The Influence of Biofeedback on Exercise Correctness and Muscle Activity

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Abstract. This paper examines the effect of an electromyography (EMG) biofeed back fitness application, and its potential to improve resistance training and exercise execution using the measure of muscle activity. To examine this, an application was built and tested using biceps curl as the reference exercise. The participants were divided into three conditions: the first condition did not receive any feedback, the second condition received feedback from a personal trainer, and the last used the feedback presented by the application. The focus is to investigate the participant's ability to activate muscle fibres in the biceps, and improve the execution in regards to minimising the shoulder involvement over three sets. The results of the study do not provide any statistically significant improvements using biofeedback versus no feedback. However, the participants with the applicational support, as well as the participants within the personal trainer condition, show a slight improvement on the visual correctness of the exercise execution. The lack of statistically significance, important observations and indications are discussed.

Keywords: Biofeedback · EMG · Exercise correctness · Fitness Muscle activity

1 Introduction

The Danish board of health recommends that the average person should perform approximately 30 min of moderate physical activity a day, reason being that physical activity is essential to maintain an adequate personal health [1]. However, encouraging people to perform physical activity, such as strength training, is difficult, since it requires general knowledge on how to perform a certain exercise and what exercise to choose in order to improve a personal weak area [2–4]. It is therefore important to find new effective ways to provide people with the right information on fitness and health.

The technological advancement regarding health information and fitness technology, such as heart rate monitors, step counter, exercise trackers, fitness and health apps, etc., have become more accessible to the public. Studies have shown that fitness and health technology have the potential to improve physical health, and increase healthcare awareness with the use of fewer resources [5–8]. However, many of these applications and technologies have deficiencies and limits, because they are not based on behavioural theories and guidelines from the medical and health industry [5, 6]. In

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the field of rehabilitation and strength training, studies have shown that the use of biofeedback technology can significantly improve the health and mobility of people suffering from brain injury, cerebral palsy and stroke [9–11]. To this end, in the field of sport science, fitness and health technology, more specifically electromyography (EMG), is used to determine the effectiveness of a certain movement or exercise in muscle activity science [12–15].

This paper hypothesise: *an EMG-based biofeedback fitness application can improve exercise execution correctness and muscle activity during strength training in comparison to conventional training*. This research will verify this hypothesis by developing and evaluating an EMG-based fitness application. The evaluation will be conducted by comparing the effectiveness of the EMG application versus conventional instructions on a specific strength training exercise.

2 Theoretical Background

This section presents general theory of physical strength training and an explanation of EMG and its means of use.

2.1 Strength Training

When developing an application, which uses EMG feedback to evaluate muscle activity and exercise correctness, it is critical to understand the physiology during strength training, in order to understand the feedback provided by EMG.

Strength training is defined as the process of breaking and rebuilding muscle tissue. When an athlete is actively performing strength training, they are inflicting a form of stress on themselves both physically and mentally. The body's reaction to this stress is to adapt by reshaping and rebuilding muscle, which can withstand this impact [16, 17]. During heavy strength training, the chemical environment of the muscle changes through the process of energy stores depletion and lactic acid accumulation, which gives the feeling of fatigue. This, alongside the breakdown of muscle tissue, is what provides the body with the signal to improve from its current state [17].

A human consists of a frame (the skeleton) which becomes mobile through the functions of the muscles. All human movement is usually triggered by a contraction of one or several muscles. When a muscle, or muscles, contract, it creates a force which affects the relevant bones and creates movement in that specific part of the body [17]. This contraction happens due to the internal structure of the muscles and the function of the neuromuscular system.

The muscle is a highly complex tissue, consisting of muscle fibres, which can contract and expand depending on the signal received from the brain. The muscle fibres are connected by connective tissue, such as tendons and ligaments, which makes up the elastic components of the muscle [16, 17]. After a long period of strength training one would see an increase in the amount of fibres and cross-sectional area and volume, which is referred to as hypertrophy.

A muscle needs a signal from the brain to active a contraction, this process is handled by the neuromuscular system. The neuromuscular system is built from the muscles themselves and the central nervous system. When a simple movement has to be made, the brain sends an impulse through the nerves to a giving motor neuron, which then activated the contraction of the muscle fibres. The speed, in which the motor neuron can activate the synchronisation of the muscle fibres, is what determines the force developed [16]. When doing a specific strength training exercise, the correct muscle activation and force developed is essential in order to perform the exercise properly. The muscle contractile force depends on the intensity and frequency of nerve impulses to be sent to the muscle. Thus, the ability to develop muscle power depends on both neural, muscle structural and biomechanical properties [16]. The intensity of a nerve impulse from the motor neurons, and the contractile force, is what can be measured by EMG.

2.2 Electromyography

Electromyography (EMG) is the study and evaluation of the electrical potential of the muscles and nerves, and is the foundation behind electro diagnostic medical consultation [12–15]. Through EMG it is possible to obtain information about the activities within the muscles and nerves, and it is mostly used in the medical field to determine nerve or muscle damage, and in sports medicine to investigate muscle activity during movement [12, 13]. EMG provides easy access to the physiological processes, which generates force within the muscles and produce movement.

The electrical signal conducted by the muscle tissue is called Muscle Unit Action Potential (MUAP) and can be detected by the electrodes in the muscles or on the surface of the skin. The MUAP is a depolarisation of the motor neuron, which occur when the central nervous system sends a signal to contract a given muscle. This depolarisation passages along the muscle fibres and produces an electrical wave which can be detected by the recording electrodes [13, 15]. When using a two-electrode EMG system, the MUAP is represented by a triphasic signal, which is the potential difference between pole A and B (see Fig. 1).

There are several factors that can influence the quality of the signal detected by the electrodes, of which some can be controlled by the user, i.a., the placement of the electrodes, the distance between the recording electrodes, orientation in regards to muscle fibres and the type of used electrodes [13, 14]. Furthermore, one of the electrical factors that can influence the fidelity and signal is the noise-to-signal ratio. This factor is the ratio between the amplitude of the EMG signal and the amplitude of the noise signal. The noise signal is defined as the signal which is not a part of the EMG signal, such as electrical interference [13, 14]. The EMG signal is relatively low, which means that amplification is needed; here, usually a differential amplifier is used (see Fig. 1). The next step is then to filter the noise from the EMG signal; here, it has been proven effective to use low pass and high pass filters to eliminate the low- and high frequencies [13, 14]. In most cases the signal is rectified and averaged to indicate the EMG amplitude, which indicates the MUAP.

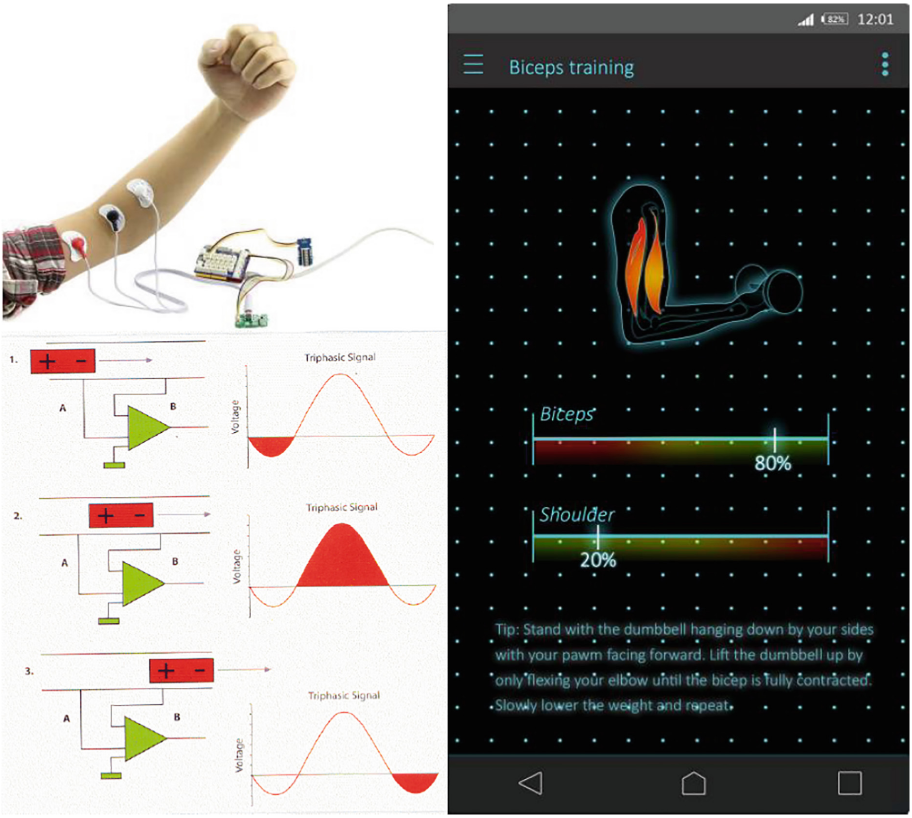

Fig. 1. On the top-left: a Grove EMG Detector sensor connected on a forearm, bottom-left: a differential amplifier generating a triphasic signal, and on the right: the application interface. (Color figure online)

3 Related Work

This section presents related work on the use of EMG feedback in rehabilitation and strength training, similar applications and important findings from related studies.

EMG has a wide range of utility and its use has been proven effectively on biofeedback applications. EMG is often used in sports and exercise studies, where it is a valuable tool to analyse movements, or compare the effect of different exercises on muscle activity, coordination and hypertrophy [18–20]. Bird et al. [19] used EMG to determine what abdominal exercise was most effective when activating the muscle fibres. In the study the EMG activity of the external oblique, upper rectus abdominis and lower rectus abdominis was collected. The data collected from the EMG allowed the investigators to analyse in what phases, concentric and eccentric, the different muscles were active, and conclude that the crunch exercise was overall better than the ab-slide [19]. Similar usages of EMG have been presented in several studies, and prove the overall effectiveness of the EMG for exercise evaluation [18–21].

Also in the field of rehabilitation the EMG has proven an indispensable tool; here, the data being received from the EMG, along with the guidance of a physiotherapist, has proven most effective on the early rehabilitation stages [9–11]. Studies on biofeedback applications and rehabilitation have showed that the use of EMG, as direct biofeedback to the user, has proven highly effective on muscle strength development and range of motion, in post-stroke- and cerebral palsy patients [9–11]. Furthermore, the use of EMG biofeedback and gamification has indicated a higher level of adherence and motivation in comparison to traditional rehabilitation exercises [9, 11]. Common for these studies is the use of EMG presents the user, physiotherapist and investigator with valuable information on the muscle activity during exercises, and the information on how to correctly guide or adjust the exercise to insure the highest amount of MUAP.

Conventional methods for measuring and improving exercise execution involve physiotherapists or personal trainers, who observe and correct the person performing the exercise. This method has proven highly effective and motivating for the user [3, 4]. However, this method has significant deficiencies in cost, accuracy, opportunity, coverage and adherence. A physiotherapist or a personal trainer typically splits their attention among several patients at different locations, which means that the patients or clients have to be self-sufficient at some level. Self-reporting is often used to ensure that the patients or clients execute the exercises themselves. However, this is often inaccurate due to forgetfulness or un- and intentional misreporting, or lack of knowledge on how to perform the exercises correctly [2]. Researches have investigated how to improve this by using wearable sensors to recognise, classify and report activities, and most studies have proved the effectiveness of wearable sensors on activity recognition [22–25]. However, the majority of this research has been conducted in controlled environments with the focus on rehabilitation, and in most cases solely GPS and accelerometers have been used [5, 22–25, 27].

In regards to the realisation outside the scientific field and towards the commercial market, there are many applications created for the purpose of improving fitness and health. Since mobile devices are both highly available and have several sensors that can be used, many application developers have created a vast number fitness and health applications with the purpose of information distribution, exercise libraries, training logging and tracking tools [5, 26, 27]. The state-of-the-art applications mostly use accelerometer and GPS; however, in some cases heart rate monitors and calorie counters are also used [5, 26, 27].

4 Design and Development

In this section decisions behind the application is presented, and the design choices for the interface justified.

The Application. Since the purpose of this application is to provide straightforward and effective biofeedback, and the nature of this study is to observe the effect of such an application, a non-intrusive method of EMG was chosen, also known as surface EMGs.

Since this study aims to prove that biofeedback can improve exercise execution, it is decided that a simplistic exercise should be used. The biceps curl is chosen due to is accessibility to measure, and because it is a simple exercise for conducting movement analysis [16]. The formal description of the biceps curl is [28]:

1. Stand up straight with a dumbbell in each hand at arm's length. Keep your elbows close to your torso and rotate the palms of your hands until they are facing forward. This will be your starting position.
2. Now, keeping the upper arms stationary, exhale and curl the weights while contracting your biceps. Continue to raise the weights until your biceps are fully contracted and the dumbbells are at shoulder level. Hold the contracted position for a brief pause as you squeeze your biceps.
3. Then, inhale and slowly begin to lower the dumbbells back to the starting position.
4. Repeat for the recommended amount of repetitions.

The Interface. Data sliders are used to display the feedback to the user. It is presented by a percentage scale, which is additionally supported by a colour gradient from red to green. The right value of how much the specific muscle should be included, within the executed exercise, is shaded in a green area (see Fig. 1). Furthermore, the application delivers an animated gif, which shows the execution of the exercise. The visualisation is reduced to solely display a human torso and the active muscles in this exercise for simplification, give a good overview, and to prevent information overload [29, 30].

EMG Recording. The physical part of the prototype consists of an Arduino Uno to which an Arduino shield is connected in order to provide direct connectivity to the four pin harness jump wires that are specific to the EMG sensors. Two Grove EMG Detector sensors are applied; one being reserved for the biceps, and the other for the deltoid. The sensors are connected to the muscle through 3.5 mm connector cables, which present three data collection caps. Each cable is connected to three disposable surface electrodes, which are placed on the muscle, so one is situated at the base of the muscle, another at the middle of the muscle, and the last one on a prominent bone, thus grounding the electrical circuit (see Fig. 1).

In this study the software reads the amplitude received from the EMG sensors at 50 Hz, and records the data using PLX-DAQ software. However, an EMG sensor measures noise along with the essential signal. Hence, an exponential moving average (EMA) band pass filter with a low cut-off alpha value of $\alpha_L = 0.3$ and a high cut-off alpha value of $\alpha_H = 0.5$ is implemented:

$$\begin{aligned} L_{co}(t) &= \alpha_L \times x(t) + (1 - \alpha_L) \times L_{co}(t-1) \\ H_{co}(t) &= \alpha_H \times x(t) + (1 - \alpha_H) \times H_{co}(t-1) \end{aligned} \tag{1}$$

Where x(t) is the sensor value at time t, and L_{co} and H_{co} are the low cut-off and high cut-off values, respectively.

5 Methods

For the evaluation of the prototype, each participant underwent two stages: a Max Voluntary Isometric Contraction (MVIC) pre-test and a proof-of-concept test. The tests were conducted in the campus fitness at Aalborg University Esbjerg.

Test Participants and Procedure. For the proof-of-concept test 15 participants volunteered for the test, 12 healthy males and 3 healthy females (age: 23 ± 3 years), all with little to no previous strength training experience. The exercise chosen for this test is the biceps curl, based on its availability for measuring and since this exercise is often miss executed [16, 31]. The electrodes were placed on the biceps brachii short head and the deltoideus posterior, since these are the muscles involved in the exercise. All the participants were assigned to one of three conditions: baseline, Personal Training (PT) and application. The baseline condition group tested the control condition, which means that they had no feedback before or during the exercise execution. The Personal Training condition group had the aid of a personal trainer both before and during the exercise execution, and the application condition had the assistance of the application. To ensure balance between groups, the test participants were artificially allocated into the three condition groups based on the MVIC pre-test, which determined the weight they could execute a single repetition of the given exercise. The MVIC pre-test was conducted by measuring the EMG amplitude generated when lifting a max weight in an isometric contraction.

Assessment. Three sets of eight repetitions had to be completed with a weight equivalent to 40% of their MVIC. The groups underwent a between-groups independent measures design, meaning that none of the participants in a given group A could be part of group B, and each participant tested the exercise individually. Both an inter-group and an intra-group comparison analysis were conducted to investigate if one condition performed better than the others, and to acknowledge any improvement between sets. The recorded data was given in MUAP from the sensors predestined for the bicep and the deltoid, respectively. Each set per individual was recorded in a separate Excel file, and afterwards all three sets were added to a file labelled for the participant.

To analyse and compare the EMG data, the data had to be normalised. Root mean square (RMS) normalisation was used to compare the intra-group and inter-group relations [18]. Since biceps curl is an exercise intended to isolate the biceps and to limit the activation of the front shoulder, the ratio between the two muscles was used, in order to compare.

Expected Results. Based on the literature review, it is expected that the application condition is equal or more effective than the PT condition, and significantly more effective than the baseline condition. Meaning that, the participants testing the application condition would show higher increase in muscle activity through the EMG values, and better exercise execution, than the PT and baseline condition.

6 Results

In this section, the results from the proof-of-concept test are presented (See Fig. 2). The data is checked for normality using Shapiro-Wilks normality test and homogeneity of variance using the Levene's variance analysis test. Next, the data is analysed using the parametric one-way independent analysis of variance (ANOVA).

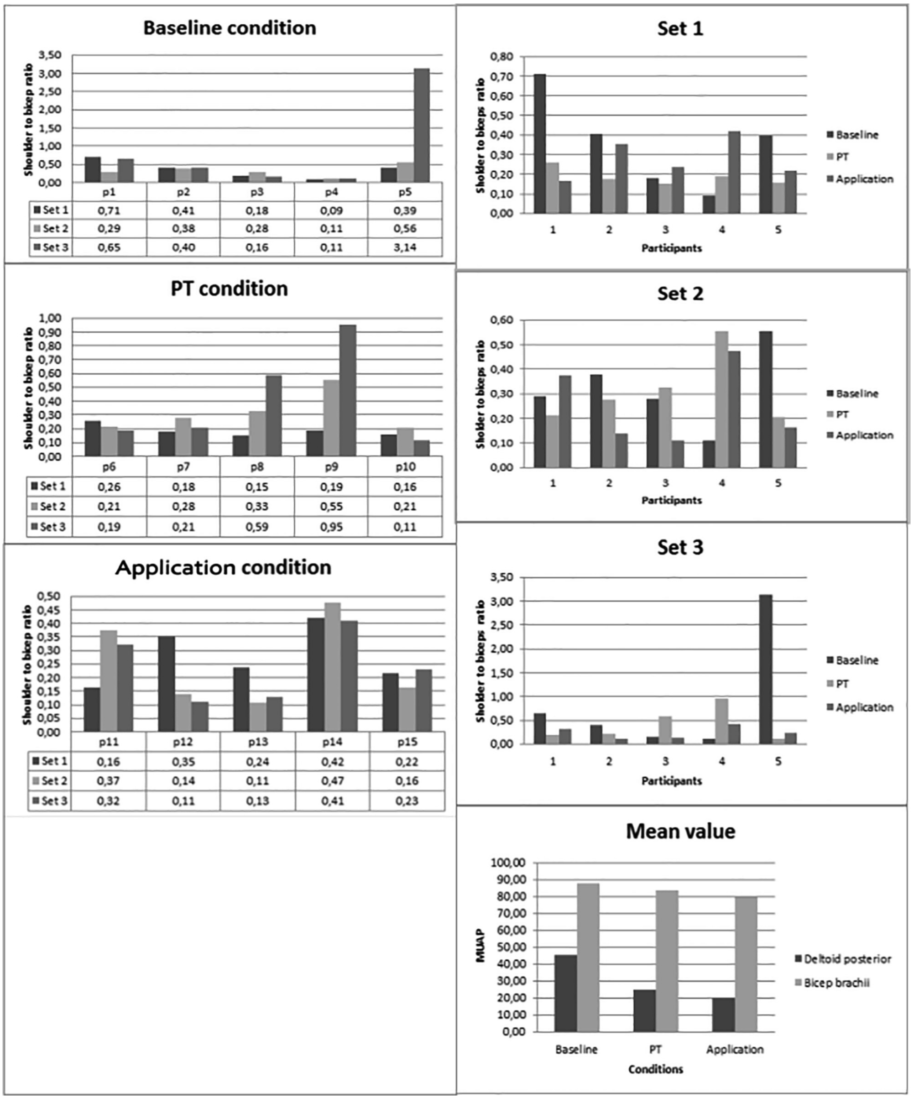

Fig. 2. The experimental results represented by histograms.

Intra EMG Ratio Result. In this subsection, the results of the intra-group analysis are presented. The data is segmented accordingly to the three conditions: baseline, personal training (PT) and application, to show if any improvements between sets are found within the groups.

For all three conditions, a one-way independent ANOVA is performed to investigate the difference between the three sets. The result of the ANOVA shows that the variances for all the sets are equal for the baseline, PT and application conditions ($f = 1.06$, $p > 0.05$; $f = 0.92$, $p > 0.05$; $f = 0.23$, $p > 0.05$, respectively).

Inter EMG Ratio Result. In this subsection, the results of the inter-group analysis are presented. Here the difference between each group is investigated, looking for a significant difference within set. In other words, if baseline condition performed better than PT- or application condition, within each set.

The data for each set underwent a one-way independent ANOVA, in order to investigate the difference between the three conditions. The result of the ANOVA shows that the variances for all the conditions for set 1, 2 and 3 are equal ($f = 1.55$, $p > 0.05$; $f = 0.31$, $p > 0.05$; $f = 0.97$, $p > 0.05$, respectively).

Inter EMG Biceps Average Result. To discover whether one condition achieved better bicep activation than the others, the Biceps and the Deltoid MUAPs are analyses between the three conditions. However, again, the ANOVA does not show a statistically significant difference between the conditions.

7 Discussion

The results of this study showed that there were no statistically significant differences between the three conditions, in both the MUAP ratio between biceps and deltoid, and the bicep and deltoid alone. Even though no statistically significant results were obtained during this study, observations showed that the application had some potential in assisting the user, similar to the personal trainer.

As mentioned in Sect. 4, the biceps curl is categorised as an isolation exercise, since only a few muscles are required in the execution of the exercise [31]. In other words, the biceps curl is an exercise which focuses on isolating the biceps muscle by avoiding the incorporation of other muscles, such as the deltoid. This could justify the lack of significant results, since the exercise might be too simplistic, which makes it hard to determine whether an individual performs better than another solely based on EMG data. Despite this, visual improvements of the execution were observed between the groups and sets during the sessions.

Based on observation, a frequent event occurred in the baseline condition, which involved a tendency of increasing the involvement of the deltoid when executing the exercise, in contrast to the PT and application conditions. This observation was strengthened when analysing the MUAP values of the deltoid activity, where the baseline condition shows a higher value than the other conditions, as seen in Fig. 2. Particularly, test participant 5 in the baseline condition group has a very high shoulder to bicep ratio during set 3, which was verified by the visual observation showing signs of fatigue and poor exercise execution. However, the baseline condition also has a higher MUAP value of the bicep, resulting in similar ratio between bicep and deltoid as the other conditions. Additionally, it was noticed that the participants in the baseline condition executed the repetitions faster than the other conditions, specifically from 1–2 s in comparison to 2.5–4 s for the PT condition and the application condition. This observation may be a contributing factor to that no difference between the three conditions was found, due to the fact that when performing strength training several factors affect the MUAP of the muscle: load, repetitions, sets, pause and time under tension [16]. In this study, all factors were normalised for all conditions, except the time under tension (TUT). All conditions performed three sets of 8 repetitions with a weight corresponding to the 40% MVIC, and with a pause of 60 s between sets. However, the TUT was determined by the individual alone, or given by the personal trainer or application. This may have resulted in the larger rate of force development in the baseline condition than the other conditions. Furthermore, this means that the baseline condition activated their muscle fibre more synchronised, making it a more explosive movement with a higher MUAP, but over a shorter period of time. This can result in being able to lift more weight, but not with better execution.

As mentioned in Sect. 3, the use of EMG biofeedback has proven highly effective in behavioural change, muscle strength development and range of motion, in post-stroke- and cerebral palsy patients [9–11]. The same kind of behaviour change and exercise improvements was observed during the testing sessions. The baseline condition did not change their execution between sets, whereas the two other conditions did. The participants in the PT condition all tried to improve their execution and performance based on the feedback given by the personal trainer. Likewise, the application condition changed their execution based on the feedback provided by the application. However, some of the participants, within this condition expressed confusion towards the feedback. Hence, the limited information might have been too inferior for the participants to fully understand the corrections needed to improve execution. Nevertheless, all participants concluded that the meaning of the feedback was to increase bicep activation and lower shoulder activation, as intended. Additionally, the participants in the application condition visually improved the execution of their repetitions by better isolating the bicep. The results in Fig. 2 also hint this tendency.

In spite of the circumstances and factors discussed above, in this study a small sample group was recruited for the testing sessions. Hence, significant results might be found in a larger sample group based on the tendencies highlighted in this study.

8 Conclusion

The main goal in this paper was to investigate the effectiveness of a developed electromyography (EMG) biofeedback fitness application and its potential improvement of strength training exercise execution using the measure of muscle activity. The results obtained from this study hinted that participant without any feedback did not alter their execution between sets. The PT- and application condition indicated a better execution visually; however, no statistically significant results were found to support this observation. Furthermore, the application condition suggests that even though the feedback presented was not perfect, the participants did in fact improve between sets, which are supported by the literature [9–11]. The lack statistical significant results, leads to the conclusion that more extensive and thorough testing of these conditions is needed in order to obtain more definitive results.

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