level, body weight, best-estimated 1-RM for each exercise and the corresponding Wilks points. The Wilks points are calculated based on the Wilks formula shown in the following equation and which tries to compensate the curvilinear relationship between body weight and maximal strength, as described by Vanderburgh et al. [VB99]. The level ring is based on the calculated Wilks points and adds gamification aspects to the home view. The Wilks coefficient is calculated with the following formula, as described by Ferland et al. [FAC20]:

The home view is the default view which shows up, once the user logs in into the application. The view is separated into two sections. The upper section gives information about the users current level, body weight, best estimated 1-RM for each exercise and the corresponding Wilks points. The Wilks points are calculated based on the Wilks formula which is shown in the following equation. Basically, the Wilks formula tries to compensate the curvilinear relationship between body weight and maximal strength, as described by Vanderburgh et al. [VB99] The level ring is based on the calculated Wilks points and adds gamification aspects to the home view. The Wilks coefficient is calculated with the following formula as described by Ferland et al. [FAC20]:

$$Wilkscoefficient = W * 500/(a + bx + cx^2 + dx^3 + ex^4 + fx^5), \tag{3.1}$$

where:

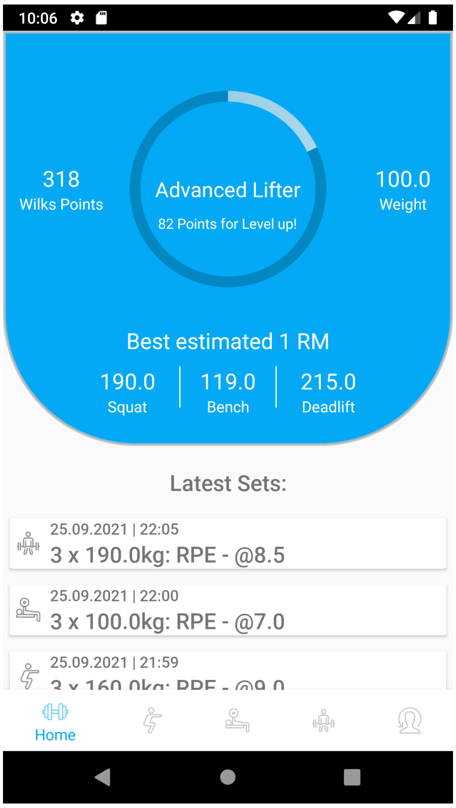


Figure 3.6.: Home view showing different information about the users' performance and the latest performed sets.

$$
\begin{aligned}
W &= \text{Total weight of best 1-RMs} \\
x &= \text{User's body weight} \\
a &= \text{-216.0475144 (male) or 594.31747775582 (female)} \\
b &= \text{16.2606339 (male) or -27.23842536447 (female)} \\
c &= \text{-0.002388645 (male) or 0.82112226871 (female)} \\
d &= \text{-0.00113732 (male) or -0.00930733913 (female)} \\
e &= \text{7.01863E-06 (male) or 47.31582E-06 (female)} \\
f &= \text{-1.291E-08 (male) or -9.054E-08 (female)}
\end{aligned}
$$

Always the latest three sets are displayed in the second section. By clicking on one of the set items, the set-detail view appears. Both sections are optically divided by a blue half-circle. The home view can be accessed through the bottom navigation bar by clicking on the very left icon, which shows a barbell under which the written meaning has been added. Figure 3.6 represents the home view.

3.2.2. Profile view

The user's name and registration date are displayed in the profile view. The following actions are possible in this view: the user's weight can be updated, and goals can be added upon clicking on the add button at the lower right corner. Goals are a gamification feature and can be set by users. Once a goal is reached, it is moved to the 'Old Goals' section. Goals can be set for a 1-RM or a *Repetition x Weight x RPE* combination. A logout possibility is also provided in this view.

3.2.3. Session view

For each of the three exercises: squat, bench press and deadlift, an icon is available at the bottom navigation bar, which navigates to the respective exercise view. In Figure 3.7 an example session view is shown which has one session in the list and the exertion-load profile already filled. Each session view has the same structure – namely, it is split into two parts. The top part shows a scroll list with all the training sessions for that exercise. All sets of a common day are mapped to a single session. Each session has an estimated 1-RM, which is calculated from the last performed set. A back button to return to the home view and an add button to add a new session are displayed in the top toolbar.

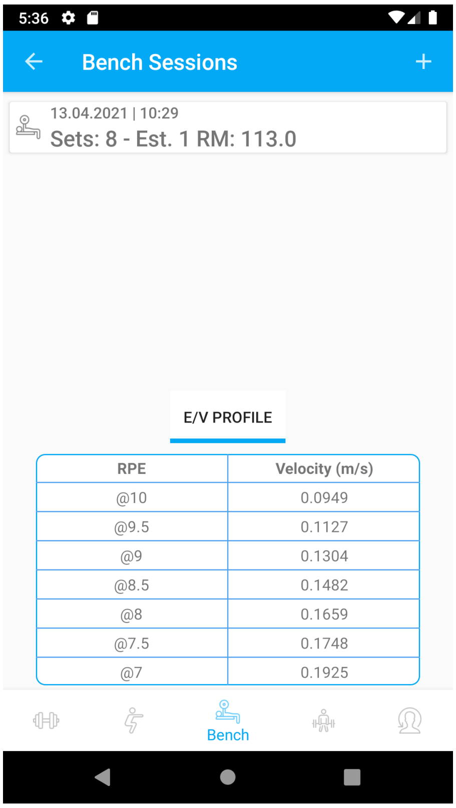


Figure 3.7.: An example of how the exertion-load profile (E/V) is displayed in the prototype application in the session view.

The exertion-velocity profile, which is calculated out of the load-velocity profile, is shown in the lower section. Since the load-velocity profile is only available after performing certain training sets, the exertion-load profile is by default not defined. Based on this profile, the lower view shows the RPE values from @7 up to @10 in 0.5 steps in the first column and the mean velocity mapped to each RPE value in the second column. With this feature, one can immediately see the velocity ranges for each RPE value.

Load-velocity profile

After registering the creation of the load-velocity profiles, the selected exercise must be performed. Six sets and an estimated one-repetition value are needed to establish a profile, as described above. Therefore, the estimated 1-RM must be entered during the creation of the very first session. After that, six sets with an automatically calculated weight are created. Each set must be performed, and the mean velocity must be entered. Once all six sets are performed, and the needed data is entered, the load-velocity profile is successfully created.

As stated by Weakly et al. [WMB+20], the load-velocity relationship can be modelled through a linear regression. Through the resulting linear regression formula, the corresponding percentage of the estimated one repetition can be calculated using the mean velocity of a repetition. The following example explains how the load-velocity relationship can be used.

Example The athlete has entered an estimated 1-RM of 120 kg and performed the six predefined sets accordingly. The sets with their weight and their mean velocity are shown in Table 3.1. The mean velocity is 0.52m/s at 50% of the 1-RM, which are 60 kg, and a mean velocity of 0.17m/s at 90% of the 1-RM, which are 108 kg. A linear regression is created by using the data points. The linear regression formula is shown in Formula 3.2, with which the mean velocity for specific percentage values of the 1-RM can be calculated. Converting the formula to obtain the percentage for a specific mean velocity value leads to Formula 3.3.

Percentage of 1-RM	Weight	Mean Velocity
40	48.00 kg	0.65 m/s
50	60.00 kg	0.52 m/s
65	78.00 kg	0.37 m/s
75	90.00 kg	0.27 m/s
85	102.00 kg	0.21 m/s
90	108.00 kg	0.17 m/s

Table 3.1.: Example of a load-velocity profile.

$$y = -0.0095x + 1,0052 \tag{3.2}$$

$$x = \frac{1.0052 - y}{-0.0095} \tag{3.3}$$

where:

x = percentage of 1-RM
y = mean Velocity (m/s)

Figure 3.8 shows a line graph with the built from the example data displayed in Table 3.1. A strong linear relationship can be seen, as the line graph has a R^2 value = 0.9882. Hence, the mean velocity and the percentage of the 1-RM share a strong linear relationship, means the closer we get to 100% of the 1-RM the lower the velocity becomes.

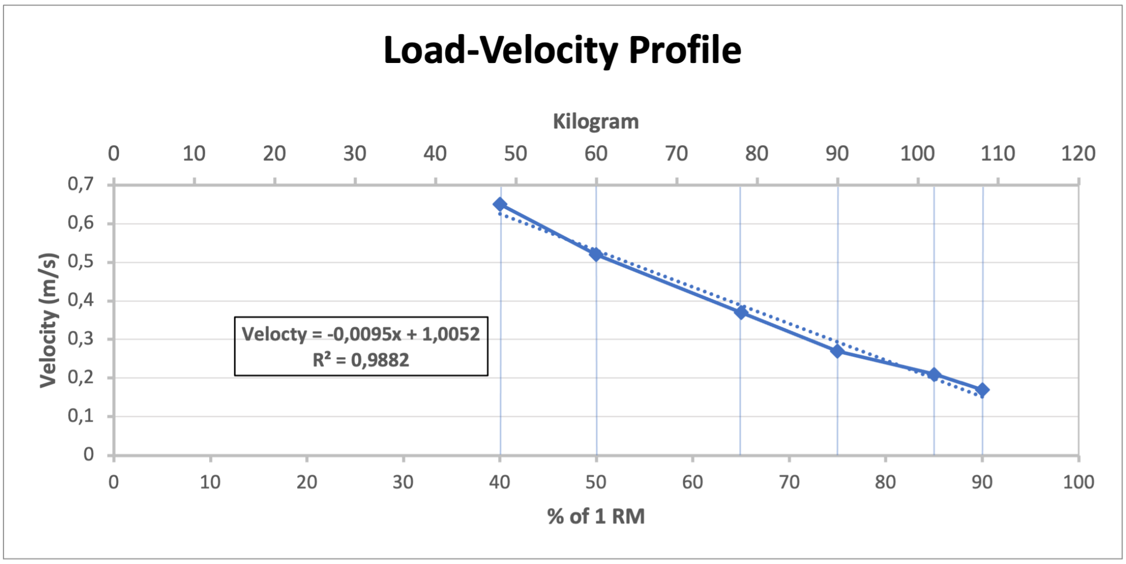


Figure 3.8.: Line diagram representing the load-velocity profile.

Since the mean velocity of the last repetition of the set is crucial for the identification of the RPE value, the RPE values from @7 to @10 can be mapped to their percentage value of the 1-RM based on the conversion table shown in Figure 2.3. The exertion-load profile can be derived through this procedure and maps each RPE value to a corresponding mean velocity value. Hence, the application can suggest an RPE value by calculating the minimal distance to the stated mean velocities. Figure 3.7 shows the representation of the exertion-load profile in the application for the RPE value @7 up to @10 in 0.5 steps. For a set where the last repetition had a mean velocity of 0.16 m/s, an RPE value of @8 would be suggested.

3.2.4. Setlist view

By clicking on a session item in the session view, the setlist view of the clicked session appears. The setlist view consists of two sections. The upper section lists all sets for the selected session. Each set is displayed with a timestamp, the number of repetitions, the chosen weight, the RPE value and the indication of whether the set is locked or open. We implemented the logic of locking a set has to lock all editable fields and trigger the calculation of the *RPE Velocity* value. A new set is added to the session by clicking on the add button in the upper right corner. Each set is displayed in the following notation:

$$Number\ of\ repetitions\ x\ Weight\ @RPE\ Value \tag{3.4}$$

The example in Equation 3.5 describes a set in which three repetitions with a weight of 150 kg were performed at an RPE value of @8.

$$3\ x\ 150\ kg\ @8 \tag{3.5}$$

In the below section, Figure 3.9 shows the filled conversion table from Zourdos et al. [ZKD+16] and Helms et al.[HCSZ16], with the highest estimated 1-RM as the basis. Due

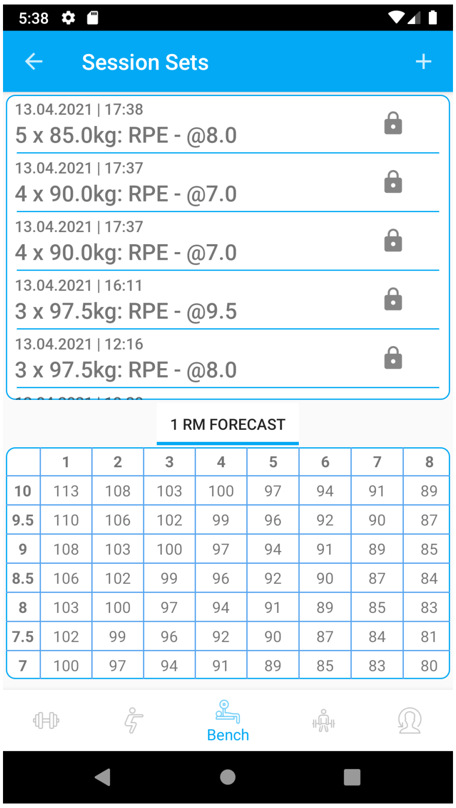


Figure 3.9.: Example RPE - repetitions table for a 1-RM of 200kg, RPE 10 to 7 and repetitions 1 to 6.

to this representation, the user can easily see which weight for which RPE value would be appropriate.

3.2.5. Set-detail view

By clicking on a set item in the setlist view, the set-detail view of the clicked set item appears. Figure 3.10 shows an example of a set-detail view. The set-detail view shows the information of a set:

- Set weight: The amount of weight on the barbell.
- *RPE Estimated*: The estimated RPE value before executing the training set.
- *RPE Actual*: The RPE value directly after executing the training set and before reviewing the mean velocity value in the PUSH application.
- *RPE Velocity*: The RPE value identified by the load-velocity profile once the mean velocity of the last repetition is entered.
- Repetitions: A text field is available to enter the mean velocity from the PUSH application for each of the repetitions. The mean velocity of the last repetition is mandatory to lock the set because no *RPE Velocity* value can be elicited without this velocity.

During the creation of a set item, the weight, the *RPE Estimated* and the number of repetitions are defined. If any mistakes occur during the creation the user is able to edit these information. Also the possibility to completely delete the set is given through the delete button. To trigger the calculation of the *RPE Velocity* value, a lock button is introduced. By clicking this button the set item gets locked, means all editable fields are being greyed out and are not editable any longer. With this step, the information gets also saved into the SQLite database to persist the data.

Most importantly the *RPE Velocity* value gets calculated based on the beforehand established load-velocity profile. Once calculated, the value gets displayed in the set-detail view. By doing so, all three RPE values are displayed in the set-detail view. Depending on the setting, the three RPE values are represented by the textual or graphical representation, which are described in the Subsection 3.2.6. The textual and graphical representation of the RPE comparison, which are displayed in the set-detail view, are the central part for answering the research questions described in Section 1.3.

The RPE comparison is represented in this view, as it is automatically triggered by the workflow of entering the mean velocity of the last repetition of the set and locking the training set. By doing so, no further step is needed to view the RPE comparison in the set representation.

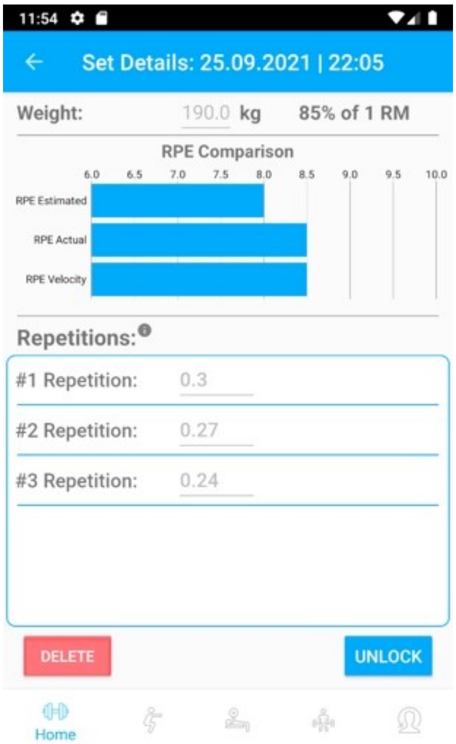


Figure 3.10.: An example of set-detail view which displays the RPE comparison, the weight and the amount of repetitions and their mean velocity of the selected training set.

3.2.6. Representations of RPE comparisons

In the set-detail view, the three RPE values are displayed. The available options for defining the RPE values are @<7, @7, @7.5, @8, @8.5, @9, @9.5 and @10. To track sets that felt easier than @7, it is possible to set the RPE values to <@7.

By displaying the values next to each other in a particular representation, a comparison between the values reveals how well the athlete estimated how the RPE would be, how the exertion after the set felt and how the exertion was according to the measured velocity. Thanks to that, users can see how good their feeling about their intensiveness was.

Two different representation approaches were implemented to evaluate if and how different representation approaches can support the athlete in improving their perceived exertion rating. The different representations are displayed only for locked sets.

Textual representation

In the textual representation each RPE value is displayed in a written format through a label describing which RPE value it is and its place between the @7 – @10 in 0.5 incremental steps plus the value @<7. Each RPE label and RPE value are in one horizontal line, with the latter referring to the former on the left side. The three RPE labels and values are arranged one below the other like in the following example:

1. RPE Estimated: @7
2. RPE Actual: @7.5
3. RPE Velocity: @9

As the value of *RPE Velocity* is calculated based on the mean velocity of the last repetition, it is not editable for the user at any time. Figure 3.11 displays a snapshot from the same example of the representation within the application. The example shows the difference between the values:

- RPE Estimated and RPE Actual share a difference of 0.5.
- RPE Estimated and RPE Velocity share a difference of 2.0.
- RPE Actual and RPE Velocity share a difference of 1.5.

By interpreting these differences, it can be claimed that the user expected the RPE of the set before executing it to be of @7, implying that three additional repetitions would still be possible. After the execution the set was rated @7.5, implying that it felt slightly heavier than initially expected. The *RPE Velocity* value resulted @9, implying that only one additional repetition would have been possible. To wrapping up the differences between the values, it can be stated that the set felt remarkably easier for the user than it actually was given the mean velocity of the last repetition.

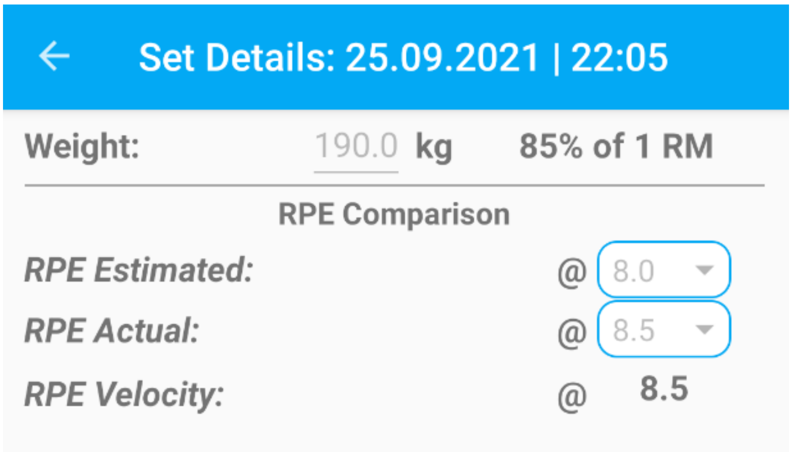


Figure 3.11.: Textual representation of the RPE comparison within the application.

Graphical Representation

The second representation approach is graphical. The representation of each value consists of a written label describing which RPE value it is and a value which is represented in a horizontal bar diagram. The x-axis values on the bar graph range from @6 up to @10 in 0.5 incremental steps. If the x-value is @<7, the bar goes only until 6.5, indicating that the RPE value is below 7. The value 6 can not be reached but is shown on the x-axis for better visualization. The three RPE labels and bars representing the value, are again arranged one below the other as in the textual representation. As an additional feature, the bars of the three values are animated, means starting at value 6.0 increasing in length until the x-axis value is reached. Figure 3.12 contains a snapshot of the application from the same example.

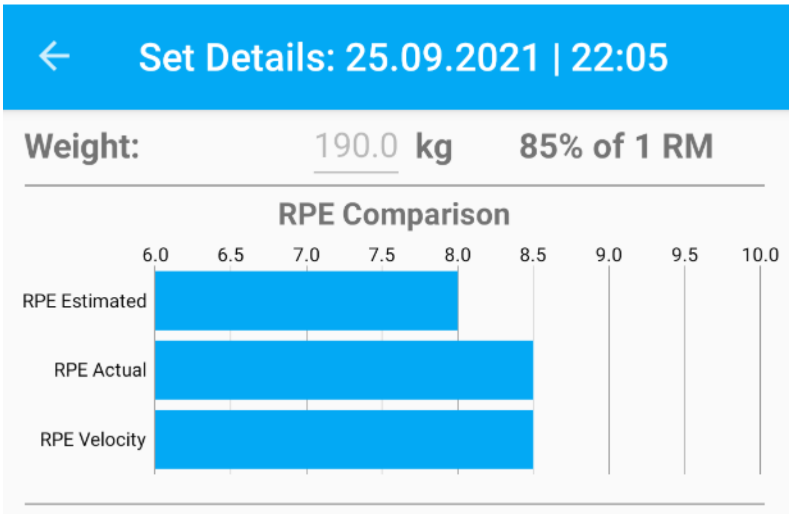


Figure 3.12.: Graphical representation of the RPE comparison within the application.

4. Preliminary Study

The initial prototype with the basic functionality was developed as part of the *LP Praktikum 2*. This initial prototype consisted of the following functionalities and views:

- Home view
- Profile view
- Setlist views for the exercises: squat, bench press and deadlift
- Set-detail view
- Login and registration functionality
- Data model

To understand what the user group would need for this application and to gather feedback, a preliminary study with different powerlifting athletes and technical interested persons was performed.

4.1. Motivation

The analysis was carried out to obtain feedback on the developed Android prototype and identify what people expected from a strength-and-fitness application handling VBT. Since these systems should be integrated into the existing athletes' training, it was crucial to keep the prototype as simple as possible. Therefore, no significant additional effort should be needed by athletes to benefit from the application.

At the time of the evaluation, no VBT tool was available; hence, a wearable smartwatch device acted as the VBT tool and faked the measuring process of the mean velocity. To this aim, a simple WearOS application was developed which faked the measurement and sent the results to the Android prototype application.

The evaluation started by introducing VBT. An introduction text, which can be found in the Appendix Section A.0.1, was also provided to the test persons for better understanding. In addition to verbal feedback through qualitative questions, different use cases were prepared for the test persons. The users performed specific steps in the application and were familiarized with the application. Four different use cases were prepared and then performed by each test person. The detailed test case described can be found in the Appendix Section A.0.2. Afterwards, they rated the test cases and provided qualitative feedback on the prototype. After completing the use cases, multiple qualitative questions were asked to gather feedback on the performed use cases, the available functionality, and missing features, which are described in the Subsection 4.2.2.

ID	Age	Gender	Years of training	Strength coach	T. Affinity	EXP with VBT*
1	26	male	10	Yes	Middle	Middle
2	23	male	2.5	Yes	High	None
3	28	male	5	No	Middle	None
4	30	male	0 - Not training	No	Very High	None
5	25	male	2	No	High	Low

Table 4.1.: Profile and background information of the evaluation participants. *T. Affinity = 'technical affinity', *EXP with VBT = 'experienced with Velocity-based training'.

4.1.1. Participants

Five persons with an age between 23 and 30, with an average age of 26.4, participated in the preliminary study. To obtain a good range in the persons' training experience, test persons with different years in training were chosen. ID 1 is training already since 10 years, being the one with the most training experience in the test group. ID 2 started 2 and a half years ago with strength training, whereas ID 3 is training already the double of that time. ID 4 is the only test persons without strength training experience as he is not training at all. ID 5 has a similar training experience as ID 2 with two years of doing strength training.

In addition to training experience, technical affinity is an interesting demographic information, as handling a smartwatch and a smartphone should be no problem to the test persons.

4.2. Results

4.2.1. Quantitative results

Since the preliminary study predominantly concerned qualitative feedback, the results of the quantitative questions might vary. Additionally, the number of participants was quite low which means the quantitative feedback on the test cases was less relevant. Nonetheless, Figure 4.1 shows that the users always strongly agreed or agreed with each of the following quantitative questions:

- Quantitative questions:
  - The workflow was easy to perform?
  - The design and user interface were appealing?
  - The displayed content was appropriate?
- Rating options:
  - Strongly Agree
  - Agree
  - Neither Agree nor Disagree
  - Disagree

– Strongly Disagree

Each question was asked after a test case was completed. In summary, 4 test cases were performed which are described in detail in the Appendix Section A.0.2. The rating about the displayed content had the best results among the three questions. In particular, for the displayed content seen during the third and the fourth test cases, all five participants strongly agreed, which may indicate a good design and user interface that also provides enough usability to perform the main use cases of the application.

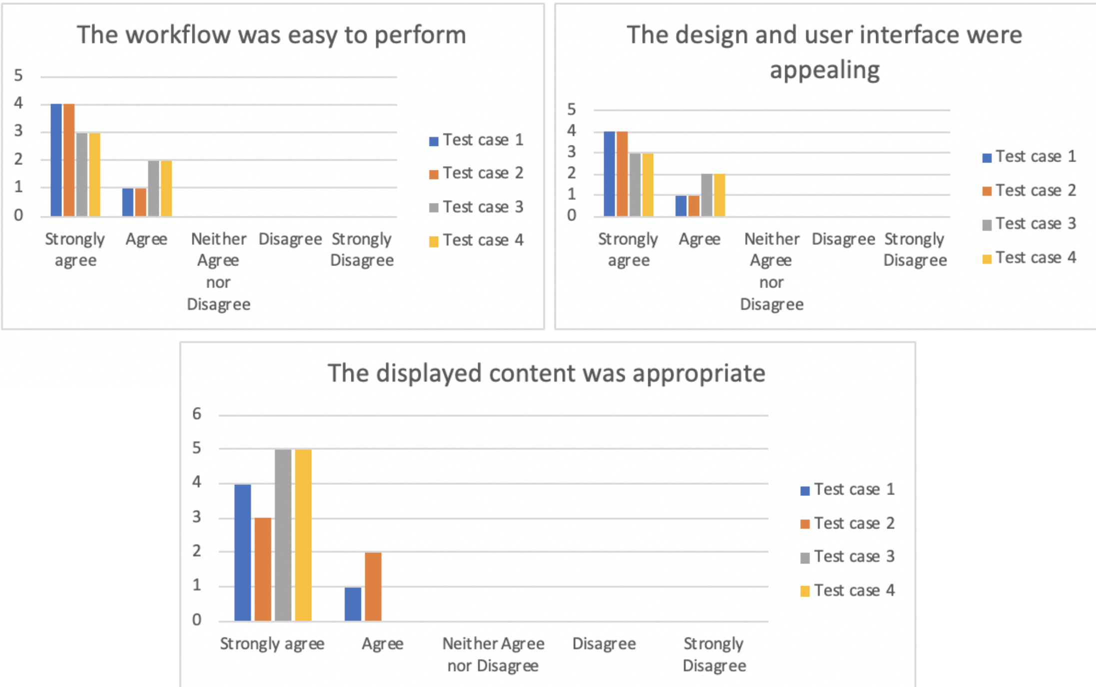


Figure 4.1.: Quantitative results of the preliminary study.

4.2.2. Qualitative results

After the test cases were performed, qualitative questions were asked to obtain more detailed feedback and also possible requirements. The following qualitative questions were part of the evaluation:

- Which three features did you like the most?
- Which three features shall be improved? How?
- Are there any further use cases which shall be supported by the application?
- Do you see any advantages or disadvantages by using the application? Would you use this application for you training?

4.2.3. Feedback from ID 1

Test person 1 already had 10 years of strength-training experience, had worked for two years as a strength coach and had some experience with VBT but the most compared to all other test persons. The person could perform all test cases easily but reported that an additional tutorial that leads the user through all main functionalities might be better than the tutorial shown after registration. The features which were liked the most were the suggestion of the RPE and the possibility to calculate the 1-RM. However, another useful feature would be including information about how the velocity evolved during a set to identify appearing sticking points.

The test person identified two possible issues: on the one hand, it was doubtful if the smartwatch would work or even fit if wrist wraps are worn. Since the smartwatch can not be placed on the wrist wraps, it could only be placed behind them. As the length of the watch band is limited, this might lead to issues. On the other hand, the countdown of 10 seconds might be to low for getting prepared for the training set. He thus suggested letting the users set the countdown time individually.

4.2.4. Feedback from ID 2

Test person 2 had a high technical affinity and also focused much on the usability of the applications. He especially liked their simplicity and the suggestion of the RPE. He understood the tutorial well, but he reported a missing back button in the tutorial's slider view and the missing search or filter functionality for the sets list. Furthermore, he noted that if many sets are entered in the result list, it becomes impossible for the user to find a specific one, and he expressed the need for an RPE-to-1-RM calculator.

4.2.5. Feedback from ID 3

The first and the second test cases did not cause any issue to ID 3. Anyhow, during test case 3 an issue with during selection of the exercise type at the smartwatch occurred. The user selected by mistake the wrong exercise type, performed the set and sent the data to the smartphone. Since there is no option to change the exercise type once the set is performed, the user suggested that the possibility to do this should be provided instead. According to him, it can easily happen that one taps on the wrong button without noticing before a heavy set. Without such a possibility, the user would need to delete the set afterwards because it would be useless, which could cause some frustration for the athlete, which must be avoided.

Like test person 2, a search or filter option was suggested by test person 3. The usefulness of the notes in the set-detail view was also questioned because there is no use case in which the test person would make some notes for a particular set. Nonetheless, test person 3 highly appreciated both the design, the simplicity and the RPE suggestion.

4.2.6. Feedback from ID 4

Test person 4 was the only one with no experience in strength training, but had a high technical affinity. Although no know-how in strength training was available, all test cases could be easily performed and understood. The design of the applications was rated as very good, but some minor findings in the design were reported: a back-button in the tutorial slider view and a text with 'Logout' under the logout-button. Furthermore, according to the test person, the dumbbell leading to the home view in the navigation bar could be changed to a house so that it is cleared that it is the home screen.

4.2.7. Feedback from ID 5

The exertion-load profiling was liked the most by ID 5, who suggested implementing a table with the combination of RPE and repetitions, as well as the mean velocity of those combinations. This table would get filled out step by step whenever a new set gets locked. Hence, the user would get an overview of the velocity of all RPE-repetitions combinations. The RPE statistics show this information somehow, but according to the test person, this additional table would provide a better overview.

During the evaluation test person 5 could perform all test cases without any problems. The home view was also liked much by the test person, with one improvement suggested. Instead of using Wilks points, the user wanted to have the total sum of the estimated 1-RMs.

4.3. Relevance for the thesis

As this preliminary study showed, the participants made many suggestions for improvements of the prototype. According to the quantitative feedback, the overall usability and sense of the application seemed to be understood and rated well. As part of this thesis, the gathered feedback was analyzed to identify which parts of the prototype should be improved, so that possible misunderstandings are removed and the focus during the RPE value representation evaluation can be fully on the textual and graphical representation, which are crucial to answer the research questions.

Based on the feedback from ID 2, it might be hard to find the sets if the user tracks them for a long time. Therefore, a clustering based on a session item was introduced to group the sets based on a daily session. By doing so, also the best estimated 1-RM value for each session got tracked and displayed in the session list view, as it can be seen in Figure 3.7. Displaying the best estimated 1-RM per session might also motivate and challenge the athlete for the next sessions.

Another suggestion was to make it possible to track the mean velocities of each repetition. Therefore, a repetition class was introduced to make that possible. This extension was also central for the representation of the RPE comparison as the calculation of the *RPE Velocity* value is based on the velocity of the last repetition of a training set. Without the possibility to track the mean velocity for repetitions, it would not be possible to calculate the *RPE Velocity* and do the RPE comparison.

A further suggestion from several test persons was the 1-RM forecast, which is visualized in Figure 3.9. As the statistics functionality confused the test persons more than it helped them, it was removed from the prototype.

In general, the application was liked by all test persons. All participants found the handling with a wearable device measuring the mean velocity highly interesting. For all strength athletes, it would be interesting to try the prototype in combination with a real VBT tool and obtain feedback on how their subjective exertion feeling matches the calculated exertion based on the measured mean velocity.

Overall, it was important to identify possible misunderstandings of the initial prototype. The identified issues were removed and also the mentioned views were improved, so that the test persons could focus on the representations of the RPE comparison during the evaluation and no further issues were present which might have affected their RPE rating and perception of RPE comparison representation.

As part of this thesis the following features were developed, as suggested:

- Class Session
- Class Repetition
- Load-velocity profile
  - Exertion-Velocity Profile
  - RPE Calculation Functionality
- 1-RM Forecast
- RPE Comparison Representation approaches
  - Textual Representation
  - Graphical Representation

5. Evaluation

1. *Which representations do powerlifters prefer for their RPE-based strength training?*
2. *How can representations help to improve RPE-values estimations?*

To answer these research questions, an evaluation was performed with two strength-training athletes, who followed the training procedure described in the following section. Due to the predominant COVID-19 situation, the fitness facilities were closed. Hence, both test persons had to have a home gym to perform the evaluation. To perform the evaluation, both test persons needed the following strength-training equipment: a barbell, a rack and weight plates to perform their highest 1-RM.

After the test persons ended their four-week cycle, the gathered training data was analyzed to find out whether representations can improve the RPE value estimation. Since two different representation approaches were used, as described in the Subsection 3.2.6, the RPE values were represented for two weeks with the textual representation and for two weeks with the graphical representation for each test person. The analysis consisted of investigating the different RPE value comparisons. The comparison always happened between two RPE values and could have one of the following results:

- First RPE value minus second RPE value < 0: Underestimation, entailing that the first RPE values indicate that the set made less exertion than what the second RPE value indicates.
- First RPE value minus second RPE value > 0: Overestimation, entailing that the first RPE values indicate that the set made more exertion than what the second RPE value indicates.
- First RPE value minus second RPE value $= 0$, entailing that Both RPE values indicate the same amount of exertion.

As three different RPE values were tracked, also three different comparisons were made:

1. Expected RPE value before performing the set against RPE value after performing the set.
2. RPE value after performing the set against RPE value calculated based on mean velocity.
3. Expected RPE value before performing the set against RPE value calculated based on mean velocity.

Furthermore, test persons' preference for RPE-value representation was investigated. The two value representations, which are described in the Subsection 3.2.6, were present during the four-week testing phase for each test person. At the end of the test phase for each test person, different qualitative questions were asked to identify the preference for RPE-value representation.

5.1. Methods

An evaluation phase for one person lasted four weeks, during which the athletes followed the usual training cycle. The test persons were advised to perform the competition lifts at least once a week and train three to four times a week, and data for the competition lifts was recorded weekly. Since only one PUSH Band 2.0 device was available, the test persons performed the evaluations in sequential order. As the costs of the VBT device was 400 USD, only one device could be provided. Since an evaluation phase below four weeks would result in a lack of data, the decision was made to gather training data for four weeks per person. Therefore, the overall evaluation time was eight weeks, hence four weeks for each person. The textual value representation displayed the RPE comparisons for two weeks and the graphical value representation for the remaining two weeks.

One test person started off with the textual representation and the second test person with the graphical representation. This was done, to be able to compare the representation approaches better, as no test person was influenced by any representation and learning affect yet. For test week 3 and 4, the test persons might already be biased or created a learning effect. Therefore, the evaluation of the representation approaches is focused on the first two weeks of the data collection phases. Nonetheless, the evaluation phase was done for four weeks for each test person, to analyze if and how the RPE comparison representation, which was present during the first two weeks, affected the RPE ratings of the second two weeks and how the RPE ratings behaved during another two weeks.

The two athletes performing the evaluation had to meet the following requirements:

- Having been on strength training for more than two years.
- Being able to perform the three competition lifts correctly according to the standards of the International Powerlifting Federation (IPF).
- Performing the competition lifts at least once in a week during the evaluation phase.
- Performing training sessions continuously for four weeks.

Additionally, it was important that both test persons were of similar age and of the same gender, to have fewer demographic differences which might affect the perception of physical exertion. Both test persons received an Android smartphone (a Samsung Galaxy S8) to perform the evaluation.

5.1.1. Evaluation procedure

In addition to assessing whether the estimation of the RPE rating can be improved with the described representation approaches, an interview at the end of the data collection phase was performed to gather feedback and information about the preferences of the test persons. Therefore, the evaluation was divided into two parts.

In the data collection and comparison phase, the test persons are performing their training. During this phase, the test persons measured their sets mean velocity with the PUSH Band and tracked the RPE information in the *Barbellocity* application. Immediately after locking a set, the test person received feedback about whether their RPE rating aligned with the calculated RPE value or deviations existed. However, at the very beginning, the load-velocity profile for each of the three exercises had to be established, as already argued earlier. Within this phase, information about how representation can improve the RPE value estimation was gathered.

The qualitative analysis was the second part of the evaluation. Since the preference for RPE-value representation was essential for answering the research questions, an interview with qualitative questions was performed to gather general feedback and more information about the test persons' preferences and opinions about the evaluation. All interview questions can be found in the Subsection 5.1.2.

Tracking and updating a set

Since the mean velocity was measured by the external device PUSH Band and its Android application, the test persons needed to interact with both, *Barbellocity* and PUSH Band, applications to track and view the RPE comparison. During that process, the PUSH application acted only as a measurement tool, which means that no other functionality was of interest during the evaluation.

To track the information correctly, the procedures of creating a set and updating it are needed. Those result in an overall set handling workflow to review the three rates of perceived exertion values of a set. This workflow is visualized in a sequence diagram in Figure 5.1. The procedure starts with the user being not logged in. The following steps describe the whole workflow. The actor is called *Athlete* and acts as an user. The athlete interacts with two different systems: the self-developed prototype application *Barbellocity* and the velocity measurement tool *PUSH App*.

1. At the beginning, the athlete must log in into the *Barbellocity* application if they are not logged in yet.

2. After the log-in, an exercise is selected by the athlete by clicking on the relative exercise icon.

3. As a next step a training session is created, which acts as a container for all sets for the selected exercise of that day.

4. The following step which is performed in the *Barbellocity* application before the set is started is to create the set object which is defined by set weight, number of repetitions and an estimated RPE value.

5. The fifth step is the selection of the exercise and the weight in the PUSH app.

6. After these data definition steps, the athlete executes the training set. After completion the athlete defines an *RPE Actual* value.

7. As the athlete completes the set, the mean velocity is displayed on the PUSH app.

8. The last step is to enter the *RPE Actual* value and the mean velocity of the last set in the *Barbellocity* application and to lock the set.

9. By doing so, the comparison of the RPE values is represented either textually or graphically.

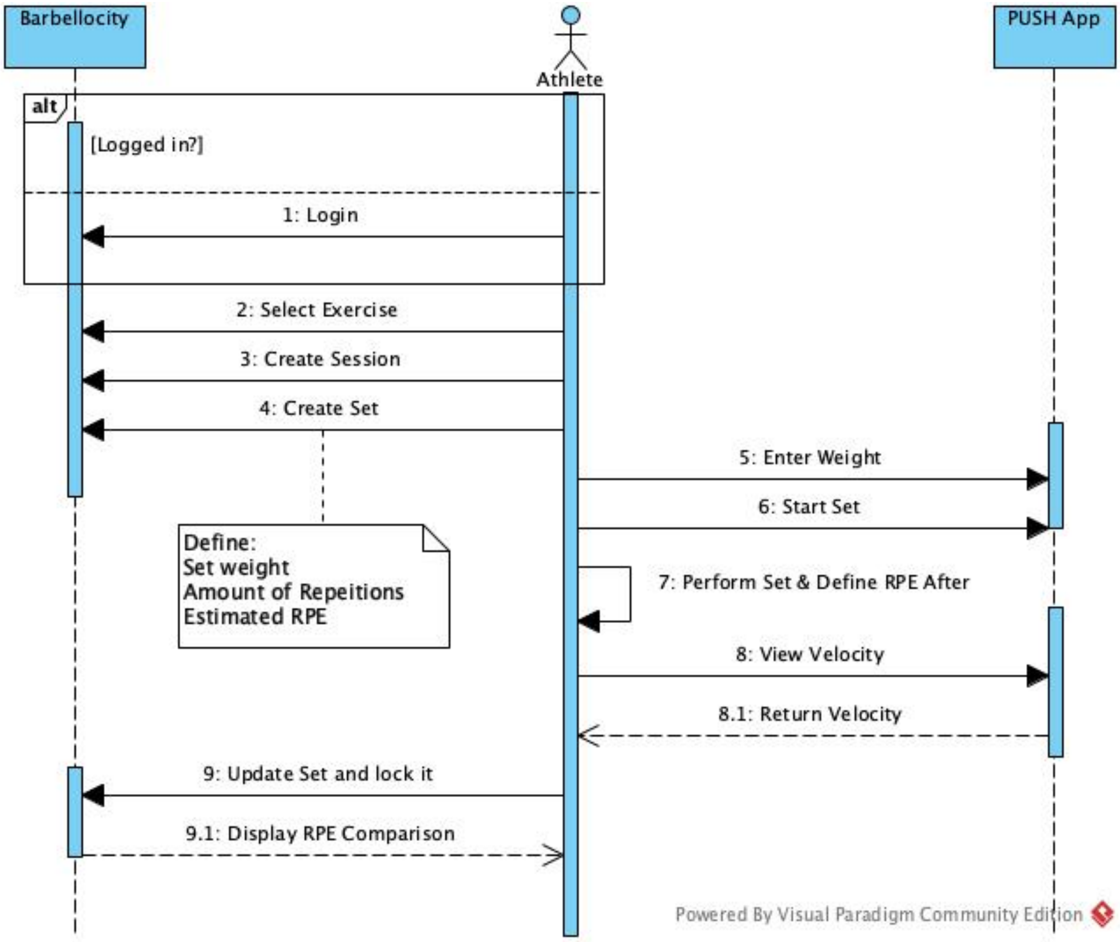


Figure 5.1.: Sequence diagram for creating, performing and updating a set with showing interaction between the athlete, the *Barbellocity* application and the PUSH Band application.

To avoid *RPE Actual* values, which are influenced by the mean velocity, it is imperative that the test person defines the *RPE Actual* value before viewing the mean velocities. Otherwise, the user might get biased by the measured velocity and enter a higher or lower *RPE Actual* value.

5.1.2. Questionnaire

Qualitative questions were asked remotely to obtain more insights and feedback from the test person. In addition to those concerning demographic information such as gender and age, the following questions were part of the qualitative analysis:

- Which RPE comparison representation did you prefer? Why?
- With which representation could you rate your *RPE Actual* better?
- Do you think you can estimate your RPE values after this evaluation phase better than before?

- Did you identify any advantage in using the combination of PRE and mean velocity as feedback for your training sets? Which one?
- Which areas of the application did you also explore except for the basic functionality of calculating RPE values, based on mean velocity?
- Were there any other features, except for the basic functionality of calculating RPE values, within the application which affected your RPE ratings? How?
- Would you use such a tool in the future for your strength training? Why? Why not?
- How did you like the testing phase overall?
- Which feature did you like the most?
- Which improvements would be good to implement? Can you think of any things which would have improved your user experience?
- Other general feedback?

5.1.3. Evaluation instructions

Before starting with the four weeks of evaluation, each evaluation person received an introduction to both *Barbellocity* and PUSH. Each test person confirmed to have performed their evaluation to the best of their knowledge. Additionally, a brief written summary was provided to them, which can be found in the Appendix Section A.0.1. The evaluation guidelines consisted of:

- a brief description of the *Barbellocity* application and what exactly needed to be tracked in that application
- the link to the official *Get Started PUSH Band 2.0* website, where the handling of the PUSH Band application is described in a detail.
- and the exact way how to establish the load-velocity profile for each exercise. Similar to the already mentioned procedure in section 'Design and Implementation'.

The whole description can be found in the Appendix section.

5.2. Participants

Before starting the evaluation, different questions were asked to gather the demographic information of the test persons. Table 5.1 shows the relative data: test person 1 was 28 years old and been doing strength training since 4 years. Test person 2 was two years younger but had been doing strength training already since 7 years. Both persons' gender was male and both participated already in local powerlifting competitions, which ensured their exercise's execution technique's level to be high enough to make VBT useful. Nonetheless, both had minimal experience with VBT. Both test persons explained that they had heard of this training method but never used it due to the unavailability of any VBT tool such as the PUSH band. Since specific technical skills are advantageous for the evaluation because they allow changing between the applications efficiently, questions about the test persons' technical affinity were also asked. Test person 1 reported a high technical affinity and test person 2 a medium technical affinity; hence, handling the applications was no issue for them. Another question was about their rating of their RPE values. Test person 1 and test person 2 rated this ability relatively high with 7 and 8, indicating high confidence in ranking their exertion values accurately.

Question	ID 1	ID 2
Age	28	26
Gender	m	m
Years of training	4	7
Experience with velocity-based training (L/M/H)*	Low	Low
Rate how well you can estimate your RPE values (1-10)	7	8
Technical affinity (L/M/H)*	High	Medium

L/M/H... Low/Medium/High

Table 5.1.: Table showing the demographic information of the test persons.

5.3. Results

5.3.1. Test Person 1 (ID 1)

To start collecting data and the calculated RPE values, the load-velocity profiles for each exercise were needed for test person 1, who is called ID 1 in the remaining sections. Hence, the first step was to estimate the 1-RMs for the exercises. The estimated 1-RMs of ID 1 were 170.0 kg for the squat, 105.0 kg for the bench press and 175.0 kg for the deadlift, as shown in Table 5.2. Summing up the three estimated 1-RMs resulted in an estimated total of 457.5 kg.

Exercises	1-Repetition-Maximum
Squat	170.0 kg
Bench Press	112.5 kg
Deadlift	175.0 kg

Table 5.2.: 1-RMs of ID 1 for the exercises squat, bench press and deadlift.

Load-velocity profiles of ID 1

After estimating the 1-RMs, six automatically calculated sets were created, similar to those shown in the example in Table 3.1. These sets were the basis for developing the load-velocity profile for each exercise. This means that a total of 18 sets, namely six sets for each exercise, were performed to establish the three load-velocity profiles, as described in the Subsection 5.1.1. ID 1 started with the creation of the load-velocity profile for the squat exercise, followed by the creation of the load-velocity profile for the bench press

Percentage of 1-RM	Squat		Bench Press		Deadlift	
40	68 kg	0,74m/s	45 kg	0,65m/s	70 kg	0,70m/s
50	85 kg	0,65m/s	56 kg	0,52m/s	87 kg	0,55m/s
65	110 kg	0,49m/s	73 kg	0,39m/s	113 kg	0,48m/s
75	127 kg	0,44m/s	84 kg	0,29m/s	131 kg	0,40m/s
85	144 kg	0,31m/s	95 kg	0,25m/s	148 kg	0,35m/s
90	153 kg	0,28m/s	101 kg	0,20m/s	157 kg	0,27m/s

Table 5.3.: Sets used to establish the load-velocity profiles for the three exercises for ID 1.

exercise. The load-velocity profile for the deadlift exercise, was done at the third training session.

Table 5.3 displays the calculated weight for each percentage value and the mean velocity at which the weight was moved. Each set is represented by a tuple consisting of:

- percentage value of the estimated 1-RM
- mean velocity at which the weight was moved

Since the first set starts at 40% of the 1-RM, the beginning is substantially moderate. Set by set, the weight became heavier and the mean velocity lower. For the bench press exercise, ID 1 performed the first set with 45 kg at a mean velocity of 0.65 m/s, the second set with 56 kg at a mean velocity of 0.52 m/s, the third set with 73 kg at a mean velocity of 0.39 m/s, the fourth set with 84 kg at a mean velocity of 0.29 m/s, the fifth set with 95 kg at a mean velocity of 0.25 m/s and the last set, representing approximately 90% of his 1-RM, with 101 kg, which was moved with a mean velocity of 0.20 m/s. Hence, the mean velocity steadily decreases as the weight becomes heavier.

By using these six data tuples, a linear regression function was built to model the linear relationship between mean velocity and percentage of the estimated 1-RM. As stated by Weakley et al. [WMB+20] the linear regression fits well to model the load- velocity profile. Furthermore, one can observe R^2 values > 0.95, as shown in Figure 5.2. The same figure also shows the data points and their trend lines for the three exercises.

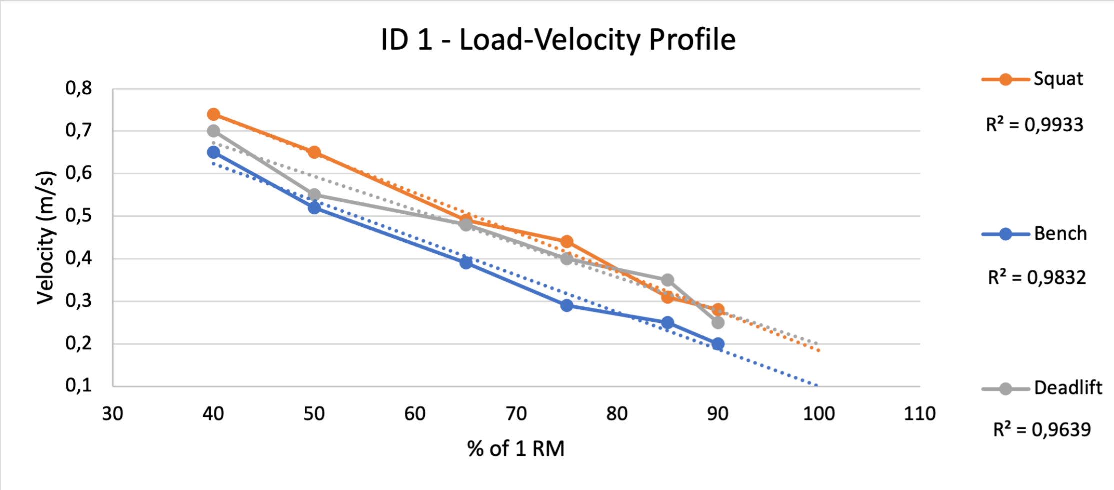


Figure 5.2.: The three load-velocity profiles for the squat (orange), the bench press (blue) and the deadlift (grey) exercise, built from six sets for test person ID 1. The mean velocity is represented in meters per second on the y-axis, and load displayed as percentage of the 1-Repetition-Maximum on the x-axis. All three linear regression models have an R^2 value > 0.95.

ID 1 started his evaluation with the textual RPE comparison representation. This means that for the first two weeks, the RPE values, after locking a set in the *Barbellocity* application, were displayed in the textual format, as described in the Methods section. During these two weeks, the three RPE values were represented in the described textual way after locking a training set. At the end of week 2, the representation changed automatically to the bar-chart-based representation. For this second half of the evaluation of ID 1, whenever a training set got locked, the animated bar charts displayed the comparison of the three RPE values. At the end of the second phase, the evaluation for ID 1 ended.

Statistical data

The actual data collection took place after the creation of the load-velocity profiles. ID 1 trained four times a week, and each powerlifting competition lift was trained once a week. Whenever one of the three exercises was trained, the number of sets for this exercise was between two and five. Hence, during the evaluation phase of four weeks, each exercise was trained four times. In total, ID 1 performed 42 sets, split up into 13 squat sets, 16 bench press sets and 16 deadlift sets, as shown in Table 5.4.

The comparison between the RPE categories from ID 1 is described in the following subsections. Each RPE value category is compared to the other RPE category.

RPE Estimated versus *RPE Actual*

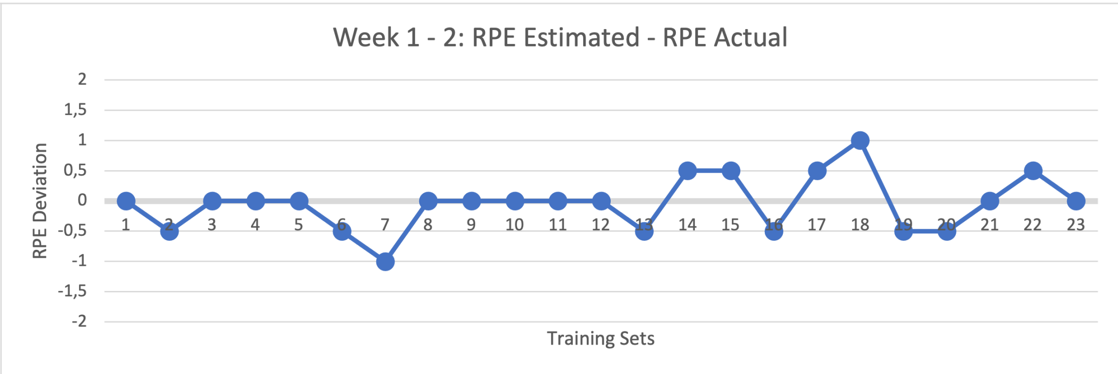
In Figures 5.3a and 5.3b, two liner graphs are displayed, showing the RPE deviations for the sets from training week 1 up to training week 4. Since the visualization changes after the first two weeks, two different linear graphs are visualized for better comparison.

It can be seen that both *RPE Estimated* and *RPE Actual* values match for many

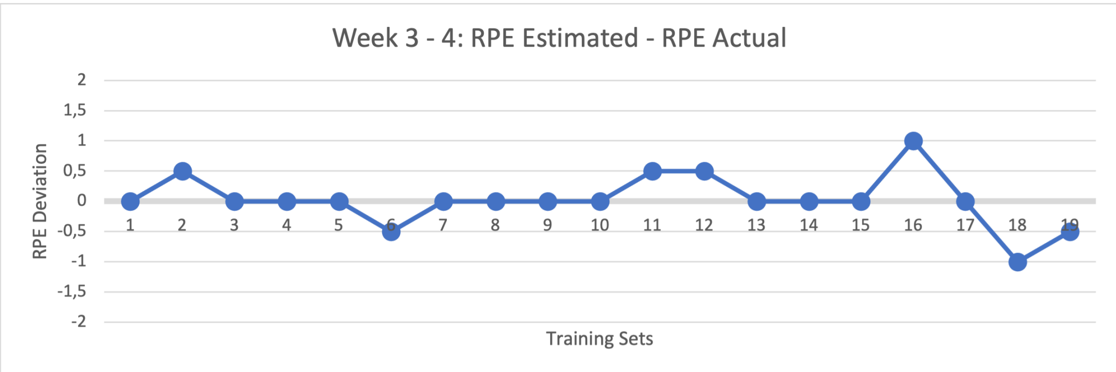
	Week 1	Week 2	Week 3	Week 4	Total	Average
Squat	3	3	2	5	13	3,25
Bench Press	5	4	4	3	16	4,00
Deadlift	4	4	2	3	13	3,25
Total	12	11	8	11	42	10,5

Table 5.4.: Statistical information about the sets performed during each week for ID 1. A total of 42 sets were performed during the four weeks of evaluation.

sets. Over 10 on-point matches were made with both representations, entailing that *RPE Estimated* and *RPE Actual* values were the same for a set. Furthermore, the highest deviation value was only one RPE value. Once an underestimation of one RPE value and once an overestimation of one RPE value, in both test parts was observed. In total, there is a remarkably high match between the between the *RPE Estimated* and *RPE Actual* values in both test phases.



(a)



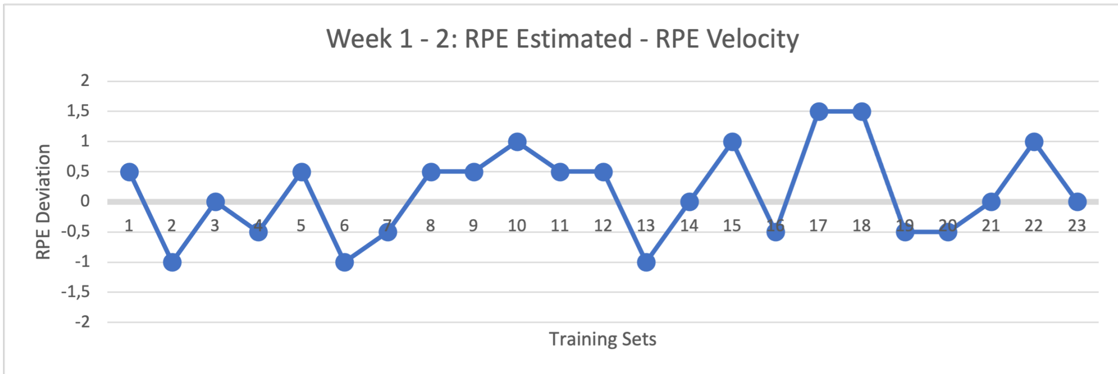
(b)

Figure 5.3.: (a) RPE deviations from the *RPE Estimated* and *RPE Actual* values for ID 1 for week 1 and week 2, in which the textual representation visualized the RPE comparison; (b) RPE deviations from the *RPE Estimated* and *RPE Actual* values for ID 1 for week 3 and week 4, in which the graphical representation visualized the RPE comparison.

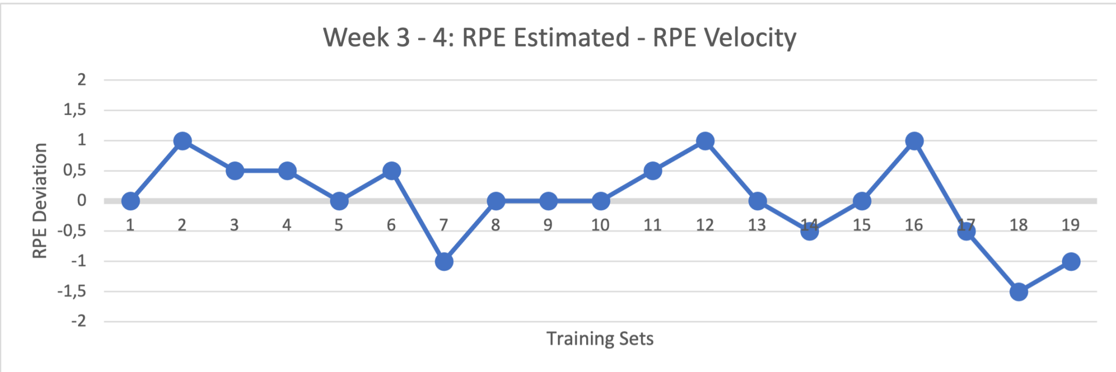
RPE Estimated **versus** ***RPE Velocity***

The second comparison is made between *RPE Estimated* and *RPE Velocity* – namely between the RPE values which was estimated to be felt and the RPE value calculated based on the mean velocity of the last repetition from the set.

In Figures 5.4a and 5.4b, the comparison is visualized in the form of two linear graphs. During the first two weeks, only for four sets both values matched on point. Overall, it can be seen that the estimated RPE values were in many cases higher than the RPE values which were calculated based on the mean velocity. This means that the athlete expected the sets to be heavier than they actually were. During the second two weeks, seven on-point matches were achieved. For seven times the estimated RPE value was higher, and for five times it was lower than what measured by mean velocity. The highest deviation was -1.5 RPE values. In conclusion, the amount of on-point matches was higher during the second two weeks. Furthermore, the number of overestimations was lower during the second phase. Compared to the first two weeks, the number of overestimations went back from 11 to seven.



(a)

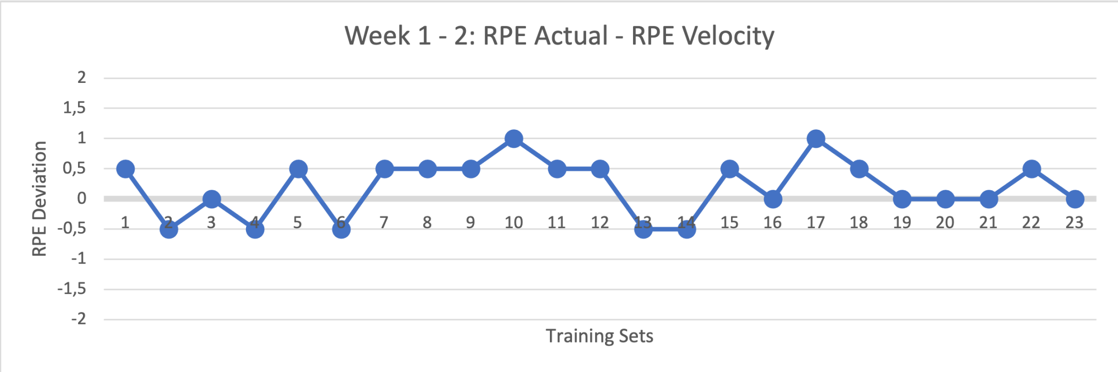


(b)

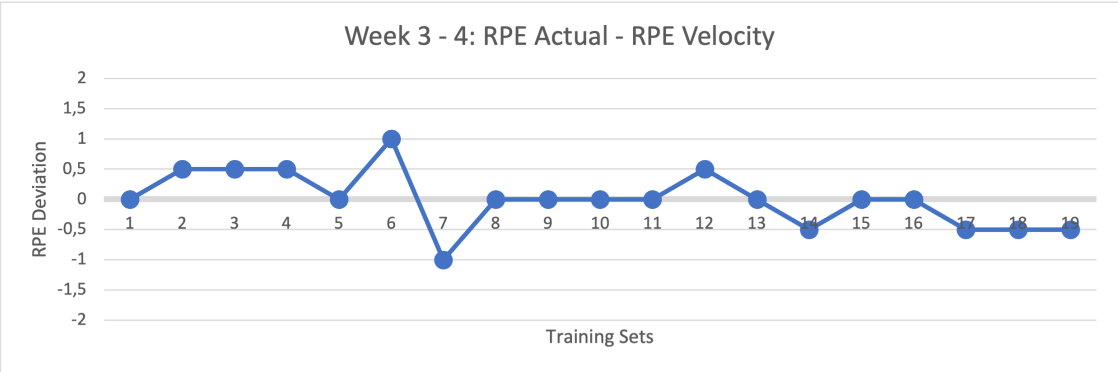
Figure 5.4.: (a)RPE deviations from the *RPE Estimated* and *RPE Velocity* values for ID 1 for week 1 and week 2; (b) Showing the RPE deviations for ID 1 for week 3 and week 4, in which the RPE comparison was displayed with the graphical representation.

RPE Actual* versus *RPE Velocity

The third comparison is between the actual felt RPE value and the RPE value calculated based on the mean velocity of the last repetition. The deviations of the RPE values of the training sets are displayed in Figures 5.5a and 5.5b. Five on-point matches took place, and five underestimations were recorded during week 1 and week 2. The remaining 12 sets were recorded as over-estimations. Out of those 12 sets, more than 80% only deviated by a 0.5 RPE value. Hence, most of the over-estimations were close at an on-point match, and the actual felt exertion was only slightly above the exertion value based on the mean velocity. During the second phase, the *RPE Actual* and *RPE Velocity* values matched for nine out of 19 sets. The remaining 10 sets had a deviation of exactly five over- and five underestimations. Remarkably, most of the over-estimations occurred during the third week, and most of the underestimations occurred during the last week. Comparing the two test phases, one can see an increase in on-point matches by nearly double the number from the first two weeks. Furthermore, a better distribution between Over- and underestimations can be identified during the second two weeks when compared to the first two weeks.



(a)



(b)

Figure 5.5.: (a) RPE deviations of the *RPE Actual* and *RPE Velocity* values from week 1 and week 2 of ID 1; (b) RPE deviations for ID 1 for week 3 and week 4.

For each comparison, in the second half of the test phase, the RPE values matched more often than during the first half. The best results were achieved for week 3 and week 4 by comparing *RPE Estimated* and *RPE Actual* values. With one third fewer exact matches, the comparison between the actual felt RPE value and the RPE value based on the mean velocity revealed the second most exact matches during week 3 and week 4. Overall, one can see better comparison results for all three comparisons during the second half of the test phase.

5.3.2. Test Person 2 (ID 2)

Test person 2 (ID 2) started the evaluation one week after ID 1 finished his evaluation. The same procedure applied for ID 1 was applied for ID 2. Hence, ID 2 created a user profile in the *Barbellocity* application followed by the load-velocity profiles. Again, the estimated 1-RMs were needed to develop the needed training sets automatically. The estimated 1-RMs of ID 2 were 180.0 kg for the squat, 122.5 kg for the bench press and 205.0 kg for the deadlift, as shown in Table 5.5. The sum total of the three estimations is 507.5 kg.

Exercises	1-RM
Squat	180.0 kg
Bench Press	122.5 kg
Deadlift	205.0 kg

Table 5.5.: 1-RMs of ID 2 for the exercises: squat, bench press and deadlift.

Load-velocity profiles

By using the estimated 1-RMs, ID 2 started with the bench press to create the load-velocity profile. He completed the automatically calculated six sets of 49 kg, 61 kg, 79 kg, 91 kg, 101 kg and 110 kg, as visualized in Table 5.6. After completing the load-velocity profile for the bench press, the profiles for the squat and the deadlift were created in the next training sessions.

Figure 5.6 shows the linear regressions for the three load-velocity profiles. Again, all three load-velocity profiles had an R^2 value above 0.95, indicating a strong linear relationship between the load, represented as the percentage of the estimated 1-RM, and the mean velocity at which the load got moved. For ID 2, too, the lowest mean velocity appears for the bench press exercise. The mean velocity for the squat exercise was higher than the

% of 1 RM	Squat		Bench Press		Deadlift	
40	72kg	0,70m/s	49kg	0,64m/s	82kg	0,68m/s
50	90kg	0,65m/s	61kg	0,50m/s	102kg	0,55m/s
65	117kg	0,52m/s	79kg	0,40m/s	133kg	0,46m/s
75	135kg	0,39m/s	91kg	0,31m/s	153kg	0,41m/s
85	153kg	0,34m/s	104kg	0,24m/s	174kg	0,34m/s
90	162kg	0,23m/s	110kg	0,18m/s	184kg	0,24m/s

Table 5.6.: Sets used to establish the load-velocity profiles for the three exercises for ID 2.

mean velocity of the deadlift exercise until the training set with 75% of the 1-RM. For the remaining two sets, one can see a minimal higher mean velocity for the sets of the deadlift exercise. Nonetheless, the squat and the deadlift have a similar mean velocity, especially when the load is increased to the maximum. The training sets of the bench press exercise had at all six sets the lowest mean velocity compared to the other two exercises.

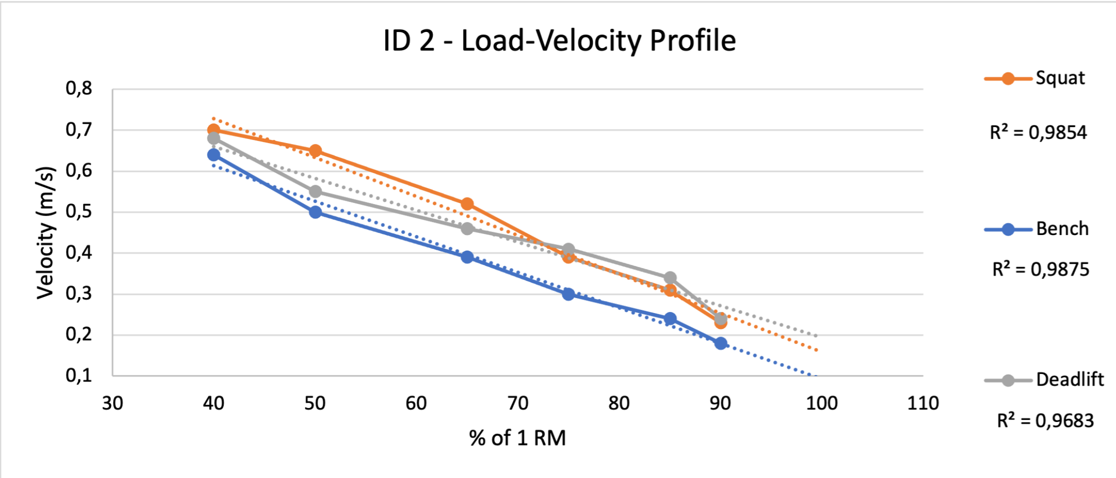


Figure 5.6.: The three load-velocity profiles for the squat (orange), the bench press (blue) and the deadlift (grey) exercise, built from six sets for test person ID 2. The mean velocity is represented in meters per second on the y-axis, and the load is displayed as the percentage of the 1-RM on the x-axis. All three linear regression models have an R^2 value > 0.95.

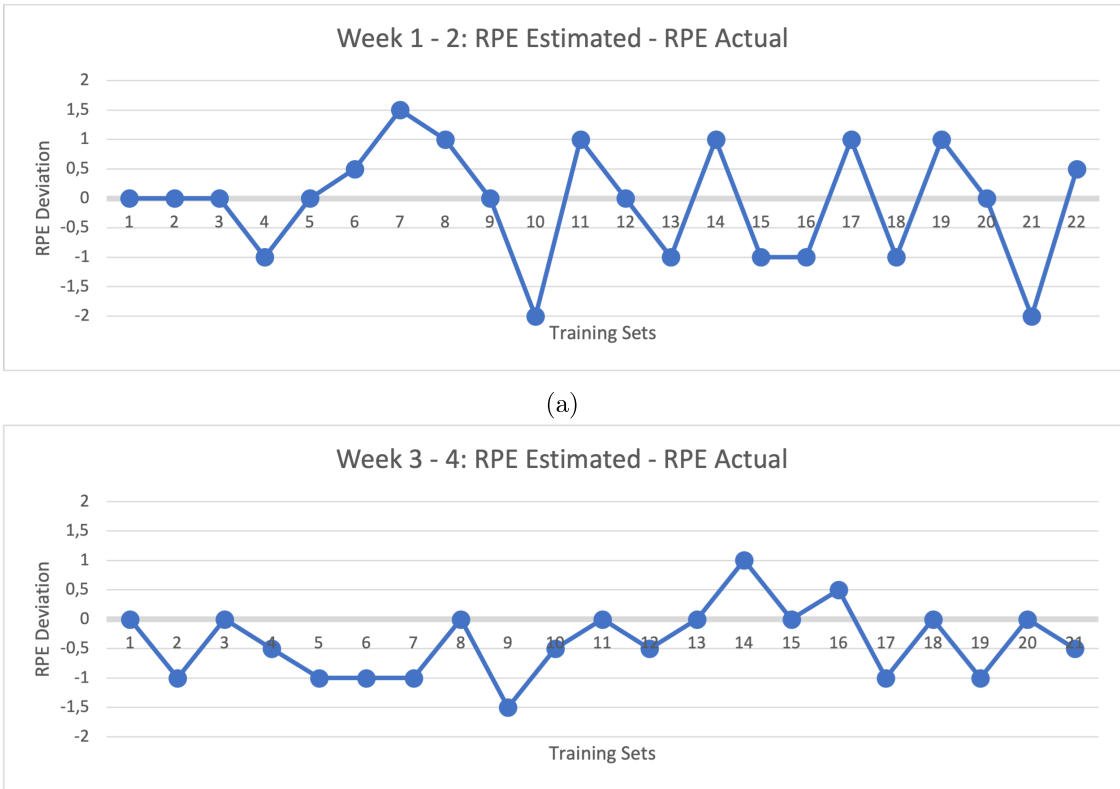
Other than ID 1, ID 2 started his evaluation with the graphical representation of the RPE comparison. This means the for the first two weeks, the RPE values, after locking a set in the *Barbellocity* application, were displayed in the bar chart format. During these two weeks, the three RPE values were represented in an animated graphical way after locking a training set. At the end of week 2, the value representation changed automatically to the textual-based representation. For the second half of the evaluation for ID 2, whenever a training set got locked, the RPE comparison was displayed with textual numbers. At the end of the second phase, the evaluation for ID 2 ended.

	Week 1	Week 2	Week 3	Week 4	Total	Average
Squat	4	4	4	4	16	4,00
Bench Press	4	4	3	2	13	3,25
Deadlift	3	3	4	4	14	3,50
Total	11	11	11	10	43	10,75

Table 5.7.: Statistical information about the sets performed during which week for ID 2. A total of 43 sets were performed during the four weeks of evaluation.

Statistical Data

ID 2 performed 43 training sets – 22 in the first two weeks and 21 in the second two weeks. The distribution of the three different exercises was the following: 16 squat sets, 13 bench press sets and 14 deadlift sets. Each exercise was trained once a week and included between two and four sets. The whole distribution of sets during the 4 weeks of data collection is displayed in Table 5.7.



(b)

Figure 5.7.: (a) Linear graph of the RPE deviations from the *RPE Estimated* and *RPE Actual* values for ID 1 for week 1 and week 2; (b) RPE deviations for week 3 and week 4.

RPE Estimated versus *RPE Actual*

The comparison between *RPE Estimated* and *RPE Actual* shows high RPE deviations during the first two weeks, as can be seen in Figure 5.7a. For the first three sets of the first week, a match, namely a deviation of 0, between the two RPE values can be observed. The following sets had only a few matching RPE values. A mix of overestimations and underestimations can be seen during the first two weeks. One outliner was training set 10, for which an *RPE Estimated* value was two RPE values below the *RPE Actual* value. Additionally, a frequent switch of high over and high underestimations can be observed for training sets 10 and 11 or 17 and 18.

In the second part of the evaluation, a slightly higher number of matches can be observed.

In total, the number of the *RPE Estimated* values was lower than that of *RPE Actual* values. Specifically, 11 underestimations were recorded during the second two weeks, as visualized in Figure 5.7b. A similarly low number of exact matches can be observed in the second part compared to the first part of the evaluation from ID 2. The number of consistent deviations, which was higher in the first two weeks, decreased in the second part of the evaluation phase.

RPE Estimated versus *RPE Velocity*

Assessing the *RPE Estimated* value against the *RPE Velocity* value allows comparing the estimated RPE by ID 2 before performing the set with the RPE value was calculated based on the mean velocity of the last repetition of a set.

Figure 5.8a shows a clear trend. In the first five times, the estimation of the RPE value before performing the set was the same as the RPE value based on the mean velocity of the last repetition of the sets. Additionally, one observes small negative and positive deviations, followed again by two exact matches. Eleven out of 22 training sets from the first two training weeks had an exact match of *RPE Estimated* and *RPE Velocity* value. An underestimation occurred five times and an overestimation for four.

After changing the RPE comparison representation to the textual representation, a similar trend can be observed. Thirteen out of 21 sets from week 3 and week 4 had an exact match. Only for one set did an overestimation occur. For the remaining seven training sets, a small underestimation of maximum one RPE value occurred.

RPE Actual versus *RPE Velocity*

The third comparison for ID 2 was between *RPE Actual* values and *RPE Velocity* values. Out of the 22 training sets from week 1 and week 2, nine sets had an exact match of the RPE values. ID 2 underestimated the RPE value six times, and an overestimation was recorded during the first part of the evaluation another six times. A twice-as-big underestimation of minus 1.5 RPE values was noted down.

In the second part of the evaluation, an overestimation was recorded only for three training sets. The same number of exact matches – namely nine on-point matches – was estimated in both the first and the second part of the evaluation. The remaining eight training sets were slightly underestimated, with a maximum of minus one RPE value. In total, the comparison values during the second half of the evaluation had slightly better comparison values than the first half.

In sum, the *RPE Estimated* and *RPE Actual* values did not match often for ID 2. Hence, the actual felt exertion was often not as planned. Interestingly, the estimated exertion matched consistently when compared to the *RPE Velocity* values. ID 2 had good results for both representation approaches concerning this comparison. A similar trend to the first comparison can be observed for the third comparison. Although the athlete could improve during the second two weeks, the results were not yet as good as in the comparison between *RPE Estimated* and *RPE Velocity*. Overall, most matches were achieved between the estimated exertion and the exertion based on the velocity from the last repetition of the sets.

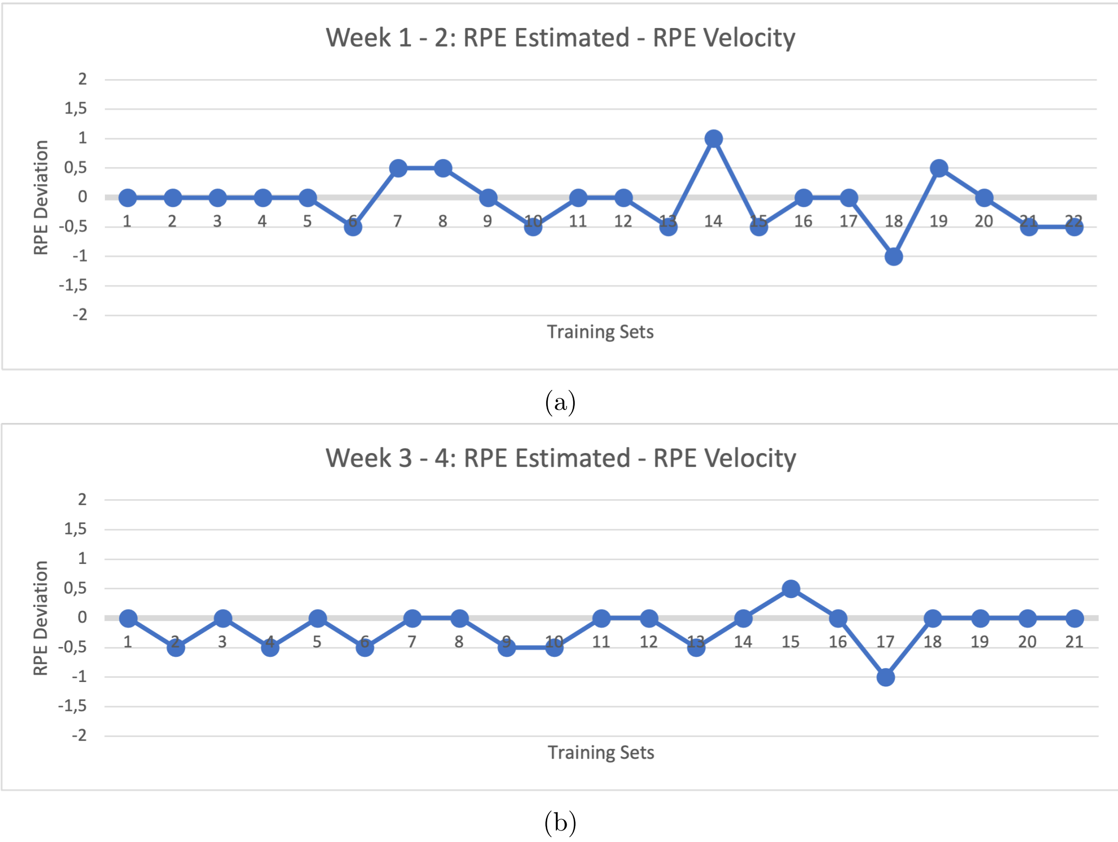
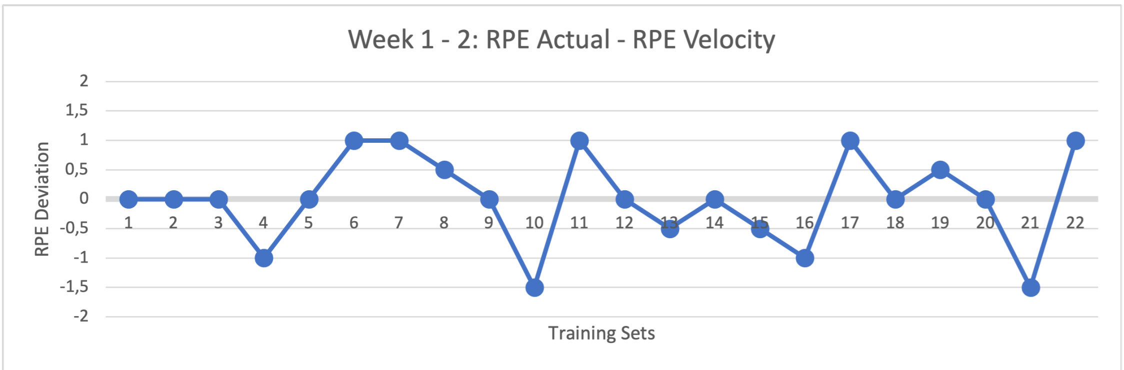


Figure 5.8.: (a) Linear graph of the RPE deviations from the *RPE Estimated* and *RPE Velocity* values for ID 1 for week 1 and week 2; (b) RPE deviations for week 3 and week 4.

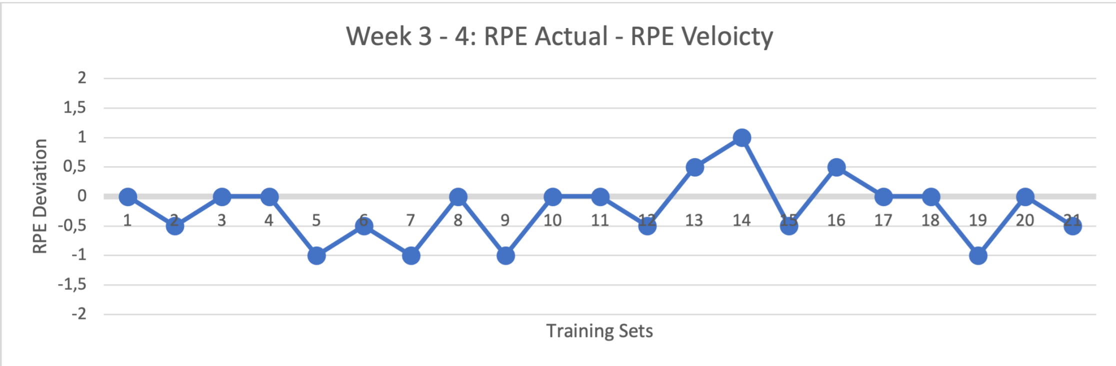
5.3.3. Summary

Overall, ID 1 had the best comparison results when comparing *RPE Estimated* and *RPE Actual* values. Nonetheless, both values often did not match with the *RPE Velocity* values a lot. By looking at the results of the *RPE Actual* and *RPE Velocity* value comparison, one can see that the *RPE Actual* was often higher than the *RPE Velocity*, indicating that ID 1 often overestimated his own exertion. Anyhow, one can see that the results for all comparisons were better during the week 3 and week 4, during which the graphical representation was showing the RPE comparison values than during week 1 and week 2 during which the textual representation was present.

ID 2 started the evaluation phase with the graphical representation. Good results can be observed during this time when comparing *RPE Estimated* and *RPE Velocity* values. Similar good results for this comparison can also be observed for week 3 and week 4 during which the textual representation was showing the RPE comparison. In sum, had ID 2 already good results during the time when the graphical representation was visible for the *RPE Estimated* and *RPE Velocity* value comparison. However, the results over all comparisons were slightly improved during the second two weeks in which the textual representation was showing the RPE comparison.



(a)



(b)

Figure 5.9.: (a) Linear graph of the RPE deviations from the *RPE Actual* and *RPE Velocity* values for ID 1 for week 1 and week 2; (b) RPE deviations for week 3 and week 4.

5.4. Qualitative questions

In total 7 questions related to the representations of the RPE comparison and 4 general questions about the application were asked. The questions about the representation approaches were covering the perception of the test users, their impressions about the two representations and also if they think, their RPE estimation skills have improved depending on the used representations.

General questions were asked about the application and testing phase to identify if any disturbances or issues were appearing during the testing phase similar to the feedback mentioned during the preliminary study, which is described in detail in Subsection 4.2.2.

5.4.1. Questions on RPE comparison representations

- Which RPE comparison representation did you prefer? Why?

  Both test persons perceived the representation approaches as appropriate ways to visualize the RPE comparison.

  ID 1 expressed a clear preference for the graphical representation because he found the values easier to compare with the bar chart.

Whereas, ID 2 stated no preference of any representation. For ID 2, both RPE comparison representations were showing the necessary information equally good.

> *I liked the bar graph more, as on the one hand the values are animated, and it was easier for me to compare the values.* (ID 1)
>
> *In principle both representations are good. Textual and graphical representation are showing the necessary information equally good.* (ID 2)

- With which representation could you rate your *RPE Actual* better?

  For this question, the answers of the test persons differ.

  ID 1 stated that he could better estimate their RPE values with the graphical representation, as the difference between the RPE categories was clearly visible.

  ID 2 stated that no noticeable difference was there between the representation approaches.

  > *I think with the bar graph my rate of perceived exertion estimations are better, as the difference between the values is better visible than with the textual representation.* (ID 1)
  >
  > *Looking back, I think there was no difference between the two representation approaches. I could not state any noticeable difference.* (ID 2)

- Do you think you can estimate your RPE values after this evaluation phase better than before?

  > *Yes, at least a little bit.* (ID 1)
  >
  > *I can hardly tell. Maybe it improved a little bit.* (ID 2)

- Did you identify any advantage in using the combination of PRE and mean velocity as feedback for your training sets? Which one?

  ID 1 and ID 2 agreed on the answer to this question. Both stated that there is an advantage in using mean velocity in combination with the RPE rating. The main argument was the objective feedback provided by the mean velocity. None of them would use only the mean velocity as a feedback tool, as they had not yet the experience or the knowledge of how to obtain the most out of it without using the RPE method.

  > *Yes, definitely. By using RPE ratings, which are highly subjective, and the mean velocity, which is highly objective, a good average is used from which anyone can benefit.* (ID 1)
  >
  > *I think it makes definitely sense to combine both. The well-known RPE ratings give the athlete the known feedback, which can be objectified in combination with the mean velocity, which gives, in sum, even a better feedback on the performance.* (ID 2)

- Which areas of the application did you also explore except for the basic functionality of calculating RPE values, based on mean velocity?

  The goals feature, the 1-RMs report and the 1-RM forecast were the functionalities which were investigated by both test persons the most. Additionally, test person 1 suggested adding the actual lifted 1-RMs beneath the estimated 1-RMs report, as this would motivate one even more.

  > *I had a look at the goals feature. I think this is nice to play a bit around and to motivate oneself, but I think this was not affecting any RPE estimations from my side. The one-repetition-maxima report at the home view was quite motivating. Maybe it is possible to add there also a section for the actual one-repetition-maxima for comparison and to check whether one really got stronger.* (ID 1)

  > *I had a detailed look at the 1-RM forecast, as I use a similar representation for this information in my training plan sheet.* (ID 2)

- Were there any other features, except for the basic functionality of calculating RPE values, within the application which affected your RPE ratings? How?

  The *1 RM forecast* table was considered as a piece of interesting information for the test persons, but it also put some pressure on them, as it noted down which weight should be lifted. Therefore, this feature might have influenced their RPE estimations

  > *I think the 1-RM forecast table subconsciously influenced the estimation behaviour, as it displays how much weight you should be able to lift at a certain RPE.* (ID 1)

  > *From my perspective the 1-RM forecast table created a bit pressure, as it shows at on glance how much weight you should be able to lift. But anyway, this is also a nice feature.* (ID 2)

- Would you use such a tool in the future for your strength training? Why? Why not?

  Test person 1 could imagine to use such tool in future. He also reported that the calculation of the RPE value based on the mean velocity can help to to hit the desired training effect and also representing the RPE values for comparison to be beneficial.

  Test person 2 had some doubts at the beginning, as he thought it would be very complicated and impractical to measure the mean velocity. In addition to those doubts, test person 2 reported the session and set handling of the *Barbellocity* application not being optimal. Nonetheless, he considered the calculation of the RPE based on the mean velocity as a great feature as well and can also imagine to use such a tool in the future.

  Yes, I can imagine using such a tool in the future. The calculation of the RPE value and the representation of the RPE beneath each other can definitely help to hit the desired training effect. (ID 1)

> *At the beginning I was a bit doubtful if is not too complex to measure the mean velocity that easily, but I was proved the opposite. To track the training data in the* Barbellocity *application, the handling of the sessions and sets is a bit too complex. Maybe this can be improved, but anyway, the suggestion of the RPE value for the training sets brings a benefit. Therefore, I can imagine using such a tool in the future.* (ID 2)

5.4.2. General questions on the testing phase and application

- How did you like the testing phase overall?

  Overall seen was the test phase liked by both test persons. However, ID 1 mentioned also that the switching between the two android applications was slightly annoying. ID 2 encountered two training sets for which not all repetitions were tracked.

  > *I liked it a lot. Only the fact that it was necessary to switch between applications was a bit annoying. Additionally, a few things could be enhanced in the PUSH application, but this is not in your hands.* (ID 1)

  > *Overall seen, it was nice to get in touch with velocity-based training. The testing phase itself was also very interesting. Only for one or two sets were the repetitions not tracked correctly by the PUSH application.* (ID 2)

- Which feature did you like the most?

  The *Repetitions - RPE* table, the best estimated 1-RMs report and the load-velocity profile tutorial were liked the most. Additionally, ID 1 mentioned that he enjoyed the calculation of the *RPE Velocity* value, which is part of the RPE comparison.

  > *In general the feature of getting the RPE calculated based on the mean velocity and the Repetitions - RPE table with the training weights were the features that I liked the most.* (ID 1)

  > *I liked the home view a lot with the report for the best one-repetition-maxima. Also the tutorial mode for the load-velocity profiles was a good help to get started.* (ID 2)

- Which improvements would be good to implement? Can you think of any things which would have improved your user experience?

  The views for the session objects and the set objects could be improved according to ID 1, as they looked very similar and were sometimes was hard to distinguish. Similar feedback was received from ID 2, who did not understand why a session object was even needed.

  > *The views for the session and the sets look very similar and sometimes I thought I was creating a set although I was creating a new session. It would be good to make a better differentiation between those two.* (ID 1)

  > *The handling between sessions and training sets was not clear to me at the beginning. I did not understand why a session is needed at all. After the*

first two training session I got used to is anyhow, but still this might be improved. (ID 2)

- Other general feedback?

  Both test persons mentioned no further feedback.

  No. (ID 1)

  No. (ID 2)

6. Discussion

An exact rating of one's physical exertion can be remarkably hard. Performance can heavily fluctuate daily, making a light load on one day impossible to lift on another. Velocity tracking tools can be used to provide objective feedback about how intensive a training set was, particularly in strength training.

To answer the research questions:

1. *Which representations do powerlifters prefer for their RPE-based strength training?*

2. *How can representations help to improve RPE-values estimations?*

an evaluation with two powerlifters was performed, which lasted for each participant four weeks. Since each test person started the first part of the evaluation with a different RPE representation approach, a comparison between the first two weeks of each test person might indicate how the RPE values can be estimated more precisely. As one goal is to understand how representations can improve the RPE value ratings, a comparison between the results from ID 1 and ID 2 for weeks 1 and 2 is performed. During this part of the evaluation, both test persons were not yet biased. Hence, the results for ID 1, which started with the textual RPE representation, and the results for ID 2, which started with the graphical RPE representation, are juxtaposed. Any comparison between the test persons' results of the second phase is not the primary focus since they might be already biased after the first part of the evaluation, in which either textual or graphical representation of the RPE comparison was present.

6.1. Comparison of ID 1 and ID 2

To check whether there are any differences in the RPE comparisons between ID 1 and ID 2, the three different RPE comparisons from each person are overlaid. Since both have performed nearly the same number of training sets, the trend of the comparison matches can also be taken into consideration. ID 2 had an estimated total of 507.5 kg, which is 50 kg more than ID 1, which can be neglected since both athletes were well trained and had training experience of multiple years.

As described in the Section 5.1.1, both athletes needed to create their load-velocity profiles for each exercise before starting the data collection. In Figure 5.2 and Figure 5.6, the load-velocity profiles are graphically displayed. The bench-press exercise had the lowest mean velocity for both athletes, and the squat and deadlift exercise had some overlapping points. For both athletes, excellent R^2 values for each exercise were achieved, implying a strong linear relationship between load, represented as the percentage of the 1-RM, and mean velocity. Similar to the study from Weakly et al. [WMB+20], the bench press' mean velocity values were around 0.2 m/s, and the squat's mean velocity values were approximately 0.3 m/s.

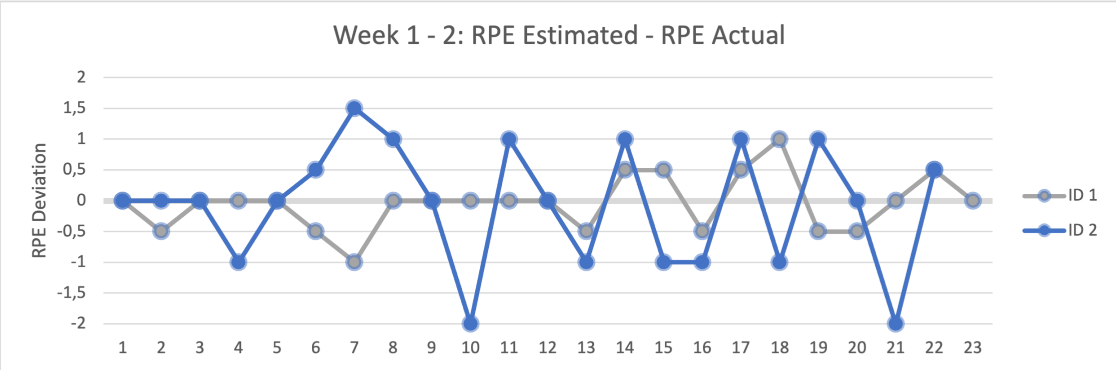


Figure 6.1.: Linear graph displaying the *RPE Estimated* versus *RPE Actual* comparison values for ID 1 (grey) and ID 2 (blue) in the first phase of the evaluation. The RPE comparison was shown in textual representation for ID 1 and in the graphical representation for ID 2 during this phase.

6.1.1. *RPE Estimated* versus *RPE Actual*

By comparing the *RPE Estimated* values with the *RPE Actual* values, one can assess whether the estimated intensiveness was actual felt after performing the exercise set – namely whether the chosen weight was too heavy or too light.

Most of the time, as stated above, ID 1 estimated his RPE value similar to his felt exertion values during the time when the textual representation was showing the RPE comparison. As there are many exact matches this might indicate a good body feeling and proper estimation of PRE values. Furthermore, this estimate may also fit with the answer provided by ID 1 on how well he thought he could estimate his RPE values. A higher fluctuation occurred for ID 2, for whom only one-third of the estimated RPE values matched with the felt physical exertion, during the time when the graphical representation was showing the RPE comparison. Interestingly, ID 2, with a value of 8, rated himself better than ID 1 did in estimating the RPE values. For ID 2, we also saw three more significant deviations for training sets 7, 10 and 21, for which the deviation value was 1.5 or higher. For two of those big deviations, it was an overestimation, meaning that ID 2 overestimated his strength on those particular days. We also see that ID 2 often had for one set an overestimation and for the next set an underestimation. This high fluctuation between over- and underestimation might indicate that ID 2 wanted to countermeasure the non-matching RPE values after seeing the RPE comparison, which was in the case of ID 2 in weeks 1 and 2 of the graphical PRE representation. In conclusion, ID 1 had more exact matches between these two RPE values than ID 2 in the first two weeks, as shown in Figure 6.1. During this time, the RPE comparison was displayed with the textual representation for ID 1, which might indicate a preference for comparing these two RPE values by a textual representation approach. Interestingly, ID 1 stated during the interview a preference for the graphical representation which does not underline the observed results.

6.1.2. *RPE Estimated* versus *RPE Velocity*

Since the *RPE Velocity* value is calculated based on the mean velocity of the last set, it can indicate how exerting a set was. This means that comparing the estimated RPE value with the calculated one, could show if the athlete trained in the exact desired load range or not.

By having looking at the similarities from the results from ID 1 and ID 2 for this comparison, one can see that ID 2 had more RPE deviations of 0.5 than ID 1, as visualized in Figure 6.2. ID 1 had also twice an RPE deviation of 1.5 and multiple times a deviation of one RPE value, whereas ID 2 had only twice an RPE deviation of one value. All the other comparison values of ID 2 where either of a 0.5 deviation or an exact match of *RPE Estimated* and *RPE Velocity* values, which might indicate a better planning of the weights and physical exertion for ID 2. Hence, ID 2 estimated his RPE values better than ID 1 when comparing them to the actual rated RPE value.

ID 1 could reach only four exact matches in the first two weeks out of 23 training sets, whereas ID 2 had 11 exact matches. These very good results from ID 2, might indicate a positive affect and a preference for the graphical representation of RPE values. The representation of the two RPE values by a bar chart might had helped ID 2, to better estimate how exerting the future training set would be. Although, ID 2 mentioned during the interview no preference for any of the two representation approaches the RPE comparison results are substantially better than ID 1, which started with the textual representation, for this comparison.

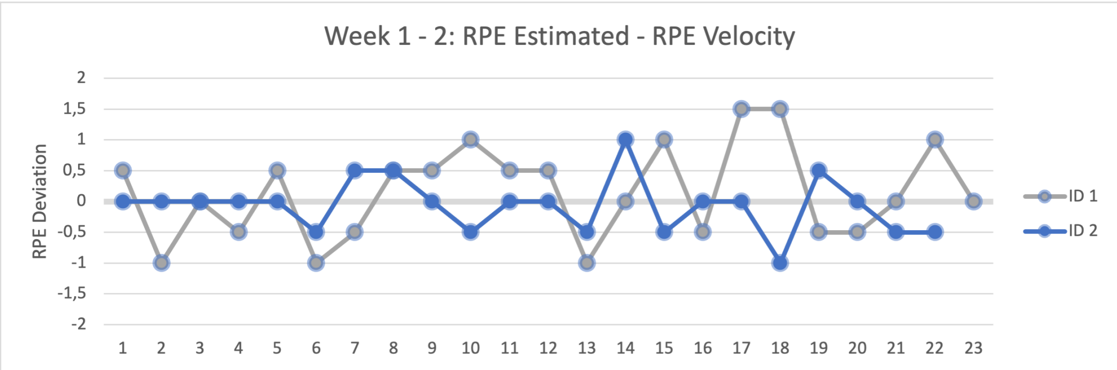


Figure 6.2.: Line graph displaying the *RPE Estimated* versus *RPE Velocity* comparison values for ID 1 (grey) and ID 2 (blue) of the first phase of the evaluation. The RPE comparison was shown in textual representation for ID 1 and in the graphical representation for ID 2 during this phase.

6.1.3. *RPE Actual* versus *RPE Velocity*

The comparison of *RPE Actual* value and *RPE Velocity* value provides information on whether the actual exertion feeling of the athlete matches the exertion based on the mean velocity of the last repetition of the performed training set. Athletes often think that sets were remarkably heavy when they were not, or vice versa. Since the mean velocity of the last repetition can be used to identify exertion, as argued by Weakly et al. [WMB+20], this comparison could show how well the athletes' feeling matches their actual mean velocity.

Figure 6.3 shows that ID 1 could reach 5 exact matches whereas ID 2 could reach 7 exact matches for this comparison type. ID 1 underestimated himself overall quite as one can see that 12 sets were estimated more exerting than the mean velocity of the last repetition of each set suggested. ID 2 had a mix of under and over estimations. Multiples sets behind each other revealed a significant difference twice, as in the case of set 10, which had a deviation of -1.5, and training set 11, with a deviation of +1. This might indicate a countermeasure of ID 2 after experiencing the significant deviation of training set 10. Since the weight of training set 11 was heavier than for set 10, one explanation could be inattention during the execution of set 10 or more attention and focus for set 11. Similar to ID 1, ID 2 could only reach eight exact matches of the RPE values.

Overall, ID 2 performed slightly better than ID 1, but still only mediocre as more than half of the estimations were not exact matches. ID 1 mostly underestimated themselves since most of the deviations of the RPE values were above 0. ID 2 could also not reach many exact matches and had also twice high deviations of -1.5. Based on these observations no preference for any of the two representation approaches can be identified, as both test persons performed quite similarly with mediocre performance.

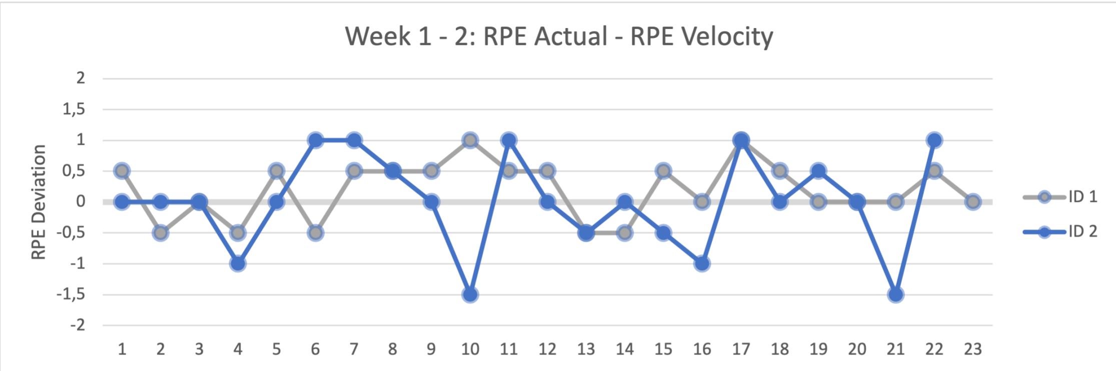


Figure 6.3.: Linear graph displaying the *RPE Actual* versus *RPE Velocity* comparison values for ID 1 (grey) and ID 2 (blue) of the first phase of the evaluation. The RPE comparison was shown in textual representation for ID 1 and in the graphical representation for ID 2 during this phase.

6.1.4. Comparison of week 3 and week 4

At the start of the second part of the evaluation, the RPE comparison representation changed to either the textual or graphical representation for each test person, depending on which representation was present during the first two weeks. Specifically, for ID 1, the textual representation changed to the graphical representation, and for ID 2, the graphical representation changed to the textual representation. By comparing the graphs of the second half of the evaluation, a better match of the values can be seen, which could indicate that the representation no longer matters after two weeks of training, and the results become increasingly similar. Additionally, no deviation greater than an RPE value of 1 could be observed. The comparison of *RPE Actual* and *RPE Velocity* values for the second two weeks shows relatively more exact matches and fewer considerable deviations for both athletes. Furthermore, concerning the comparison of *RPE Estimated* and *RPE Velocity*, better results can be seen compared to the results from the first two weeks, which might indicate a positive learning effect throughout the second half of the evaluation, regardless of the present RPE comparison's representation. The graphs for week 3 and week 4 can be found in the Appendix in Section A.0.3.

6.1.5. Interpretation of comparisons

Overall, one can see a better performance of ID 2 in comparing *RPE Estimated* and *RPE Velocity* than ID 1. ID 1, who started with the textual RPE comparison representation, could only reach quite good results when comparing *RPE Estimated* and *RPE Actual* values, which means that the planned exertion matched the actual felt exertion frequently. Nonetheless, both values often did not match the exertion suggested by the mean velocity. Hence, the for the remaining two RPE comparison only few matches were performed. These observation might indicate, that the textual representation of the RPE comparison could not help ID 1 to improve the RPE estimations. This observation is strengthened when investigating the results from the second two weeks from ID 1, in which the graphical representation was present.

As mentioned before, ID 2 had remarkable results during the first two weeks when comparing *RPE Estimated* and *RPE Velocity*. The ID 2's planned exertion values often matched the exertion based on the mean velocity of the sets' last repetition. Interestingly, the *RPE Actual* values from ID 2 fluctuated more, indicating that many sets felt heavier or lighter than the planned exertion and the exertion based on the mean velocity. As ID 2 performed well in the comparisons between *RPE Estimated* against *RPE Velocity* during the first phase of the evaluation, the graphical representation could have helped ID 2 for rating the *RPE Estimated* values. Since, ID 2 performed mediocre for the comparisons in which the *RPE Actual* value was rated, no positive affect of the graphical representation on rating the *RPE Actual* values can be observed, after analyzing the first two weeks only.

Summarizing the results for the representation approaches from the first two weeks, one can see that with the textual representation only acceptable results were reached by ID 1 when it comes to comparing *RPE Estimated* and *RPE Actual* values. By representing the RPE comparison with the graphical approach, remarkable results were reached by ID 2 for the comparison of *RPE Estimated* and *RPE Velocity* values. Although the results of ID 2 for the first comparison, which are displayed in Figure 6.1, were not matching often, ID 2 could reach mediocre results for the third comparison type. Overall seen were the results of the RPE comparisons during the first two weeks slightly better from ID 2, for whom the RPE comparison was shown with the graphical representation.

However, by analysing the comparison of *RPE Actual* and *RPE Velocity* values of weeks 3 and 4, good results can be observed for both athletes. Comparing the first and second phases of the evaluation, one can also notice better results for the second phase for both athletes' overall comparisons, which might indicate that after two weeks, the athletes got better and better in estimating their actual exertion after performing their training sets.

As this improvement can be observed for both athletes, its effect seems to be independent of the RPE comparison's representation. We observed a better performance when the graphical representation was visual during the first two weeks, but both athletes performed similarly well during the second two weeks. Hence, the graphical representation could already improve the RPE ratings at the beginning. Additionally, after two weeks of using VBT, the estimation of the RPE value seems to have improved independently of the RPE-value representation.

6.1.6. Interpretation of the interviews

Since the number of test persons was low, more information was gathered through an interview with them. Specifically, predefined qualitative questions were asked on learning methods, usability, ability to estimate physical exertion and how the REP comparison representations were perceived.

ID 1 expressed a preference for graphical data representation. When asked with which representation they could estimate themselves better, ID 1 stated that he noticed a better feeling with the graphical representation. Especially for ID 1, a better comparison between *RPE Actual* and *RPE Velocity* in week 3 and week 4 can be observed in which the RPE representation was changed to the graphical approach. This observation may also relate to ID 1's claim that a better feeling was present with the graphical value representation. Another remark supporting this statement is that ID 1 also mentioned generally having a better feeling of estimating RPE values after this VBT evaluation.

ID 2 found no noticeable difference between the representations. By looking at the results from the first and the second part, it can be seen that no huge difference in the number of exact matches and deviations is present for ID 2, which also supports his statement. ID 2's answer to the question 'Do you think you can estimate your RPE values now better than before?' was 'No', which also underlines his statement. At any rate, the results relative to the *RPE Estimated* and *RPE Velocity* were already good in the first two weeks.

In addition to feedback on the value representations, the tool and the test persons' user experience were also discussed. The goal was to identify if issues were popping up which would have influenced the test persons in their perception of the RPE comparison representations, how the other features were perceived by them and which improvements would be good to be implemented.

Both test persons liked the automatic filling of the RPE-repetitions table. Although it helped ID 2 in choosing the training weight, he reported a certain amount of pressure by seeing this information, especially due to the fact that, according to the table, he had to be able to perform a certain weight at a certain exertion. Nonetheless, according to ID 2, it was also motivating to see what the exact 1-RM would be on particular days. This possible pressure could have also affected ID 2 in estimating the *RPE Estimated* value, as according to the table a certain exertion is suggested for the weight - repetition combinations.

In addition to the mentioned aspects, ID 1 also explored the goal feature in the profile view, which is a nice usability feature but did not affect any RPE estimation nor how the RPE comparison representation was perceived, according to them. The representation of the personal records for the three powerlifting exercises at the home screen, was reported to be a remarkable feature to stay motivated and to see what the best-estimated maximum would be. Additionally, the possibility to enter the actual personal records from a powerlifting competition was valued as appropriate, as it would allow spotting the difference between the actual best performance and the best training performance. As stated by ID 1, this extension would be appropriate. One shortcoming mentioned by both test persons, was the handling between sessions and training sets. Since the RPE comparison representation was shown for each training set, this shortcoming could have had an influence on the test persons perception of the representations. However, after the first two training sessions, they got used to the handling.

Overall, the evaluation phase was well received by both athletes, who expressed a preference for including a VBT tool in their current training to obtain better feedback. The only shortcoming which was mentioned, was the handling between training session and training set objects. Nevertheless, after a few training sessions they got used to it. A preference for the graphical representation was mentioned by ID 1. This statement can also be underlined by the RPE comparison values, as ID 1 had better comparison values during week 3 and week 4, in which the graphical representation was present. In contrast to ID 1, ID 2 found no noticeable difference between the two representation approaches and stated therefore no preference. Also no big difference in the number of exact matches and deviations is present for ID 2 when comparing the first two weeks with the second two weeks. However, it worth mentioning that ID 2 had already good comparison values during the first two weeks, in which the graphical representation was present.

Besides from these observations, both saw an advantage by using not only the mean velocity of a training set but also combining it with their known exertion scale. Since the PUSH Band was straightforward, both athletes could imagine using such it in the future. The only discouraging element is the current price of around 400 Euros, which is still too much to them for purchasing the tool. In conclusion, both athletes recommended using a VBT tool since it was fun to use and benefited their strength training.

6.1.7. Summary

In summary, the research question can be answered the following way, based on the gathered information from the RPE comparisons and the interviews:

1. *Which representations do powerlifters prefer for their RPE-based strength training?*

   A preference for the graphical representation of RPE values can be inferred, based on the feedback on the qualitative questions and the analysis of training data, which was gathered during an evaluation phase, which lasted four weeks for each of the two participating powerlifters.

2. *How can representations help to improve RPE-values estimations?*

   Representations can help to improve the RPE-values estimations, by representing the RPE values of previous training sets in a way, so that the athletes can clearly see how the differences between the estimated exertion, the felt exertion and the exertion based on the mean velocity of the last repetition are. A slight improvement in estimating RPE values after two weeks of training and viewing the RPE comparison in either textual or graphical way, was observed. Hence, both, textual and graphical representation of RPE values, can help to improve the RPE-values estimation.

6.2. Limitations

In training, especially strength training, it takes much time to improve. In addition to hard work, also consistency is one key factor for improvement. Powerlifting is a sport of maximal strength, which requires the right training technique to prevent injuries and use the maximum strength to lift the highest weight. Therefore, training experience and supervised training are needed to be able to perform the lifts with the desired technique.

Good technique is also crucial to benefit from VBT. If the technique differs from the athletes' specific technique, the mean velocity may be higher due to a technique deviation.

Therefore, test persons were required who could perform the three evaluated exercises with good and consistent technique, which also conforms to the rules from the IPF. Additionally, specific training experience and strength were also crucial to the selection of the test persons. In the case of the two test persons, both could perform each of the three exercises easily with their body weight. Furthermore, due to the COVID-19 crisis, fitness centres or gyms were closed, leading the test persons to find the process harder since they had to have the needed equipment available in their homes to perform their training.

Since the evaluation needed as much training data as possible, it was acceptable to train each competition exercise once a week for both test persons. Although both of them were training four times per week, maybe more data could have been gathered for each exercise if trained more often. As both persons preferred to continue with their current training plan, which included each exercise only once a week, their request was accepted. Furthermore, training high-effort exercises, such as the deadlift, three or more times per week is not recommended since much physical effort is needed to perform the sets properly, and rest periods are needed to prevent injuries.

Another limitation for the evaluation was the availability of VBT devices, which was the PUSH Band 2.0. Although this tool is much cheaper than classic linear transducer devices for VBT, the price of 400 Euros is still high. Therefore, only one device was bought for this evaluation, which led the evaluations with the test persons to be conducted one after the other instead of in parallel. Hence, the whole evaluation phase took eight weeks. As the device was made in Canada, the shipment process also took longer than expected. After the device arrived, another disadvantageous circumstance occurred, as it broke after the third training session. Luckily, the manufacturer sent a working device within the following two weeks.

6.2.1. Lessons learnt

In addition to the mentioned limitations also some lessons learnt were identified. Since the mean velocity was measured by an external commercial tool, the PUSH Band 2.0, the whole measurement process depended on this tool. Unfortunately, two days before starting the evaluation, the received device no longer worked. Hence, the evaluation with test person 1 was postponed by two weeks until a working device was received. One lesson learnt from this instance is that relying on external tools or devices poses risks, as they may break down during evaluation phases.

Another lesson learnt was identified during the collection of the answers for the qualitative questions. Since rating one's exertion is highly subjective, it might be affected by the athlete's mood. Hence, a rating or an evaluation of the test persons' mood might have been interesting. Nonetheless, during the interview following the test phase, both athletes stated not having had any noticeably different moods or felt any physical restrictions during their sessions.

A third lesson learnt concerned the number of test persons who participated in the evaluation. Since only two persons participated, the results might vary if the evaluation would have been done with more participants. To gain more insight and further feedback, the number of participants and that of available tracking devices should be increased.

7. Conclusion and Future Work

Physical exertion is felt by each person very individually. In strength training, and especially in powerlifting, rating one's perceived exertion is a standard method to measure intensiveness. VBT brings objectivity to identifying intensiveness. Through the mean velocity of the last repetition of a training set, the intensiveness of a set – namely, how exerting it was – can be interpreted. Combining the subjective RPE and the suggested intensiveness based on the mean velocity of the last repetition from a training set can improve strength training.

Comparing the objective feedback from the mean velocity to the subjective rating from the athlete can provide information about how well the athlete can rate themselves. The representation of this information is essential. To understand how representation of certain values might influence the viewer, the following research questions were investigated:

1. *Which representations do powerlifters prefer for their RPE-based strength training?*
2. *How can representations help to improve RPE-values estimations?*

Training data was gather for four weeks for each of the two athletes. Within these four weeks three RPE values were tracked for each training set: the expected exertion, the felt exertion and the exertion based on the mean velocity of the last repetition of a set. Since the evaluation phase took four weeks per athlete and two representation approaches were investigated, the RPE comparison was displayed for two weeks with each representation. The two investigated representations of the RPE comparison of the three RPE values, were on the one hand a textual representation and on the other hand a graphical representation. The two representation approaches were described in detail in Subsection 3.2.6.

Both athletes used a self-developed Android prototype application called *Barbellocity*, which was initially developed as part of the *LP Praktikum 2* and was extended as part of this thesis. This application was used to track the athletes' training sets and exertion ratings.

As part of the training workflow the expected and felt exertion were entered manually by users based on their feeling, and the exertion, based on the mean velocity of the last repetition, was calculated according to the basics of VBT. Since the mean velocity had to be measured, a commercial device, the PUSH Band 2.0, was used for calculating the mean velocities.

To understand which representation would be preferred and how the representations of values can improve RPE value estimation, the different RPE comparison results of each test person were analyzed. The three RPE values were compared and interpreted according to the current representation for each set. The results showed that test person 2, who started in the first two weeks with the graphical representation, performed considerably well. Good comparison value for the *RPE Estimated* against *RPE Velocity* and for *RPE Actual* against *RPE Velocity* comparisons was observed for test person 2.

In addition to this evaluation phase, qualitative feedback was gathered from the test persons. The qualitative feedback showed a preference for the graphical representation of test person 1. Test person 2 was not stating any preference on the representation of the RPE comparison. Test person 1 also claimed to feel better at estimating his RPE values. After evaluating and comparing the gathered training data and the feedback to the qualitative questions, a preference for graphical data representation can be inferred, as well as positive feedback on combining VBT with a rating of the perceived exertion. Therefore, the graphical representations of the rating of perceived exertion values are recommended to improve the RPE value estimation. Another observation was made when investigating test week 3 and week 4. As a result, no difference was identified between the comparison values of the two test persons since both persons improved their RPE ratings. Therefore, it seems that after two weeks of using VBT, the estimation of the RPE value can improve independently of the RPE-value representation.

Moreover, a possible benefit of the combination of VBT and RPE-based training, especially for athletes with excellent technique and training experience, was identified from the qualitative feedback of the test persons.

Unfortunately, the evaluation was limited by time frame, number of available VBT tools and due to the current COVID-19 crisis and closed fitness centres. Therefore, the following potential improvement points for future work were identified:

- Increasing the number of test persons.
- Using additional representation approaches.
- Using LPTs to measure mean velocity, thus obtaining more exact results.

Performing evaluations with the above-mentioned points being considered provide a better recommendation about which representation fits best for strength training, especially for powerlifting, as well as how the benefit can be maximized. Therefore, performing similar evaluations with a higher number of test persons would be desirable for future work. Moreover, additional representation approaches would provide more feedback about what might help powerlifters during their strength training.

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A. Appendix

A.0.1. Introduction text

Preliminary Study

The system *Barbellocity* is a smartphone application prototype with which the three competition lifts in powerlifting can be tracked. Additionally, a smartwatch is faking the process of measuring the velocity at which the barbell gets lifted. The target of the system is to suggest based on the mean velocity a RPE value. The smartwatch application is used to start a set and to fake measure the mean velocity. After execution the mean velocity result will be displayed at the smartphone prototype. In addition to suggestion RPE values, the prototype consists of many other features which shall make the tracking of one's performance easier.

Evaluation

Barbellocity - Application: The system *Barbellocity* is a smartphone application prototype with which the three competition lifts in powerlifting can be tracked. At the very beginning it is needed to create the load-velocity profile for each exercise, so the RPE values can be later suggested based on the entered mean velocity. How to create a load-velocity profile is guided through a tutorial mode within the application. The system supports the repetition range from 1 to 8 and a RPE range from 7 to 10, whereas RPE values below 7 can be marked as <7.

PUSH - Application: Through the PUSH Band 2.0, the mean velocity can be measured for each repetition of a training set. The result is displayed at their own developed application. How this application can be used is described on the following website: How to PUSH.

Procedure (Load-Velocity Profile created): Procedure (load-velocity Profile created): For each day and exercies one training session can be created, which clusters the training sets for that exercise. To create a training set, the weight, the number of repetitions and the estimated RPE value need to be entered. Afterwards the training set shall be performed and the mean velocity be measured with the PUSH Band V2.0. Right after that, the *RPE Actual* value should be defined. This value has to be defined before checking the mean velocity at the PUSH application, as the mean velocity might influence the definition of the felt exertion. Finally, the *RPE Actual* vale and the mean velocity of the last repetitions shall be entered in the *Barbellocity* application and the training set be locked. Now a *RPE Velocity* should be displayed.

A.0.2. Test case description of the preliminary study

Test case 1

As a new user you want to sign up in the *Barbellocity* application. Afterwards you want to log out and once again log in.

Test case 2

As a goal oriented athlete, you are setting yourself goals everyday. Also in the application you want to define a *1 RM goal* and a *RPE-Weight goal*.

Test case 3

Since you set yourself now some goals you are ready to get started. You want to start a first deadlift set with the smartwatch which fakes your mean velocity measurement. After this definition you are faking the movement of the deadlift exercise. Finally, the results are displayed which you want to view in the smartphone application.

Test case 4

Since you identified your physical exertion to of the value 8, you are entering this value but also correcting the weight, as it was chosen wrongly. At the end you are locking the set. By doing so, the mean velocity is used to suggest an RPE value which shall be displayed now at the training set view.

A.0.3. Linear graphs of Comparison Results from Week 3 & Week 4

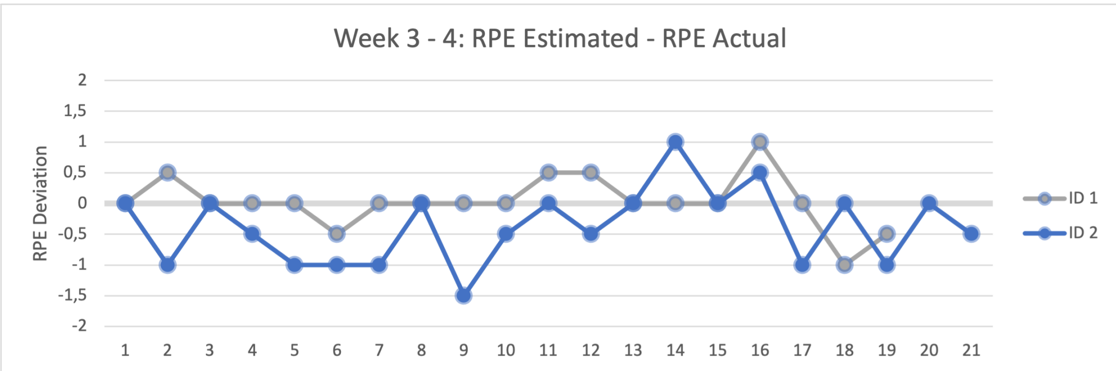

Figure A.1.: Linear graph displaying the *RPE Estimated* versus *RPE Actual* comparison values for ID 1 (grey) and ID 2 (blue) of the second phase of the evaluation.

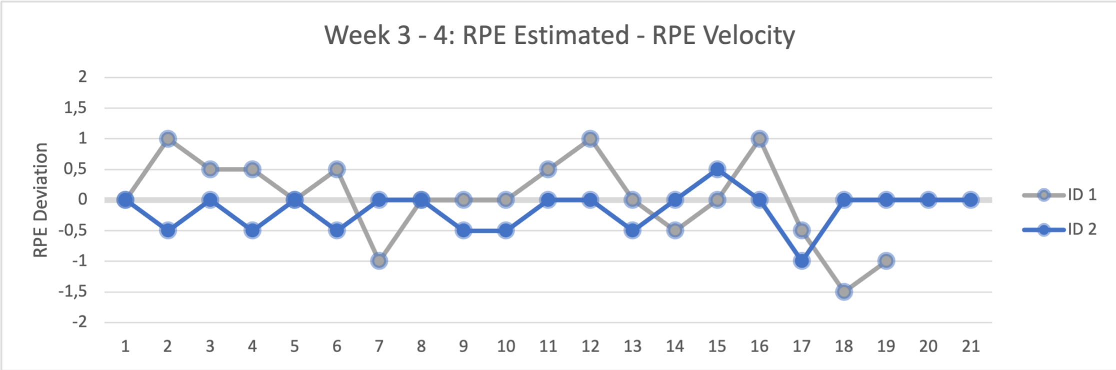

Figure A.2.: Linear graph displaying the *RPE Estimated* versus *RPE Velocity* comparison values for ID 1 (grey) and ID 2 (blue) of the second phase of the evaluation.

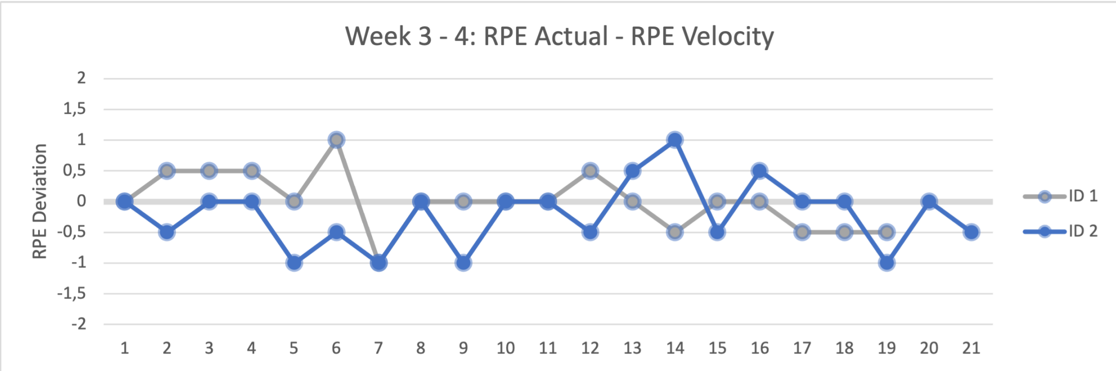

Figure A.3.: Linear graph displaying the *RPE Actual* versus *RPE Velocity* comparison values for ID 1 (grey) and ID 2 (blue) of the second phase of the evaluation.

A.0.4. Training data of ID 1 and ID 2

Week	Type	#	Weight	1	2	3	1 vs 2	1 vs 3	2 vs 3
1	Squat	4	125	7,5	7,5	7	0	0,5	0,5
		4	125	7,5	8	8,5	-0,5	-1	-0,5
		4	120	8,5	8,5	8,5	0	0	0
	Bench	2	105	9	9	9,5	0	-0,5	-0,5
		2	95	8	8	7,5	0	0,5	0,5
		4	90	7	7,5	8	-0,5	-1	-0,5
		4	95	8,5	9,5	9	-1	-0,5	0,5
		4	90	8	8	7,5	0	0,5	0,5
	Deadlift	4	120	7	7	6,5	0	0,5	0,5
		4	127,5	7,5	7,5	6,5	0	1	1
		4	127,5	7	7	6,5	0	0,5	0,5
		4	120	7	7	6,5	0	0,5	0,5
2	Squat	6	120	8	8,5	9	-0,5	-1	-0,5
		6	120	9	8,5	9	0,5	0	-0,5
		6	115	9	8,5	8	0,5	1	0,5
	Bench	6	82,5	7	7,5	7,5	-0,5	-0,5	0
		6	87,5	9	8,5	7,5	0,5	1,5	1
		6	90	9	8	7,5	1	1,5	0,5
		6	90	9	9,5	9,5	-0,5	-0,5	0
	Deadlift	6	117,5	6,5	7	7	-0,5	-0,5	0
		6	125	7	7	7	0	0	0
		6	125	7,5	7	6,5	0,5	1	0,5
		6	120	6,5	6,5	6,5	0	0	0

Week	Type	#	Weight	1	2	3	1 vs 2	1 vs 3	2 vs 3
3	Squat	5	115	6,5	6,5	6,5	0	0	0
		5	120	7,5	7	6,5	0,5	1	0,5
	Bench	6	82,5	7	7	6,5	0	0,5	0,5
		6	90	9	9	8,5	0	0,5	0,5
		6	90	9	9	9	0	0	0
		6	87,5	8	8,5	7,5	-0,5	0,5	1
	Deadlift	5	122,5	7	7	8	0	-1	-1
		5	130	7	7	7	0	0	0
4	Squat	5	100	6,5	6,5	6,5	0	0	0
		4	120	6,5	6,5	6,5	0	0	0
		4	125	7	6,5	6,5	0,5	0,5	0
		4	125	7,5	7	6,5	0,5	1	0,5
		4	120	6,5	6,5	6,5	0	0	0
	Bench	6	80	7	7	7,5	0	-0,5	-0,5
		6	87,5	9	9	9	0	0	0
		6	85	8	7	7	1	1	0
	Deadlift	4	127,5	6,5	6,5	7	0	-0,5	-0,5
		4	135	7	8	8,5	-1	-1,5	-0,5
		4	135	7,5	8	8,5	-0,5	-1	-0,5

Table A.1.: Training data of ID 1

Week	Type	#	Weight	1	2	3	1 vs 2	1 vs 3	2 vs 3
1	Squat	3	145	6,5	6,5	6,5	0	0	0
		3	150	6,5	6,5	6,5	0	0	0
		3	150	6,5	6,5	6,5	0	0	0
		3	145	6,5	6,5	7,5	-1	0	-1
	Bench	7	92,5	7	7	7	0	0	0
		7	97,5	9	9,5	8,5	0,5	-0,5	1
		7	95	8	7,5	6,5	1,5	0,5	1
		7	95	8	7,5	7	1	0,5	0,5
	Deadlift	3	160	6,5	6,5	6,5	0	0	0
		3	172,5	7	7,5	9	-2	-0,5	-1,5
		3	180	8	8	7	1	0	1
2	Squat	6	142,5	8,5	8,5	8,5	0	0	0
		6	150	8,5	9	9,5	-1	-0,5	-0,5
		6	150	9,5	8,5	8,5	1	1	0
		6	142,5	8,5	9	9,5	-1	-0,5	-0,5
	Bench	6	95	7	7	8	-1	0	-1
		6	102,5	9	9	8	1	0	1
		6	102,5	9	10	10	-1	-1	0
		6	95	8	7,5	7	1	0,5	0,5
	Deadlift	3	160	6,5	6,5	6,5	0	0	0
		3	172,5	7	7,5	9	-2	-0,5	-1,5
		3	180	8	8,5	7,5	0,5	-0,5	1
3	Squat	4	142,5	6,5	6,5	6,5	0	0	0
		4	147,5	6,5	7	7,5	-1	-0,5	-0,5
		4	147,5	6,5	6,5	6,5	0	0	0
		4	142,5	6,5	7	7	-0,5	-0,5	0
	Bench	6	90	7	7	8	-1	0	-1
		6	95	7,5	8	8,5	-1	-0,5	-0,5
		6	95	8	8	9	-1	0	-1
	Deadlift	4	160	6,5	6,5	6,5	0	0	0
		4	170	6,5	7	8	-1,5	-0,5	-1
		4	177,5	8	8,5	8,5	-0,5	-0,5	0
		4	177,5	8	8	8	0	0	0
4	Squat	1	160	6,5	6,5	7	-0,5	0	-0,5
		3	152,5	7	7,5	7	0	-0,5	0,5
		3	152,5	7,5	7,5	6,5	1	0	1
		3	152,5	7	6,5	7	0	0,5	-0,5
	Bench	6	95	7	7	6,5	0,5	0	0,5
		6	102,5	9	10	10	-1	-1	0
	Deadlift	1	185	7	7	7	0	0	0
		3	172,5	7	7	8	-1	0	-1
		3	172,5	7,5	7,5	7,5	0	0	0
		3	172,5	7	7	7,5	-0,5	0	-0,5

Table A.2.: Training data of ID 2

where:

#	= Number of repetitions
1	= *RPE Estimated*
2	= *RPE Actual*
3	= *RPE Velocity*
1 vs 2	= RPE Estimated compared to RPE Actual
1 vs 3	= RPE Estimated compared to RPE Velocity
2 vs 3	= RPE Actual compared to RPE Velocity