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External Focus of Attention and Augmented Feedback: A Training Study

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Referent: Prof. Dr. Wolfgang TAUBE
Betreuer-In: MICHAEL WÄLCHLI, MARTIN KELLER

DOMINIC RYSER

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1 Abstract

Purpose: It is common for physical education teachers and coaches to use instructions and feedback in order to guide an individual during motor skill learning and to enforce performance enhancement. In an attempt to find the optimal guidance method the present study investigated the effects of augmented knowledge of result feedback (aFB) compared to a combination of promoting an external focus of attention through instruction (EF) and aFB on the immediate performance and short-term learning. Furthermore, neurophysiological adaptions to the ballistic training in the form of motor evoked potential (MEP) and short-latency intracortical inhibition (SICI) were examined. Based on existing literature it was hypothesized that performances and short-term learning improve and cortical excitability is facilitated after a short period of ballistic force training when aFB is provided, whereas the group provided with a combination of EF+aFB achieves better results than the group receiving just aFB.

Method: Twenty-two subjects underwent a ballistic training consisting of two sets of thirty isometric plantar foot flexion movements applied to a force pedal, with the goal to improve maximum rate of force development (mRFD) with every trial. Subjects were randomly assigned to either the neutral group, the aFB group or the EF+aFB group. A visual display of the achieved performance was provided after every trial on a computer screen to participants of the aFB and EF+aFB group. Subjects of the EF+aFB group additionally received the instruction to focus on the force pedal when executing the ballistic plantar foot flexion task. Maximum voluntary contractions (MVC), mRDF, TMS-evoked MEP and SICI were measured before, immediately after and ten minutes after the training period.

Results: Opposite to our predictions the results showed no effect of aFB and a combination of EF instruction and aFB on performances, learning and cortical excitability after a short ballistic training of isometric plantar foot flexion force.

Discussion and Conclusion: The contradictory behavioral results seem to be attributed to the choice of a simple task in the present study. While many studies provided evidence that aFB and EF have an enhancing effect on the performance and motor learning of a complex skill, it is speculated that this might not apply to the plantar foot flexion task used in the present study. Furthermore, the lack of neurophysiological adaption of corticospinal and intracortical excitability in the present study is suggested to be due to methodological reasons. Additional studies should further investigate and specify the methodological determinants underlying the neurophysiological adaptions found in previous experiments.

2 Introduction

In physical education and coaching the instructor's task is to teach new or to help to improve existing motor skills. Hereby the instructor has a variety of methods available in order to help an individual succeed in a motor task but usually has little time to do so. It is therefore crucial for the instructor to know, which strategy is the most efficient. Two methods proven to have a positive effect on motor skill performance and learning are (1) to provide the individual with external feedback on the execution of the movement or the performance outcome and (2) to use instructions and feedback to influence an individual's focus of attention. In the following paragraphs the two methods will be analyzed in more detail.

For motor skill execution and learning feedback refers to all information essential for the motor control. According to Schmidt and Lee (2011) feedback can be categorized into intrinsic feedback or augmented feedback. Intrinsic feedback relates to afferent and reafferent information collected by an individual's sensory system through the engagement with the outer environment. The intrinsic feedback provides information about the movement of objects in the environment as well as information about our own body movement and position within the same environment. Clearly, intrinsic feedback is inevitable for motor control and learning. In contrast, the extrinsic feedback or also known as augmented feedback serves as additional information to the sensory system for motor control provided by an external source (e.g. an instructor or computer etc.). In physical education and coaching it is common that the instructor provides the student or athlete with external information about their motor skill execution or performance.

As for augmented feedback modality, there are two types of augmented feedback an instructor can give in order to help individuals in their learning or adaption process. One type of augmented feedback is to provide the learner with feedback about the movement execution of a skill i.e. the instructor provides the learner with information about the quality of the movement. This type of feedback is known as knowledge of performance (KP). KP is the most commonly used type of augmented feedback used in physical education and coaching. The other type of augmented feedback is to give information about the outcome or result of the performed motor skill, which is known as knowledge of result (KR). Although KP might be commonly used in the field, KR is the type of augmented feedback most research about augmented feedback and motor learning is based on. This circumstance might be due to the ease of quantifying and manipulating KR compared to KP (Winstein, 1991). KP and KR were, despite their different referral to motor skill performance and execution, considered the same in their mechanics (Schmidt & Young, 1991). Various studies showed that KR is important in motor learning (Buekers et al., 1992; Salmoni et al., 1984; Winstein, 1991). When comparing KP with KR some research revealed evidence that providing KP is beneficial over KR for motor performance, whereas others did not show any difference between the two augmented feedback types (for review see Lauber & Keller, 2014).

Another aspect of augmented feedback that has been widely discussed is the frequency with which augmented feedback is given during motor skill learning. The guidance theory (Salmoni et al., 1984) postulates that augmented feedback guides the learner to the correct execution of a motor task and improves performance. The guidance hypothesis also mentioned negative effects on learning when providing a high frequency of augmented feedback. This circumstance is explained with a dependency of the learner on external feedback, which leads the learner to neglect task-intrinsic feedback processes and would hinder them in the absence of augmented feedback to successfully execute the motor skill. Another concern with a high frequency is, that the learner would make too many adjustments in the learning process so that learning a stable movement pattern is prevented (Salmoni et al., 1984). There are several different studies that challenge the guidance hypothesis by providing evidence, that the learning process of a motor skill as well as the performance do not suffer from a high frequency augmented feedback (e.g. after every trial) (Keller et al., 2014; Moran et al., 2012; Wulf et al., 2010; Wulf & Shea, 2002). The role of the frequency of augmented feedback is inconclusively. With regard to physical education, where an instructor has to provide feedback to several students within a short period of time, the frequency cannot be sufficiently controlled and equally distributed among the students and therefore might not play a crucial role in facilitating motor learning (Magill, 1994).

Motor learning theories like the closed-loop theory (Adams, 1971) and the schema theory (Schmidt, 1975) imply the importance of KR on motor skill learning. In an alternative theory to those of Adams and Schmidt, the ecological action theory (Gibson, 1979), were individuals use environmental information in order to control motor movement, augmented feedback may play a less essential role (Magill, 1994). Magill (1994) argued that augmented feedback can be necessary for motor skill learning or can be neglected under certain circumstances. He explained that, augmented feedback is necessary when sensory feedback essential to execute the skill is not available or when the learner has no prior knowledge on how to accomplish a certain motor task. Nevertheless, Magill also argued that augmented feedback might not be necessary if there is enough task-intrinsic information in order for the learner to improve their skill on their own or if the learner is provided with a thorough instruction on how to correctly perform the motor skill. Furthermore, Magill also mentioned that augmented feedback could either enhance or hinder motor skill learning. The skill level that can be achieved when enough task-intrinsic information is available could only be further improved, when additional, augmented feedback is provided. Magill therefore assigned an enhancement effect to augmented feedback that enables to reach a higher level of excellence. Negative affects on motor skill learning can occur when the augmented feedback provided is false or the learner becomes dependent on augmented feedback in order to succeed in the skill (Magill, 1994). Aside from the different effects augmented feedback could have on a learning individual, there have been numerous exercise studies published presenting the benefits of augmented feedback in the immediate performance and the learning process of a variety of different motor tasks (for review see Lauber & Keller, 2014). For example, in a kinetic study conducted by Hopper et al. (2003) sixteen volunteers from a female elite field hockey team executed two trials of three repetitions of leg press without visual feedback as well as two trials of three repetitions with visual feedback. For visual feedback a computer screen was used, which showed subject's performance after each trial in form of a bar graph. The results showed a significant positive effect of power performance when visual feedback was provided compared to when no visual feedback was given. Another study by Ekblom and Eriksson (2012) revealed a beneficial effect of augmented biofeedback on muscle activation and strength during maximal voluntary concentric and eccentric muscle actions. In this study fifteen female volunteers performed two sets of three isometric knee-flexion maximum voluntary contractions. After the first set without feedback, subjects were randomly assigned to either a control group or a feedback group. Subsequently in the second set, subjects in the control group performed the identical motor task as in the first set, whereas the subjects in the feedback group were provided with concurrent feedback about their achieved EMG-activity in their M. vastus medialis. The results showed that subjects who received an EMG-feedback were able to significantly increase maximum voluntary isometric knee flexion compared to baseline values, whereas maximum voluntary isometric knee flexion of subjects from the control group did not show any change at all or even showed a decrease. A third study in the field of prevention and rehabilitation examined the influence of augmented feedback on stance stability (Taube et al., 2008). Subjects' center of pressure (COP) displacement was measured when standing in an upright position on either a stable or an unstable surface. A laser pointer held in their hand, which was tied to the subjects' hip, and aimed at a target at the wall in front of them was used as augmented visual feedback device. The results showed that when subjects were able to use the laser pointer the amount of COP displacement was significantly reduced on both surfaces. Therefore, the study provides evidence that visual augmented feedback can positively affect postural control.

Despite a variety of studies that have shown a beneficial affect of augmented feedback on motor performance and motor learning, it has to be mentioned that no generalizability can be made about the determinants of augmented feedback, which enforces motor performance or learning (Lauber & Keller, 2014; Magill, 1994; Wulf & Shea, 2002). For teachers and coaches it is therefore crucial to always consider the underlying variables like the appropriateness of a specific augmented feedback type, the movement complexity and the competences and knowledge of the learner (Magill, 1994). Two further studies are presented in order to highlight the benefits of augmented feedback. The study conducted by Moran et al. (2012) aimed to determine whether augmented feedback in form of the measured tennis service speed (KR) could enhance learning to improve the tennis service speed after a training intervention. In a first experimenting fourteen high-leveled junior tennis players had to do fifteen serves to the T of the service box on the deuce side and rate if their service speed of the executed serve was faster or slower in respect to the immediately preceding one. The results from this first experiment showed that the tennis player were not able to successfully judge whether a service was faster or slower than other ones. In their second experiment ten of the same high-leveled junior tennis players plus one additional player were either assigned to the augmented feedback group, which received KR feedback about their achieved service speed immediately after each service shown on a large electronic display, or to the control group, which did not receive any augmented KR feedback. The players undertook a pre-test (to determine their baseline service speed), six weeks of training (consisting of ninety consecutive services into different targets within the service box, plus some services during match practice drills), a post-test, another six weeks of training without any augmented KR feedback (services during match practice drills) and a retention-test. Both groups significantly improved their tennis service speed in respect to their baseline service speed. The augmented KR feedback group improved their service speed significantly lager then the control group without augmented KR feedback. Considering that the performances of the augmented KR feedback group in the retention-test (after the second training block of six weeks without augmented KR feedback) were still on the same level as during post-test, the study showed a clear learning effect of a new service technique. Moran et al. (2012) concluded that the reasons of the benefits of augmented KR feedback on the learning process are, that it provides important information about the movement results in order to sufficiently rate their performance. Hence the tennis players were able to distinguish a high service speed from a slow one when provided with augmented KR feedback (Experiment 2) compared to when no augmented KR feedback was provided (Experiment 1) and therefore adjusting their movement pattern. Moran et al. (2012) further mentioned that there could also be a motivational aspect to the benefit of augmented feedback. Displaying the resulted speed of the tennis serve could have encouraged the players to improve their speed with every try and therefore made them aware of a more effective service technique or increase the power output of the neuromuscular system. Furthermore, Moran et al. (2012) argued that providing information about the result (KR) enhances focusing on the effects of motor movements and therefore promoting an external focus of attention. It is well established that an external focus of attention improves the performance as well as learning of motor skills (for review see Wulf, 2013). Augmented feedback in form of KR might therefore be a tool to implement an external focus of attention (Moran et al., 2012). A second study conducted by Keller et al. (2014) about the influence of augmented feedback on the jump performance of drop jumps came to a similar conclusion. Thirty-four participants did twelve supervised drop jump trainings within four weeks. A pre-test was done before and a post-test after the trainings intervention. The participants were randomly assigned to one group that received augmented KR feedback about their jump height after every drop jump, one group that received only for half of their attempts augmented KR feedback and a control group which did not receive any external feedback at all. Augmented KR feedback was provided in form of displaying the jump height on a computer screen. The results showed that jump heights were significantly higher when augmented KR feedback was provided compared to when no augmented feedback was available. Additionally, groups receiving augmented KR feedback showed greater improvement in their jump heights after the four weeks training intervention then the group without augmented feedback. In contrast to Moran et al. (2012), Keller et al. (2014) argued that the advantages in performance enhancement of augmented KR feedback are unlikely due to additional information that help to accurately rate their performance and subsequently adjust the motor commands since jump performances declined immediately after augmented KR feedback was withdrawn (no carry-over effect). Nevertheless, Keller et al. (2014) supports the suggestion of Moran et al. (2012) that a stimulation of motivation and a shift towards an external focus of attention might be responsible for immediate performance enhancement when providing augmented KR feedback.

When reviewing the existing literature about augmented feedback it can be concluded that the beneficial effects of augmented feedback in form of KR are due to an increase in motivation to achieve a better result with every try (Keller et al., 2014; Keller et al., 2015; Moran et al., 2012; Wälchli et al., 2015) and a shift towards an external focus of attention (Keller et al., 2014; Moran et al., 2012).

A second method associated with a positive effect on motor performance and motor learning a physical education teacher or coach could use to help an individual to learn or improve a motor skill, is to influence their attentional focus through instructions or feedback. Being able to direct the attention to the important aspects of the motor task is of great importance to achieve excellency in sports. According to Nideffer (1976), in sport psychology the attention control during the execution of a motor skill can be directed in four ways: either internally broad or narrow or externally broad or narrow. To direct the attention internally would mean to concentrate on one's body signals. When directing the attention internally-broad one would focus on the overall condition of the body, whereas when the attention is directed internally-narrow one would only focus on one specific parameter of the body e.g. heart rate. In contrast, directing the attention externally would mean to concentrate on signals from the environment. Directing the attention externally-broad would therefore indicate to focus on the broader environment (e.g. the counterattack of the opponent team), oppose to an externally-narrow direction of the attention, where one would only focus on one aspect of the environment (e.g. the behavior of the direct opponent player). In motor learning another distinction has been made about the focus of attention, which has a significant impact on motor performance and motor learning. The empirical literature distinguishes between an internal focus of attention and an external focus of attention (for review see Wulf, 2013). The internal focus of attention refers to an attention directed towards the individual's own body movement. For example during a tennis serve the athlete would focus on the swing of his arm. Opposite to an internal focus of attention is an external focus of attention, by which the focus is directed towards the effects of the individual's movement rather than the body movement itself (i.e. the tennis player would focus on the swing of the tennis racket during a tennis serve rather than his arm). As already mention, the focus of attention can be influenced through either instructions or feedback. Instructions are information about the correct movement pattern or technique to be used in order to excel a motor task and is given before the execution of a motor skill. Feedback, on the other hand, refers to the quality of the executed movement and performance and is either given concurrent or after the motor task is completed.

There are several studies suggesting that an external focus of attention is superior to an internal focus of attention or no instructions or no feedback at all in the learning process as well as for the performance outcome in a variety of different motor tasks (balance, accuracy, muscular activity etc.), for different levels of expertise (novice to experts) and for different age groups (children to elderly people) (for review see Wulf, 2013). In a study by Porter et al. (2010) instructions were used to induce a focus of attention. The aim of this study was to investigate if the performance of a standing long-jump was enhanced when providing external focus of attention instructions compared to internal focus instructions. 120 subjects were randomly assigned to either a group, which received instructions inducing an external focus of attention or a group receiving instructions inducing an internal focus of attention. After a short warm-up participants had to perform five standing long-jumps with two minutes rest in between each trial. Before each trial group specific instructions were given. Participants of the external focus group had to focus on jumping as far past the start-line as possible, whereas participants of the internal focus group were instructed to focus their attention on extending their knees as fast as possible. The results showed that subjects within the external focus group jumped significantly farther than subjects in the internal focus group. Another study that used instruction to induce a focus of attention aimed to reveal differences between an internal and an external focus of attention on pre-movement time and accurate isometric force production (Lohse, 2012). Twenty-four participants, equally assigned to either the external focus group or the internal focus group, had to perform isometric planter foot flexion on a force platform, with half of the participants in each group targeting a force of either 25% or 50% of their maximum voluntary contraction (MVC). Subject engaged in a training session of sixty trials under their allocated focus of attention condition. Subjects in the external focus group were instructed to focus their attention on the push against the platform, whereas the internal focus group was instructed to focus their attention on the contraction of their calf muscle. In a retention and transfer test one week after the training session, subjects had to perform twenty isometric plantar foot flexions with the same percentage of MVC target as during their training session, but without any specific instructions. In order to investigate transfer effects, subjects had to target a different force exertion on the platform than during the training session (i.e. those who training with a target of 25% of MVC had to do the transfer test with a target of 50% of MVC and vice-versa). The results showed that subjects training with instructions inducing an external focus of attention were able to exert force more accurate in respect to their force target. Furthermore, they showed a reduction in pre-movement time in early trials, which was interpreted as an improvement in motor planning. The external focus group also improved learning, since they performed better in the retention and transfer test, where no attentional focus instructions were given. A third study conducted by Wulf et al. (2002) examined the effects of feedback inducing different attentional foci on motor performance and learning in two different experiments. In the first experiment participants practiced the volleyball tennis service. Four groups were formed; two groups consisting of novice players (no volleyball experience at all) and two groups with advanced volleyball player. Within those groups players where further assigned to either a group receiving feedback about their performance with respect to their own body movement (internal focus feedback) or a group receiving feedback about their performance with respect to the movement effects (external focus feedback). Each participant performed twenty-five volleyball tennis serves in two training sessions separated by a week. A retention-test consisting of fifteen trials without feedback was held one week after the second training session. After every fifth trial, one out of four feedback statements was given to the subjects in order to provide them with information, on how to improve the subsequent trials. One of the feedback statements for the internal focus group was for example: "Shortly before hitting the ball, shift your weight from the back leg to the front leg" (Wulf et al., 2002, p. 174). The feedback statement referring to the same movement technique, but inducing an external focus of attention was: "Shortly before hitting the ball, shift your weight toward the target" (Wulf et al., 2002, p. 174). These results showed that both groups (novices and advanced players) receiving external focus of attention feedback performed the volleyball tennis serves more accurately during practice and during the retention-test than the internal focus feedback group. These findings show, that feedback inducing an external focus of attention is more beneficial to motor skill performance and motor skill learning compared to feedback inducing an internal focus of attention. These results are contrary to the view that a focus on the body movement is essential for learning (Adams, 1971). The second experiment in the study of Wulf et al. (2002) focused on the interaction between feedback frequency and attentional focus. As mentioned earlier in this introduction, the guidance hypothesis (Salmoni et al., 1984) postulates that feedback after every single trial has a negative effect on motor learning since the dependency on the external information hinders intrinsic-feedback processes. Therefore, frequent feedback would be assumed to prevent learners from focusing their attention on their own body movement i.e. internally. Alternatively, Wulf et al. (2002) suggest that the benefits of reducing feedback frequency could be the result of a less induced internal focus of attention. To support this suggestion with evidence, they made an experiment with fifty-two participants assigned to one of four different feedback groups: external focus or internal focus feedback with a feedback frequency of either 100% or 33%). Participants had to perform thirty practice trials of a lofted soccer pass into a target area and ten trials during a retention-test without feedback one week after. One of five feedback statements was given to the external and internal focus group after either each trial or after every third trial. The results showed that the external focus feedback group was again more accurate in their passes than the internal focus feedback group independent of feedback frequency. As predicted by the authors, a reduced feedback frequency was only beneficial within the internal focus of attention group during practice and the retention-test. For the external focus feedback group, the opposite was true; subjects receiving feedback after every trial performed better than those receiving feedback only after every third trial. The benefit of a reduced feedback when providing feedback inducing an internal focus of attention could therefore be due to a reduction in attention on the own body movement.

The above presented studies are just examples representing the establishment in the literature, that an external focus of attention is more beneficial in motor skill performance and motor skill learning than an internal focus of attention. Wulf (2007) explains the reasons for the superiority of the external focus with the constrained action hypothesis according to which an external focus fosters an automaticity in movement control, whereas an internal focus of attention constrains the process of the body's own movement regulation. A dual-task experiment conducted by Wulf et al. (2001) supports this hypothesis with evidence. Twenty-eight students of the University of Munich participated in this study and were randomly assigned to either an internal focus group or an external focus group. The subjects had to perform a balance test on a stabilometer and additionally respond to several randomly presented audible signals by pressing a button as fast as possible. It was assumed that the better the performance of the secondary task (pressing the button when an audible signal was present), the less the attentional demand for the primary task (balancing task). Subjects within the internal focus group were instructed to try to keep their feet on the stabilometer horizontal, whereas subjects in the external focus group were asked to focus on keeping the markers attached to the platform horizontal. The participants had seven trials of ninety seconds on the stabilometer for two days. Before every trial subjects were instructed with the allocated focus of attention. On the third day a retention-test with seven trials of ninety seconds without a reminder of the focus of attention was performed. The results revealed that both groups were improving their reaction time for the second task (responding as fast as possible to the audible signals) constantly with the external focus group achieving better results throughout the study than the internal focus group. Hence participants from the external focus group were able to execute the balance task with a greater automaticity than those focusing internally. A second conclusion drawn out of the study was that participants with an external focus were able to make more smaller and quicker adjustments during the balance task, which was interpreted by the authors as a better self-regulation of the motor system. Another study supporting the constrained action hypothesis was executed by Vance et al. (2004). The aim of this study was to reveal differences in the neuromuscular system when doing biceps curls under an internal focus and an external focus condition. The participants of that study had to perform two sets of ten bicep curls under both an internal and an external focus. When instructed to focus internally, participants were to focus on the movement of the arm, whereas the participants had to focus on the movement of the curl bar under external focus conditions. Electromyography (EMG) activity was measured for the biceps brachii and triceps brachii. The results showed that (1) the movements were unconsciously executed faster under external focus conditions and (2) the muscle activity in both muscles was lower when focusing on the curl bar (external focus) rather than on the movement of the own arm (internal focus). Therefore, both results provided evidence for more effectiveness and efficiency in motor movement execution with an external focus of attention and are in line with the constrained action hypothesis.

Promoting an external focus of attention has also be suggested as a valid method in implicit motor learning (Poolton & Zachry, 2007). Implicit motor learning attempts to allow more automaticity when performing a motor skill with the advantage of a consistent performance even under stress, an enhanced multi-tasking ability and possibly a delay of physiological fatigue. Therefore, instructions and feedback inducing an external focus of attention, act similar as implicit motor learning by limiting the dependency on working memory (Poolton & Zachry, 2007).

In conclusion it can be stated, that promoting an external focus of attention when learning or executing a motor skill leads to a more efficient learning process (faster progression and better sustainability) and a better performance (motor effectiveness) than an internal focus of attention or non instructions at all (for review see Wulf, 2013). An explanation can be found in Wulf and colleague’s constrained action hypothesis, which consists of an automaticity of the movement control and greater movement efficiency (Wulf, 2007).

Both, promoting an external focus of attention and providing augmented feedback appear to be valid methods for an instructor to enforce motor learning and improve immediate performances of an individual. In order to identify, which of the above mentioned instruments leads to the best performance result, Keller et al. (2015) compared the methods of augmented KR feedback with an external focus of attention and an internal focus of attention induced by instructions. In this study, nineteen participants performed twelve series consisting of eight counter movement jumps (CMJ). All participants performed four series with augmented KR feedback (visual display of the jumping height), four series with an instruction inducing an external focus of attention (concentration on a tennis ball hanging from the celling above the force plate) and four series with an instruction promoting an internal focus of attention (concentration on leg extension). The results showed that jump heights were the best under the augmented KR feedback condition followed by the external focus and internal focus conditions. The finding, that the external focus condition is superior to an internal focus condition, is in line with previous studies (for review see Wulf, 2013). New is the observations, that providing augmented KR feedback seems to be more effective than an alteration of the focus of attention. In contrast to the earlier presented proposition of Moran et al. (2012) and Keller et al. (2014) that the enhanced performance when augmented KR feedback is provided might derive from a promotion of an external focus of attention by shifting the attention towards the effects of the movement, the recent study by Keller et al. (2015) suggests that this could not be a key characteristic. Keller et al. (2015) rather proposed that the superiority of augmented KR feedback to an external focus of attention might be due to an increase in motivation (the first jump under augmented KR feedback condition was already higher than under the other two conditions). Furthermore, within-series analyses revealed that jumping heights were higher at the end of a series under augmented KR feedback condition, but reduced under external and internal focus condition. Therefore, it was argued that displaying the result of each attempt kept the participants interested and motivated to improve the jump height, which consequently led to a greater effort exertion under augmented KR feedback condition compared to the other conditions. In summary, the presented study provides evidence for an enhanced performance when augmented KR feedback is provided compared to instructions inducing an external or internal focus of attention.

The presented findings showed that both, an external focus of attention and augmented feedback contribute to improve motor learning and immediate performance outcomes with the augmented KR feedback method outperforming the external focus of attention method. Considering that augmented feedback improves motor learning and immediate performances due to motivational aspects rather than a change in the focus of attention (Keller et al., 2015), an instruction promoting an increased focus towards an external source additionally to augmented KR feedback could improve the learning effects and performance outcomes even more. In an attempt to find the most efficient guidance to maximize performance, Wälchli et al. (2015) compared the combination of augmented feedback and instructions inducing an external focus of attention with just augmented feedback , monetary reward and combinations of augmented feedback with monetary reward and augmented feedback with an external focus of attention and monetary reward or no instructions or feedback at all. Eighteen participants performed sixteen series (two series per condition and six series under neutral condition) of six countermovement jumps (CMJ), with the goal to reach the highest jump hights. The results showed that under the EF+aFB condition subjects achieved the best performances. Giving instructions inducing EF additionally to providing subjects with aFB enhanced jump performances significantly more than when just providing aFB or a RE. Furthermore, the muscle activity of the M. recuts femoris was significant lower, when performing CMJs under conditions including EF compared to under neutral condition. The authors concluded that this superiority of the combination of EF+aFB are due to the additive benefits of intrinsic motivation (from aFB) and improved movement efficiency (from EF).

To support these findings with additional evidence the first aim of the present study was therefore to examine the behavioral effects of augmented KR feedback (aFB) and a combination of instructions inducing an external focus of attention and augmented KR feedback (EF+aFB) on immediate performance and short-term motor learning of a ballistic force production task. Based on the literature reviewed, it was hypothesized that a combination of EF+aFB would result in greater maximum rate of force development (mRFD) and greater maximum voluntary contraction (MVC) after a short ballistic training period then when providing only aFB or no feedback at all.

"Short periods of training in motor tasks can increase motor cortical excitability" (Giesebrecht et al., 2012, p. 2485). In a study conducted by Muellbacher et al. (2001) evidence was provided that the human primary cortex (M1) is involved in immediate motor learning. Participants of this study had to practice ballistic pinch movements with the right thumb and index finger for sixty minutes, with the goal to increase their maximum pinch force and acceleration. Additionally, the motor excitability expressed as the motor evoked potentials (MEPs) triggered by a transcranial magnetic stimulation (TMS) in the trained muscle as well as in a control muscle not involved in the training was measured. The data of the motor behavior (pinch force and acceleration) and motor excitability (MEP) of pre-practice, after thirty minutes of practice and at the end of practice were compared. The results showed that the participants were able to increase the maximal pinch force and acceleration after the training intervention significantly. Furthermore, MEPs were significantly larger than baseline values in the trained muscle after the ballistic training, but not in the control muscle, which was not involved in the training. In follow-up measures thirty days after the training session, pinch force was still enhanced, whereas MEPs returned back to baseline levels. The study further revealed a linear correlation between the increase in pinch force and the increase in TMS-evoked MEP amplitude, which indicated the involvement of the human M1 in short term motor learning. In another study, Rogasch et al. (2009) examined the change in corticomotor excitability of a ballistic thumb training task in young and old adults. Fourteen young adults (18-24 years) and fourteen old adults (61-82 years) engaged in a training consistent of 300 ballistic abductions of the right thumb with the goal to enhance thumb abduction acceleration. The change in MEP in the target muscle as well as in a control muscle were measured through TMS before, after and thirty minutes after the training block. The results showed, that peak thumb abduction acceleration increased in both groups. Corticomotor excitability represented by TMS-evoked MEP amplitude was increased in the target muscle in young adults, but not in old adults. The authors hypothesized that the lack of motor excitability in the target muscle of older adults was due to a different thumb kinematics during the training session. The study provided further evidence of an increased motor cortical excitability after a short motor learning period in younger adults. A third study published by Giesebrecht et al. (2012) investigated if changes in motor excitability after a short training period also occur on a spinal level. In their experiment, participants engaged in a ballistic index finger abduction training (150 movements), with the goal to increase the acceleration of that index finger. TMS induced cervicomedullary motor evoked potentials (CMEPs) were measured before and after the ballistic training. Similar to the findings of Muellbacher et al. (2001), the result showed both an increase in acceleration of the index finger as well as an increase in CMEPs after training compared to baseline values. As well as in the study of Muellbacher et al. (2001), CMEPs returned to their control values ten minutes post-training. These findings suggest, that spinal levels could also contribute to changes in MEP after a ballistic training. Reviewing the literature it can be concluded, that short periods of ballistic training evoke neurophysiological changes in form of an increased motor cortical excitability.

Another factor that has an influence on the cortical excitability is the intracortical inhibition (ICI). Paired-pulse TMS serves as a non-invasive technique to determine ICI in human primary cortex. Preceded short interval TMS stimuli (within 1-5ms) with an intensity lower then the motor activity threshold are associated with an inhibition of MEP (Kujirai et al., 1993). This so termed short latency intracortical inhibition (SICI) reflects the excitability of inhibitory circuits in the motor cortex induced by y-aminobutyric acid (GABA), an inhibitory neurotransmitter in the central nervous system (Coxon et al., 2006; Rosenkranz et al., 2007; Rothwell et al., 2009). Studies have shown that a low local GABA concentration in the motor cortex leads to enhanced motor learning (Floyer-Lea et al., 2006; Ziemann et al., 2001). The influence of training on SICI is inconsistent. Many studies detected a reduction in SICI after a short training period (Liepert et al., 1998; Perez et al., 2004; Rosenkranz et al., 2007; Stinear & Byblow, 2003), another study did not show any change (Rogasch et al., 2009).

Therefore, a second aim of this study is to investigate the effects of different training conditions, namely aFB and EF+aFB, on the neurophysiological adaptions of the corticospinal and intracortical excitability (MEPs and SICI). We hypothesized that a short ballistic training period would increase TMS-evoked MEP amplitude in the target muscle compared to the baseline values, whereby the combination of providing aFB and promoting EF results in higher MEP values then when just providing aFB. Because of the inconsistency of the results regarding the influence of ballistic training on SICI no hypothesis could be made for these adaptions.

3 Method

3.1 Subjects

Twenty-two volunteers (16 men, 6 women, mean age 25 years, range 22 to 33 years) with no history of neurological and/or orthopedic injuries participated in this study. All participants have given written informed consent, once they have read a participant information sheet about the study procedure, applied methods and devices. The experimental procedure was in line with the latest declaration of Helsinki and was approved by the ethics commission of the Canton of Fribourg. The participants were randomly assigned either to the control group (neutral), the augmented feedback group (aFB) or the external focus and augmented feedback group (EF+aFB). Table 1 shows the group constitution and demography of the participants within each group.

Tab. 1: Group constitution and demography of participants in the different groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB). Age, body height and body weight are presented as mean ± standard deviation (SD).

Group	Subjects	Male	Female	Age (yrs.)	Body height (cm)	Body weight (kg)
Neutral	8	6	2	24 ± 2	174.1 ± 10.7	68.1 ± 12.8
aFB	7	6	1	26 ± 3	178.3 ± 9.4	78.7 ± 10.5
EF+aFB	7	4	3	27 ± 4	174.7 ± 10.0	66.9 ± 12.6

3.2 Experimental Arrangements

Before each experiment, electromyography (EMG) electrodes (Blue Sensor P, Ambu A/S, Ballerup, Denmark) were placed on the muscle belly of the M. soleus (SOL), M. gastrocnemius medialis (GASm) and M. tibialis anterior (TA) of the right leg of each participant. The reference electrode was placed on the tibial plateau of the right leg. Muscular activity was obtained by a custom built EMG device (EISA, University of Freiburg, Germany). Participants laid then comfortably in a supine position onto a horizontal leveled chair seat whit the lower legs hanging off at the end of the seat. The right foot of participants was fixated onto a pedal, which was part of the isokinetic system (Cybex, CSMi Solutions, Stoughton, MA, USA) measuring the performance of the plantar foot flexion movement. The foot was positioned with an ankle joint angle of ninety degrees and with the right lateral malleolus aligned with the torque center of the pedal. The pedal boarders were adjusted to the foot size in order to ensure an optimal force transmission of the plantar foot flexion movement and to keep the foot in position. The right knee of participants was immobilized in an extended position to inhibit any movement from the knee joint. Participants were asked to keep their hands loose on their stomach.

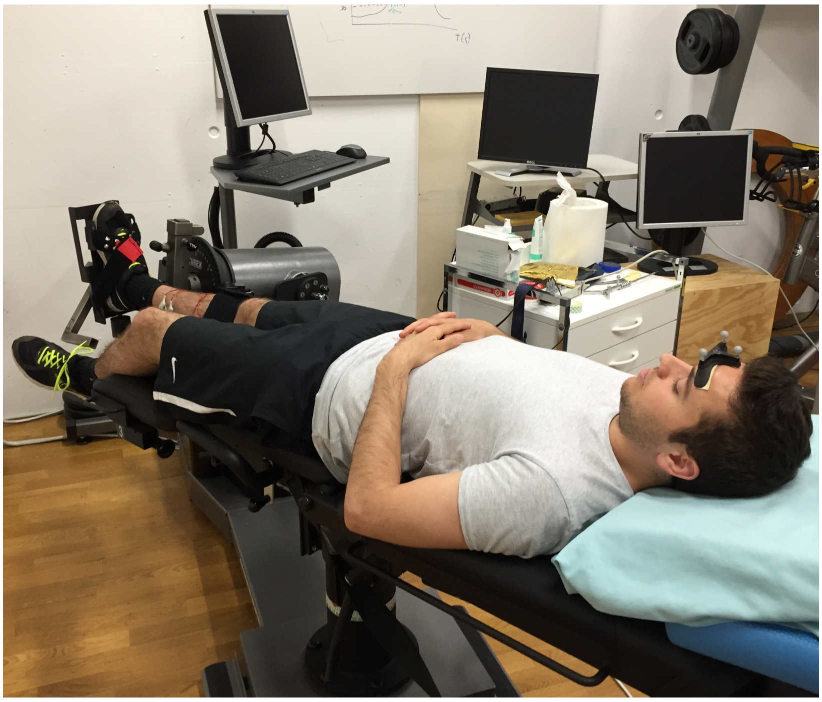

Fig. 1: Representative picture displaying the experimental arrangement and positioning of the participant.

Transcranial Magnetic Stimulation (TMS). TMS was performed using a figure eight shaped coil connected to a MagPro X100 wiht MagOption stimulator (MagVenture A/S, Farum, Denmark). Stimulations were applied to the motor cortex contralateral to the right lower leg and positioned to optimally stimulate the muscles SOL, GASm and TA. The optimal position for the stimulation was explored by applying a stimulus with a suprathreshold intensity and moving the coil tangential over the motor cortex area representing the lower right leg. The coil position, which produced the largest motor evoked potential (MEP) amplitude in the SOL, GASm and TA was memorized using a TMS-navigation system (Localite GmbH, Sankt Augstin, Germany), which ensured a consistent and exact coil placement at the exact same position during the tests. For each participant resting motor threshold (rMT) in the muscle of interests (SOL, GASm and TA) were then determined by altering the stimulus intensity at the located optimal site. The rMT was defined as the minimum stimulus intensity required to evoke MEP amplitudes of ≥50 µV in minimum 3 out of 5 consecutive stimuli. rMT is expressed in % of the maximum stimulator output. Test stimulus intensity was set to 120% of rMT. To determine short latency intracortical inhibition (SICI), paired-pulse TMS was performed applying a conditioning subthreshold stimulus of 80% of rMT followed by the test suprathreshold stimulus of 120% of rMT. The interstimulus interval (ISI) was set at 2.5 ms. All TMS intensities remained constant throughout the experiment.

3.3 Experimental Procedures

Measurements. Baseline values, post-test and retention-test measurements consisted of motor evoked potentials (MEPs), short latency intracortical inhibition (SICI), maximum voluntary contraction (MVC) and maximum rate of force development (mRFD) (fig. 2). MEPs and SICI measurements in the SOL, GASm and TA were obtained applying ten single-pulse TMS (120% of rMT) alternating with ten paired-pulse TMS (80% of rMT followed by 120% of rMT). TMS measurements were performed as close as possible after training. For the measurement of maximum plantar foot flexion strength participants were asked to perform three all-out plantar foot flexions with the right foot with a short break in between each trial. In order to measure mRFD values participants performed ten ballistic plantar foot flexions with the right foot without any instructions given (control mRFD), followed by ten ballistic plantar foot flexions with instructions and feedback provided according to their assigned group. Plantar foot flexions were paced with an audible tone. Verbal encouragement was given to each participant. The order of the measurements was kept the same for all participants: Pre-test: TMS followed by MVC and mRFD; post-test: MVC and mRFD followed by TMS; retention-test: TMS followed by MVC and mRFD.

Instruction and feedback. Augmented knowledge of result (KR) feedback was provided through visually displaying the achieved MVC and mRDF after each trial on a computer screen. The following instruction for the aFB group was used: “Execute a plantar flexion as fast and hard as possible and try to increase the number on the computer screen with every try“. As for the EF+aFB group the following instruction was used: “Push the pedal back as fast and hard as possible and try to increase the number on the computer screen with every try“. The control group (neutral) did not receive any instruction or feedback other than task-explanatory information throughout the experiment.

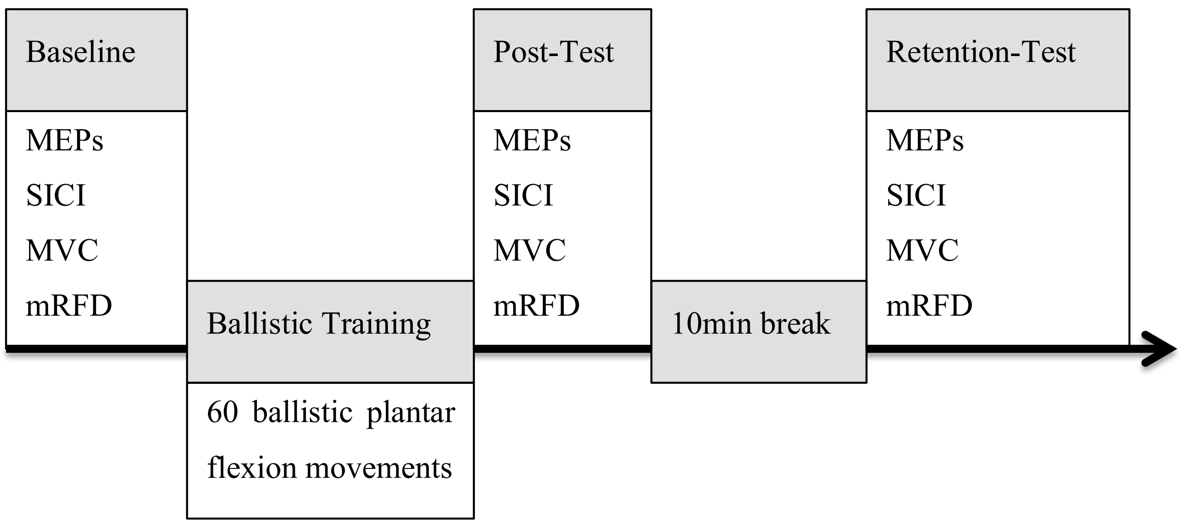

Fig. 2: Schematic representation of the experimental design. Baseline, post-test and retention-test measures included the assessment of motor evoked potentials (MEPs), short latency intracortical inhibition (SICI), maximum voluntary contraction (MVC) and maximum rate of force development (mRFD).

Ballistic training. After the assessment of the baseline values participants engaged in a short period of ballistic force training. The training block consisted of two sets of thirty consecutive isometric plantar foot flexions with the right foot with a short break of thirty seconds in between sets. The movements were paced with an audible tone. Instructions and augmented feedback were provided for participants in the aFB and EF+aFB group as described earlier. Verbal encouragement was given to each participant. Post-test measurements were conducted immediately after the training period and the retention-test was executed ten minutes after the post-test.

3.4 Data and Statistical Analysis

MEPs and SICI values were determined measuring peak-to-peak amplitudes. MEPs are presented in μV whereas SICI is expressed as the difference of single-pulse TMS MEP and paired-pulse TMS MEP in % of single-pulse TMS MEP. MVC and mRFD were measured using an isokinetic system (Cybex, CSMi Solutions, Stoughton, MA, USA). For mRFD values in pre-, post- and retention-test only the three best out of ten trials of each participant were considered in the analysis. MVC was expressed in *N m/ms* and mRFD in *N m*. EMG data was recorded and analysed with "Imago Record" software (LabView-based National

Instrument, Austin, Texas). MEPs, SICI, MVC and mRFD were analysed with the computer software MATLAB (The MathWorks Inc., Natick, MA, USA).

Differences in EMG activity and force development were tested using ANOVA. Bonferroni-corrected t-tests were calculated to assess differences between tests. The level of statistical significance was set at $p < 0.05$. For reasons of a complete overview of the statistical results, all t-test results were presented, independent of significance of ANOVA tests. The statistical analysis was performed using the computer program SPSS. All results are presented as mean ± standard deviation (SD).

4 Results

4.1 Behavioral Effects

The results in the present study show that neither of the three subject groups was able to significantly improve mean maximum voluntary contraction (MVC) output after a short ballistic training period. Figure 3 shows the change in mean MVC in % of the baseline values for the three subject groups. The neutral group as well as the augmented feedback group (aFB) performed slightly worse after the training period than prior to the training (-1,13% p = 0.78 and -1.73%, p = 0.57). Only the external focus and augmented feedback group (EF+aFB) insignificantly improved their mean maximal force by +6.77% (p = 0.36) in the post-test compared to baseline values. Both, the neutral and the aFB groups' mean MVC performances returned in the retention test near to baseline levels (neutral group +0.55% of baseline values, p = 0.93; aFB -0.69% of baseline values, p = 0.87). The EF+aFB group performed +8.39% (p = 0.20) better in the retention-test than under pre-test conditions.

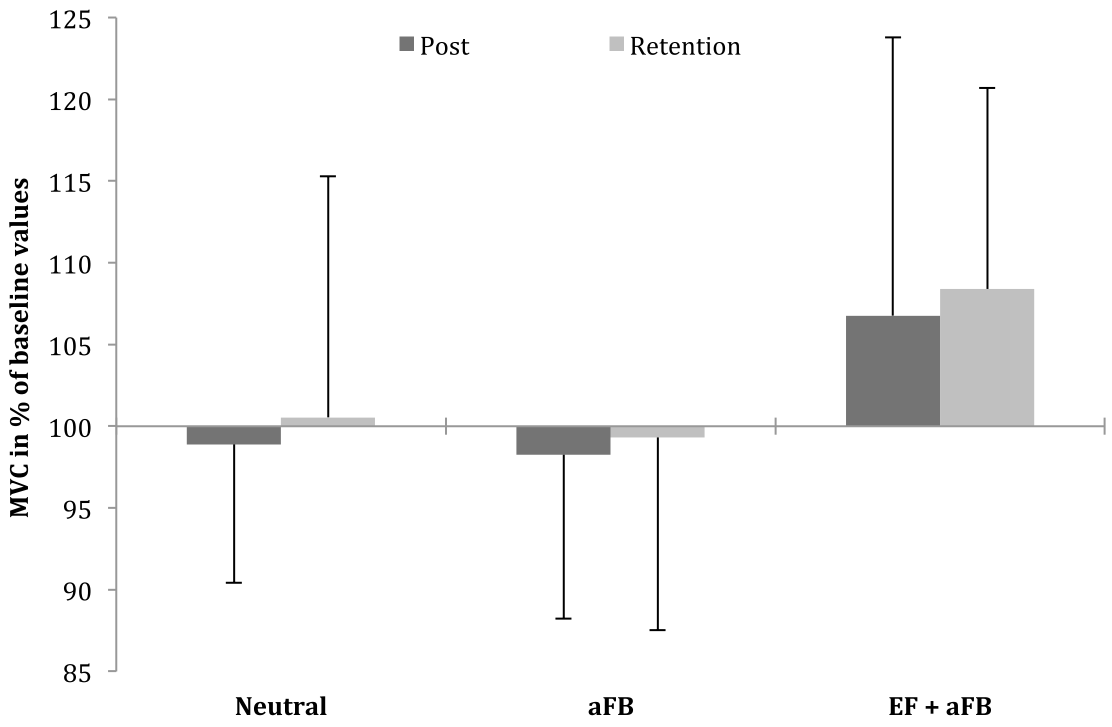

Fig. 3: Change in mean maximum voluntary contraction (MVC) under post-test and retention-test conditions expressed in % of the baseline values for each of the three subject groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB)

The ANOVA showed no significant time effect between pre-, post- and retention-test conditions ($F_{2,4} = 0.39$; $p = 0.68$; $\eta^2_{p} = 0.20$). Furthermore, there was no significant interaction effect between time and groups ($F_{4,38} = 0.55$; $p = 0.70$; $\eta^2_{p} = 0.55$).
Therefore, neither the ballistic training period nor the different instructions could improve subjects' mean MVC in the present study. Since MVC did not significantly decrease between pre-, post- and retention test, an influence of fatigue on the performance can be excluded.

Tab. 2: Measurements of maximal voluntary contraction (MVC), control maximal rate of force development (con mRFD) and maximal rate of force development with group specific instructions (mRFD) before, after and ten minutes after the ballistic training period of sixty plantar foot flexions for the groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB). Values are presented as mean ± standard deviation (SD).

		Neutral	**aFB**	**EF+aFB**
MVC	pre	125.23 ± 23.56	141.97 ± 33.59	127.25 ± 31.29
(N m/ms)	post	123.82 ± 19.31	139.51 ± 32.32	135.86 ± 33.47
	retention	125.92 ± 19.86	141.00 ± 36.46	137.92 ± 40.25
con mRFD	pre	759.36 ± 190.24	938.78 ± 275.11	664.05 ± 188.58
(N m)	post	742.13 ± 212.91	1008.30 ± 253.50	761.23 ± 215.06
	retention	751.93 ± 204.75	1013.87 ± 231.87	725.90 ± 211.29
mRFD	pre	775.17 ± 192.00	1064.67 ± 244.48	709.56 ± 204.16
(N m)	post	753.18 ± 209.20	1018.67 ± 230.51	752.79 ± 208.37
	retention	776.88 ± 220.55	1023.84 ± 239.45	812.23 ± 257.05

The mean maximal rate of force development (mRFD) achieved during the short training period consisting of sixty ballistic plantar foot flexion movements are presented in figure 4. Mean training mRFD was smaller than the mean mRFD baseline values for all three groups. Only one single mean mRFD performance reached baseline values during the training period (trial nr. 27 of the EF+aFB group). The EF+aFB group performed the training with an average mRFD closest to their measured baseline mean mRFD (-7.39%) compared to the other two groups. On average, the aFB group training with greater mRFD (-11.37%) in respect to their baseline mRFD than the neutral group (-13.99%). Comparison of the first five plantar foot flexions of the ballistic training with the last five show an insignificant decrease in mean mRFD for the neutral group (-1.16%, p = 0.72) as well as for the EF+aFB group (-2.26%, p = 0.36) and an insignificant increase for the aFB group (+0.24%, p = 0.96). Thus, a further indication that fatigue did not interfere with performance.

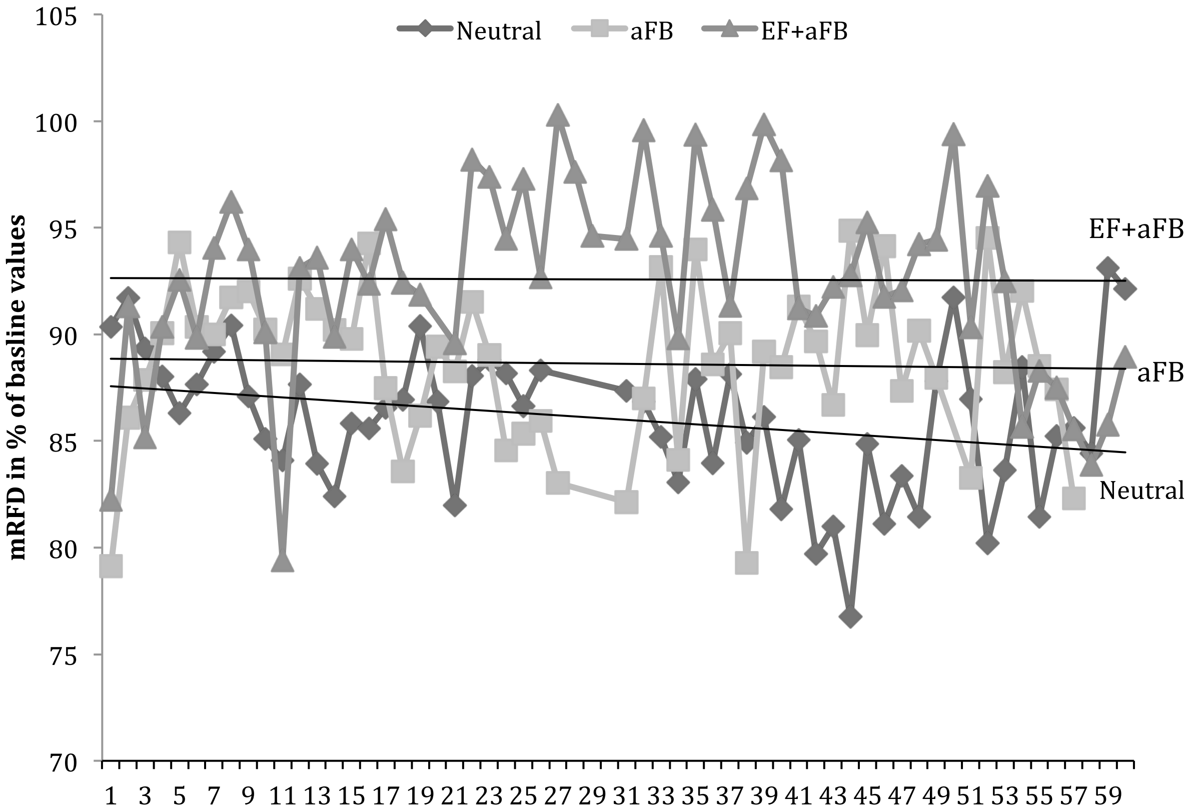

Fig. 4: Mean maximum rate of force development (mRFD) of each ballistic plantar foot flexion during the training period expressed in % of the mean baseline mRFD for the groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB).

Maximum rate of force development (mRDF) was measured before, after and ten minutes after the ballistic training period. For the mean control mRDF no specific instructions were given to any of the groups. For the neutral group changes in control mRFD between pre- and post-test (-2.27%, p =0.51) and pre- and retention-test (+1.32%, p = 0.63) were insignificant. Subjects of the aFB group achieved the highest control mRFDs in all three test conditions. The mean control mRFD in the aFB group were only insignificantly improved from pre- to post-test (+7.41%, p = 0.52) and from pre- to retention-test (+0.55%, p = 0.39).

Post-test control mRFD measured in the EF+aFB group were only insignificantly improved (+14.63%, p = 0.15) compared to the pre-test. The mean control mRFD measured in the retention-test of the EF+aFB group were slightly lower than those achieved during the pre-test

(-4.64%, p = 0.30). The ANOVA of mean control mRFD revealed no significant effect between pre-, post- and retention-test conditions within the three subject groups ($F_{2,4} = 1.350$; $p = 0.271$; $\eta^2_{p} = 0.066$). Furthermore, there was no significant time × group interaction effect ($F_{4,38} = 0.614$; $p = 0.655$; $\eta^2_{p} = 0.061$) for control mRFD.

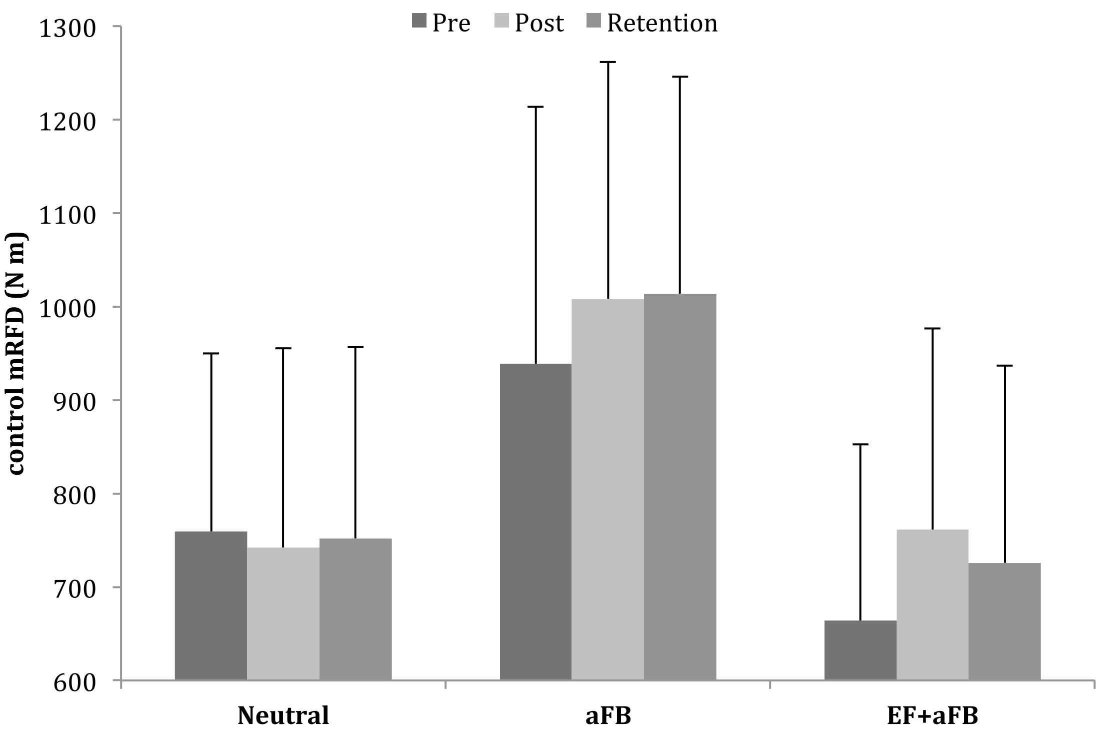

Fig. 5: Mean control maximum rate of force development (control mRFD) pre, post and ten minutes after the training period of the groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB) without group specific instruction and feedback.

Oppose to the control mRFD measurements, group specific instructions where given during a second set of mRFD measurements. Mean mRFD measured pre, post and ten minutes after the training period of each subject group providing group specific instruction and feedback are shown in figure 6.

Changes in mean mRFD between pre- and post-test (-2.84%, p = 0.21) as well as pre- and retention-test (+3.15%, p = 0.95) of the neutral group were insignificant. Mean mRFD achieved in the aFB group did not differ significantly between pre- and post-test (-4.32%, p = 0.45) nor between pre- and retention-test (+0.51%, p=0.47).

For the EF+aFB group no significant changes in mean mRFD could be detected between pre- and post-test (+6.09%, p = 0.28) and between pre- and retention-test (+7.90%, p = 0.10).

Calculated ANOVA for mRFD showed no significant time effect ($F_{2,4}$ = 0.774; p = 0.468; η^2_p = 0.039) and no significant time × group interaction effect ($F_{4,38}$ = 1.559; p = 0.205; η^2_p = 0.141).

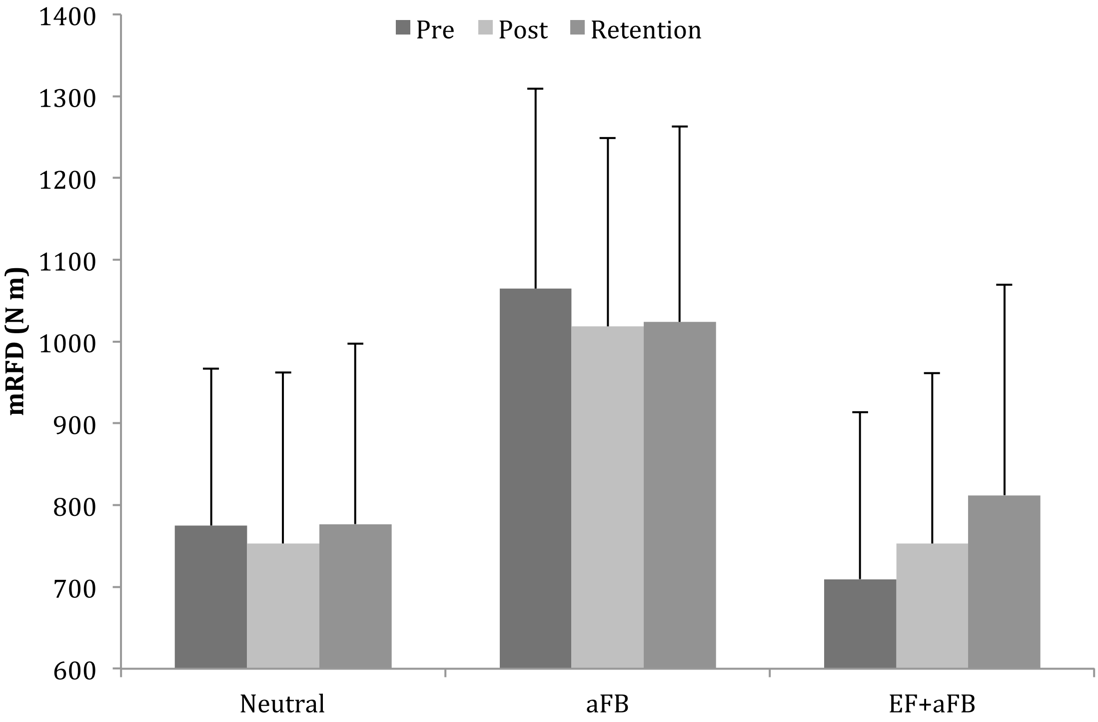

Fig. 6: Mean maximum rate of force development (mRFD) pre, post and ten minutes after the training period of the subject groups neutral, augmented feedback (aFB) and external focus and augemented feedback (EF+aFB) providing group specific instruction and feedback.

When comparing mean control mRFD with mean mRFD performances under instruction and feedback condition it can be stated that subjects generally achieved better performances during the second set of mRFD measurements i.e. under instruction and feedback conditions (except for EF+aFB group in the post-test).

However, the differences between mean mRFD under control and instruction condition were non-significant for the neutral group (pre: p = 0.43, post: p = 0.39, retention: p = 0.09) and aFB group (pre: p = 0.14, post: p = 0.44, retention: p = 0.75) as well as for pre-test (p = 0.12) and post-test (p = 0.59) measurements of the EF+aFB group. Only the difference between mean control mRFD and mean mRFD with instructions and feedback of the EF+aFB group during the retention-test was significant (p = 0.006). Comparison of changes in mean mRFD in percentage to mean control mRFD is presented in figure 7.

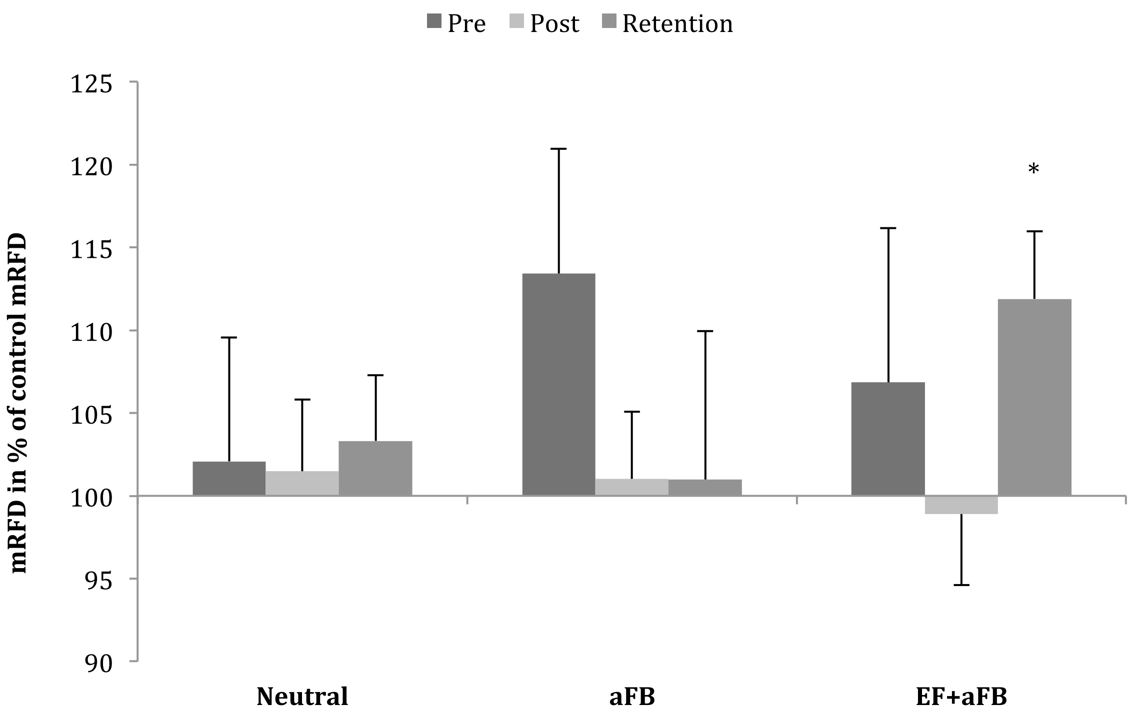

Fig. 7: Change in mean maximum rate of force development (mRFD) with group specific instructions and feedback in % of the mean control maximum rate of force development (control mRFD) without instructions and feedback. * = $p < 0.05$.

4.2 Neurophysiological Effects

Measurements of the mean motor evoked potential (MEP) of the M. gastrocnemius medialis (GASm) of the right leg showed a non-significant change between pre- and post-test conditions (+27.63%, p = 0.62) for the neutral group. Changes in mean MEPs between pre- and retention-test (+37.20%, p = 0.48) as well as changes in mean MEPs between post- and retention-test (+7.50%, p = 0.89) of the neutral group were not significant. For the aFB group, pre- to post-test MEPs did not differ significantly (+60.45%, p = 0.17) nor did pre- to retention-test (+49.46%, p = 0.19) and post- to retention test differences (-6.84%, p = 0.65). As for the EF+aFB group post-test mean MEPs insignificantly decreased by -5.14% (p = 0.86) in comparison to the pre-test mean MEPs. Mean MEPs in the GASm for the EF+aFB group decreased slightly between pre- and retention-test (-0.76%, p = 0.88) and increase insignificantly between post- and retention-test (+4.62%, p = 0.78).

The ANOVA of MEP values in the GASm showed no significant time effect ($F_{2,4} = 1.391$; $p = 0.262$; $\eta^2_p = 0.072$) and could also not reveal any time × group interaction effect ($F_{4,36} = 0.542$; p = 706; $\eta^2_p = 0.057$). Mean MEP in the GASm of the three groups under pre-, post- and retention-test conditions are presented in figure 8.

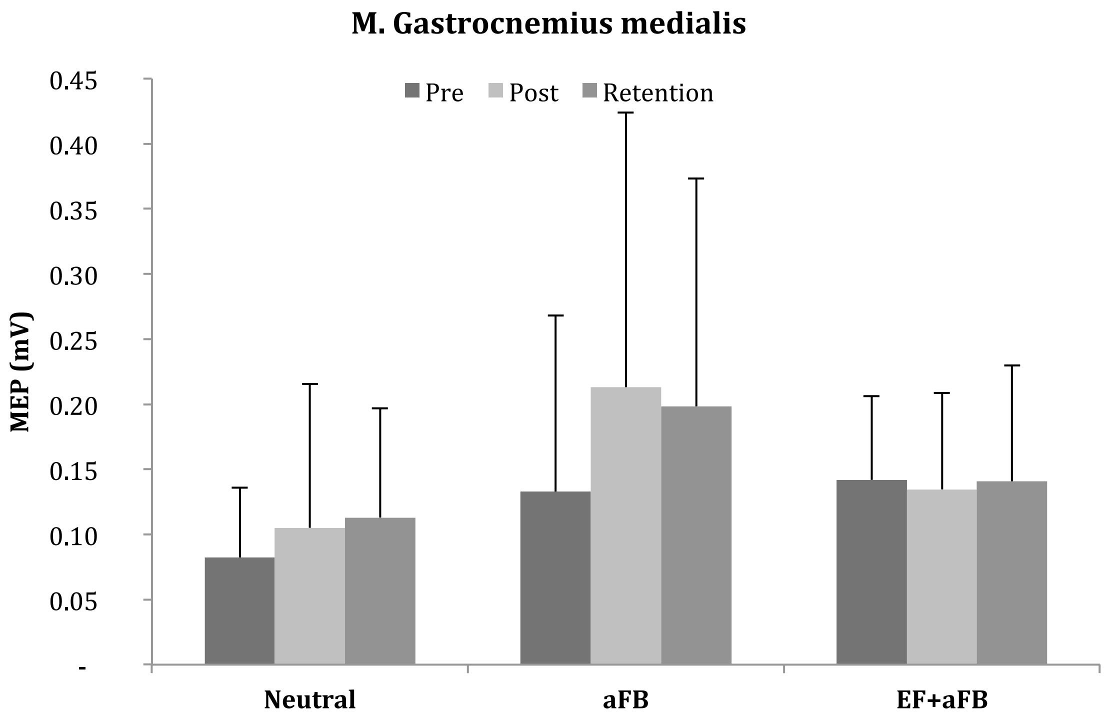

Fig. 8: Mean motor evoked potential (MEP) measured for the M. gastrocnemius medialis (GASm) for the three subject groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB) before, after and ten minutes after the ballistic training period.

Tab. 3: Measurements of motor evoked potential (MEP) and short latency intracortical inhibiton (SICI) in percentage of the MEPs in the M. gastrocnemius medialis (GASm), M. soleus (SOL) and M. tibialis anterior (TA) of the right leg before, after and ten minutes after the ballistic training period of sixty plantar foot flexions for the groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB). Values are presented as mean ± standard deviation (SD).

		Neutral		**aFB**		**EF+aFB**	
		MEP (mV)	*SICI (%)*	*MEP (mV)*	*SICI (%)*	*MEP (mV)*	*SICI (%)*
GASm	pre	0.08 ± 0.05	42.38 ± 27.82	0.13 ± 0.14	61.09 ± 22.47	0.14 ± 0.06	76.27 ± 14.87
	post	0.11 ± 0.11	36.19 ± 40.03	0.21 ± 0.21	63.98 ± 28.55	0.13 ± 0.07	69.38 ± 28.82
	retention	0.11 ± 0.08	41.37 ± 40.19	0.20 ± 0.18	57.46 ± 34.07	0.14 ± 0.09	70.24 ± 26.31
SOL	pre	0.13 ± 0.07	44.38 ± 28.51	0.23 ± 0.17	51.74 ± 28.87	0.12 ± 0.06	69.22 ± 18.19
	post	0.13 ± 0.08	46.63 ± 37.24	0.24 ± 0.20	59.95 ± 27.91	0.15 ± 0.03	64.20 ± 33.43
	retention	0.11 ± 0.06	33.44 ± 29.47	0.24 ± 0.17	62.03 ± 24.18	0.15 ± 0.05	58.83 ± 27.77
TA	pre	0.44 ± 0.33	54.26 ± 19.96	0.53 ± 0.32	63.54 ± 19.83	0.37 ± 0.24	73.21 ± 18.33
	post	0.40 ± 0.25	32.77 ± 53.76	0.70 ± 0.62	72.57 ± 22.37	0.39 ± 0.26	66.57 ± 30.57
	retention	0.38 ± 0.29	34.77 ± 29.85	0.63 ± 0.47	75.45 ± 19.80	0.39 ± 0.16	68.06 ± 26.57

Paired-puls transcranial magnetic stimulation (TMS) to the motor cortex serves to measure intracortical inhibition (ICI). Mean measured short latency intracortical inhibition (SICI) for the neutral group showed that mean paired-puls MEPs in the GASm was inhibited by 42.38% (± 27.82%) in comparison to mean single-puls MEPs under pre-test conditions. The inhibition of mean MEP of the neutral group decreased subsequently insignificantly in the post-test (-14.61%, p = 0.25) and retention-test (-2.38%, p = 0.93) and increased insignificantly between post- and retention-test (+14.32%, p = 0.93).

As for the aFB group measured mean paired-pulse MEP in the GASm resulted in a inhibition of 61.09% (± 22.47%) compared to the mean single-pulse MEP in the pre-test. Post-test measurements of mean SICI-pulse showed an inhibition of 63.95% (± 28.55%) in respect to the mean single-puls MEP, which reveals an insignificant change in mean MEP inhibition in the GASm of +4.72% (p = 0.72) between pre- and post-test of the aFB group. In the retention test measured mean SICI-MEP was 57.46% (± 34.07%) smaller than mean single-puls MEP. Changes in MEP inhibition in the GASm were insignificant between pre- and retention-test (-5.93%, p = 0.69) and between post- and retention-test (-10.18%, p = 0.59) of the aFB group.

Pre-test mean paired-pulse MEP in the GASm was 76.27% (± 14.87%), post-test mean paired-pulse MEP was 69.38% (± 28.82%) and retention test mean paired-pulse MEP was 70.24% (± 26.31%) inhibited in respect to the mean single-pulse MEP for the EF+aFB group. The changes in mean SICI-MEP inhibition in the GASm between pre- and post-test (-9.03%, p = 0.52), pre- and retention-test (-7.90%, p = 0.54) and post- and retention-test (+1.25%, p = 0.82) were all non-significant for the EF+aFB group.

Measurements of the mean SICI of MEP in GASm showed no significant changes between test times ($F_{2,4} = 0.884$; $p = 0.422$; $\eta^2_p = 0.049$) nor showed they any time × group interaction effect ($F_{4,34} = 0.281$; $p = 0.888$; $\eta^2_p = 0.032$). Inhibition of mean MEPs in GASm of the three groups neutral, aFB and EF+aFB are presented in figure 9.

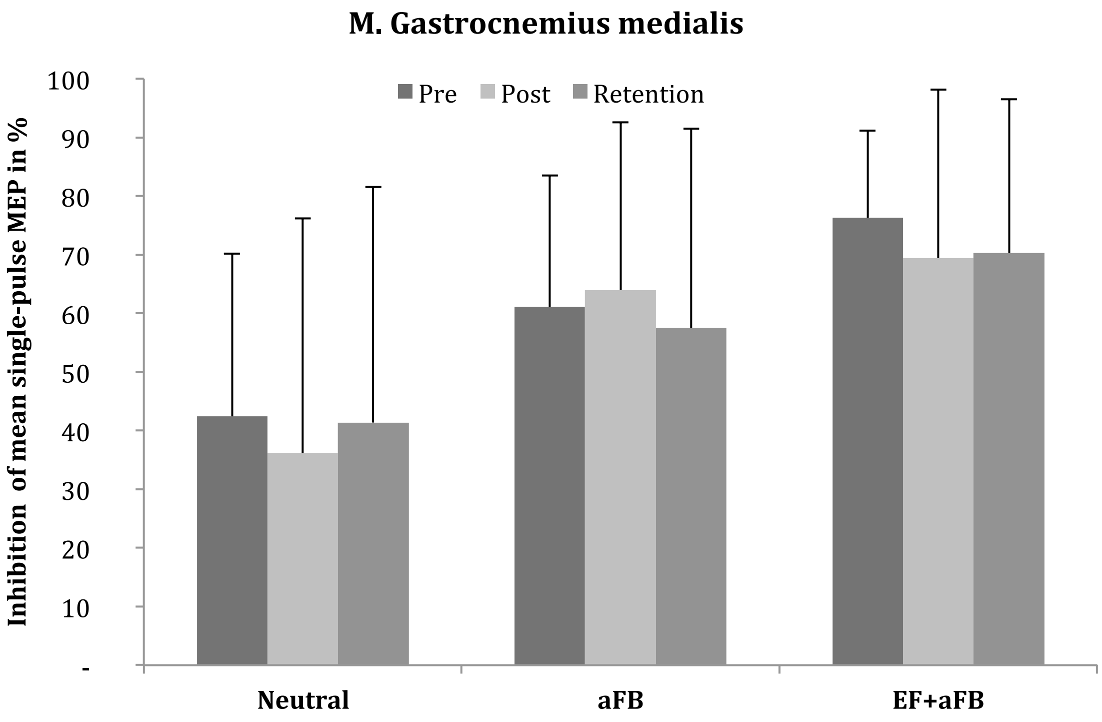

Fig. 9: Difference between mean paired-pulse motor evoked potential (MEP) and mean single-pulse MEP expressed in % of mean single-pulse MEP in the M. gastrocnemius medialis (GASm) of the groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB) of pre-, post- and retention-test.

The results in the presented study show that mean MEP in the M. soleus (SOL) of the right leg did not differ significantly between pre- and post-test (-2.29%, p = 0.90), between pre- and retention-test (-14.88%, p = 0.81) and between post- and retention-test (-12.89%, p = 0.54) for the neutral group.

Mean MEP in the SOL for the aFB group changed only insignificantly between pre- and post-test (+7.52%, p = 0.42), between pre- and retention-test (+4.47%, p = 0.80) and between post- and retention-test (-2.84%, p = 0.88).

As for the EF+aFB group no significant difference in mean MEP in the SOL could be detected between pre- and post-test (+20.01%, p = 0.33), pre- and retention-test (+21.29%, p = 0.31) and between post- and retention-test (+1.06%, p = 0.88).

Calculated ANOVA could not reveal a time effect ($F_{2,4} = 0.652$; $p = 0.527$; $\eta^2_{p} = 0.035$) and no time × group interaction effect ($F_{4,36} = 0.096$; $p = 0.983$; $\eta^2_{p} = 0.011$) for mean MEPs in the SOL. Measured mean MEPs in SOL of the groups neutral, aFB and EF+aFB under pre-, post- and retention-test conditions are presented in figure 10.

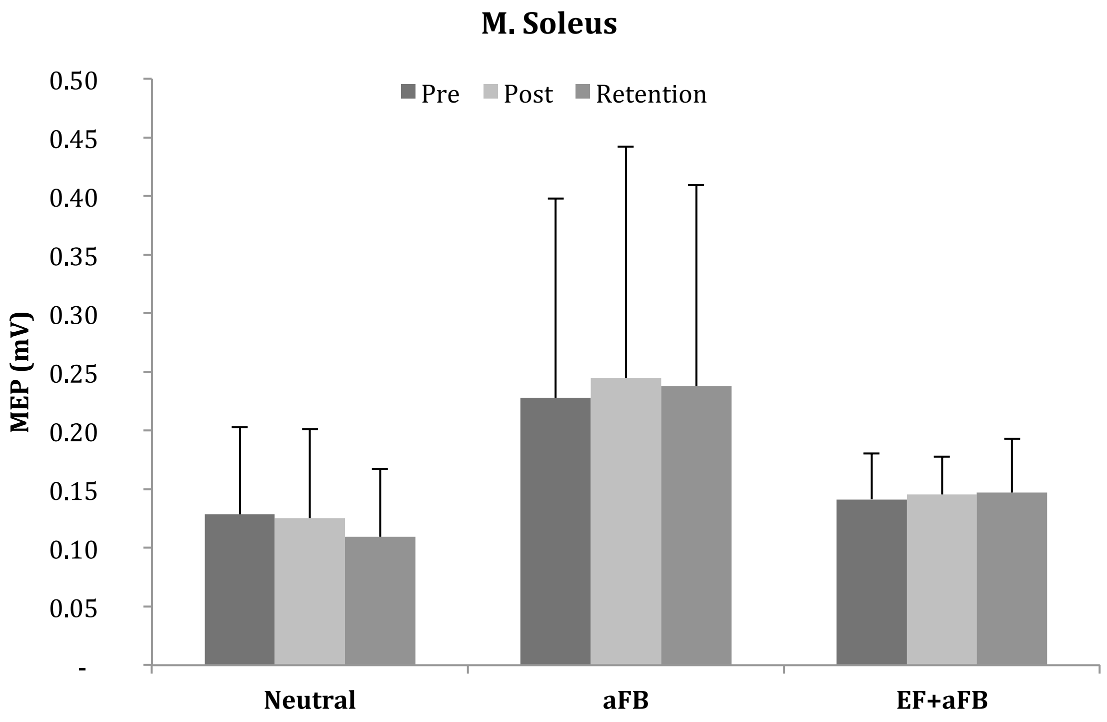

Fig. 10: Mean motor evoked potential (MEP) measured for the M. soleus (SOL) for the three subject groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB) before, after and ten minutes after the ballistic training period.

Measured mean SICI-pulse was 44.38% (± 28.51%) smaller than mean single-pulse MEP in the SOL for the neutral group in pre-test. SICI only changed insignificantly between pre- and post-test (+5.06%, p = 0.79) and pre- and retention-test (-24.65%, p = 0.42) for the neutral group. The inhibition of mean single-pulse MEP in SOL in the retention-test was 33.44% (± 29.47%) for the neutral group, which represents only a non-significant change between post- and retention-test of -28.27% ($p = 0.58$).

Mean SICI of the aFB group amounted 51.74% (± 28.87%) of the mean single-pulse MEP in the SOL in pre-test. Post-test measurements of mean SICI of mean single-pulse MEP in the SOL was 59.95% (± 27.91%) and therefore only insignificantly higher than during the pre-test (+15.87%, $p = 0.17$) for the aFB group. Mean SICI for the aFB group in the retention-test showed an insignificant increase of +19.88% ($p = 0.09$) and +3.45% ($p = 0.80$) in comparison to the pre-test and post-test respectively.

As for the EF+aFB group, mean paired-pulse MEPs in the SOL showed an inhibition of 69.22% (± 18.19%) under pre-test conditions, 64.20% (± 33.34%) under post-test conditions and 58.83% (± 27.77%) under retention-test conditions in respect to mean single-pulse MEPs. Changes in SICI for the EF+aFB group in SOL between the three test times were all insignificant (pre- to post-test: -7.25%, $p = 0.64$; pre- to retention-test: -15.01%, $p = 0.38$; post- to retention-test: -8.36%, $p = 0.47$).

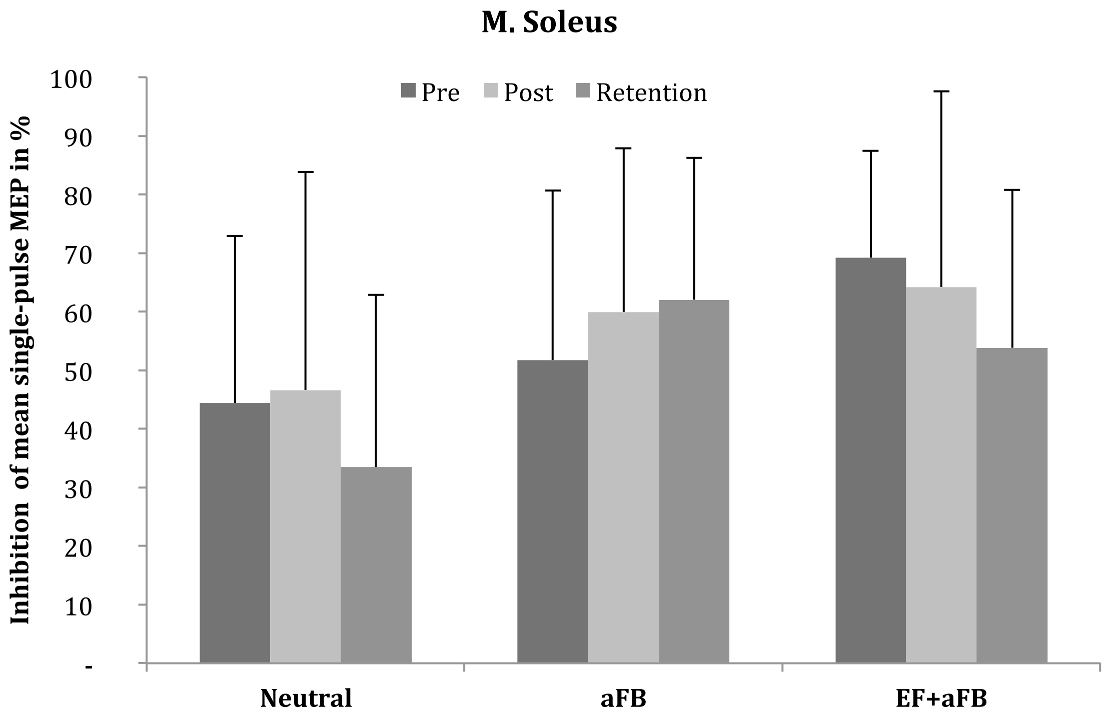

Fig. 11: Difference between mean paired-pulse motor evoked potential (MEP) and mean single-pulse MEP expressed in % of mean single-pulse MEP in the M. soleus (SOL) of the groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB) of pre-, post- and retention-test.

The ANOVA showed no significant time effect ($F_{2,4}$ = 0.364; p = 0.698; η^2_{p} = 0.021) and no significant time × group interaction effect ($F_{4,34}$ = 1.010; p = 0.416; η^2_{p} = 0.106) for SICI of MEPs in the SOL. SICI values of MEPs in the SOL for the three groups neutral, aFB and EF+aFB in pre-, post- and retention-test are presented in figure 11.

TMS evoked mean MEPs measured in the M. tibialis anterior (TA) of the right leg amounted to 0.44 µV (± 0.33 µV) in the pre-test, 0.40 µV (± 0.25 µV) in the post-test and 0.38 µV (± 0.29 µV) in the retention-test for the neutral group. Changes in mean MEPs in the TA between pre- and post-test (-9.45%, p = 0.63), pre- and retention-test (-13.42%, p = 0.38) and post- and retention-test (-4.38%, p = 0.67) were all insignificant for the neutral group.

As for the aFB group, mean MEPs measured in the TA in the pre-test were 0.53 µV (± 0.32 µV), 0.70 µV (± 0.62 µV) in the post-test and 0.63 µV (± 0.47 µV) in the retention-test. Alike the neutral group, changes in mean MEPs in the TA for the aFB group between test times were non-significant (pre- to post-test: +31.84%, p = 0.19; pre- to retention-test: +18.12%, p = 0.21; post- to retention-test: -10.41%, p = 0.40).

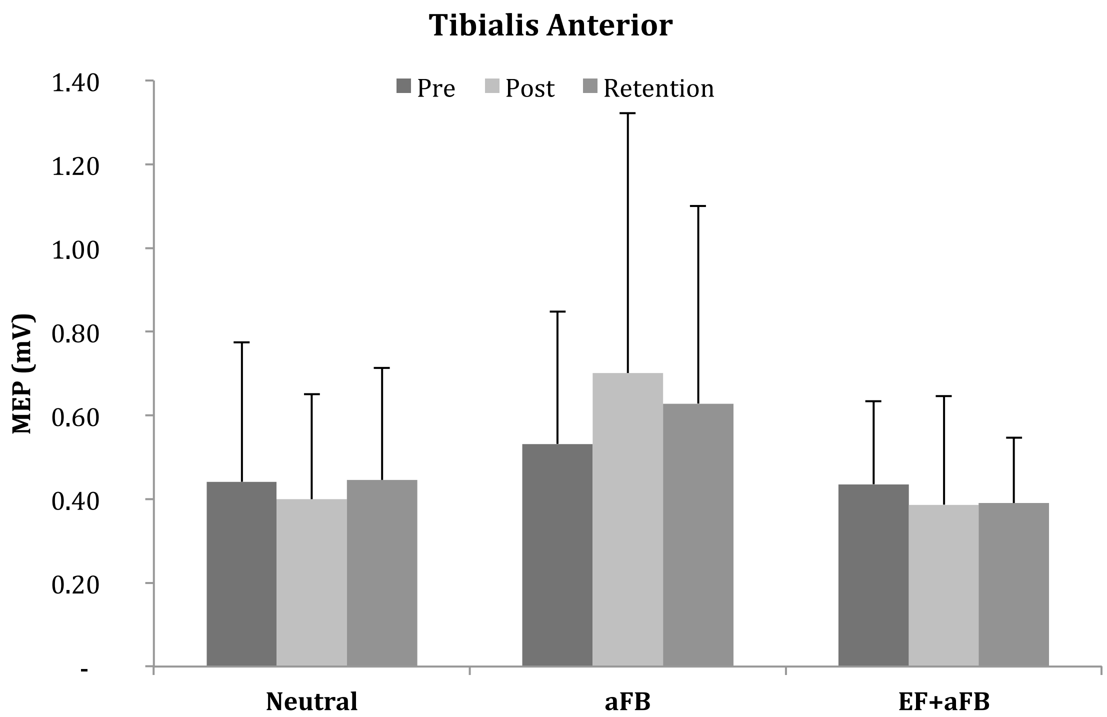

Fig. 12: Mean motor evoked potential (MEP) measured for the M. tibialis anterior for the three subject groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB) before, after and ten minutes after the ballistic training period.

The results of achieved mean MEPs in the TA for the EF+aFB group showed no significant difference between pre- and post-test (pre-test: 0.37 ± 0.24 µV; post-test: 0.39 ± 0.26 µV; difference: +3.59%, $p = 0.86$), pre- and retention-test (pre-test: 0.37 ± 0.24 µV; retention-test: 0.39 ± 0.16 µV; difference: +4.48%, $p = 0.86$) and between post- and retention-test (post-test: 0.39 ± 0.26 µV; retention-test: 0.39 ± 0.16 µV; difference: +0.86%, $p = 0.96$).

The ANOVA of mean MEPs in TA detected no time effect ($F_{2,4} = 0.362$; $p = 0.699$; $\eta^2_p = 0.021$) and no interaction effect between test times and subject groups ($F_{4,34} = 1.117$; $p = 0.365$; $\eta^2_p = 0.116$). Measured mean MEPs in the TA for the groups neutral, aFB and EF+aFB under pre-, post- and retention-test conditions are presented in figure 12.

Mean paired-pulse MEPs in TA of the neutral group showed an inhibition of 54.26% (± 19.96) in the pre-test, 32.77% (± 53.76%) in the post-test and 34.77% (± 29.85%) in the retention-test in respect to mean single-pulse MEPs. Differences in mean SICI of MEPs of the neutral group were insignificant between pre- and post-test (-39.61%, $p = 0.23$) and post- and retention-test (+6.10%, $p = 0.66$). Changes in mean SICI of MEPs in TA were significant between pre- and retention-test (-35.92%, $p = 0.02$) of the neutral group.

As for the aFB group, paired-pulse MEPs in TA were 63.54% (± 19.83%) in the pre-test, 72.57% (± 22.37%) in the post-test and 75.45% (±19.80%) in the retention-test reduced in comparison to the mean single-pulse MEPs in the same muscle. None of the differences in mean SICI of MEPs in the TA were significant for the aFB group (pre- to post-test: +14.21%, $p = 0.06$; pre- to retention-test: +18.75%, $p = 0.05$; post- to retention-test: +3.97%, $p = 0.66$).

Monitored mean SICI of mean MEPs in the TA showed an inhibition of 73.21% (± 18.33%) in the pre-test of the EF+aFB group. Mean paired-pulse MEP inhibition only insignificantly changed between pre- to post-test (-9.07%, $p = 0.46$) to 66.57% (± 30.57%) for the EF+aFB group. EF+aFB group retention-test measurements of mean SICI in the TA amounted to 68.06% (± 26.57%), which represented a non-significant difference of -7.04% ($p = 0.39$) and +2.24% ($p = 0.75$) in comparison to pre-test and post-test measurements respectively.

The ANOVA showed no time ($F_{2,4} = 1.277$; $p = 0.292$; $\eta^2_p = 0.070$) and no time × group interaction effect ($F_{4,34} = 1.851$; $p = 0.142$; $\eta^2_p = 0.179$) for SICI of MEPs in the TA. Measured SICI values of MEPs in the TA for the groups neutral, aFB and EF+aFB in pre-, post- and retention-test are shown in figure 13.

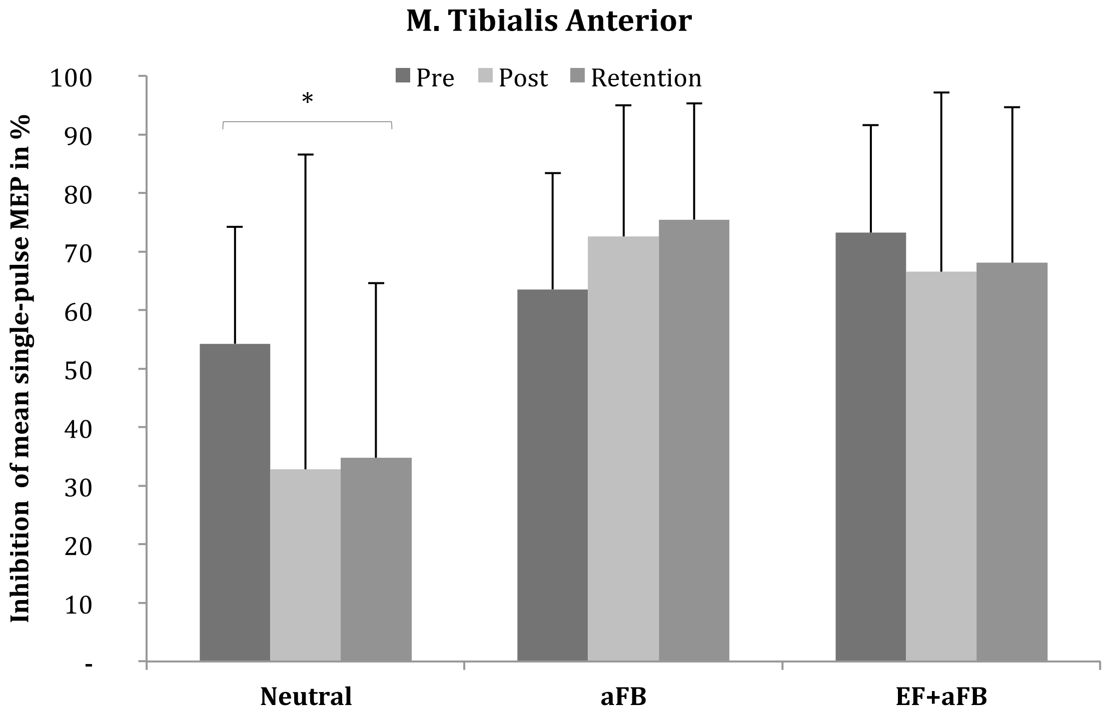

Fig. 13: Difference between mean paired-pulse motor evoked potential (MEP) and mean single-pulse MEP expressed in % of mean single-pulse MEP in the M. tibialis anterior (TA) of the groups neutral, augmented feedback (aFB) and external focus and augmented feedback (EF+aFB) of pre-, post- and retention test. * = $p < 0.05$.

5 Discussion

The empirical literature provides a large number of evidence that augmented knowledge of result feedback (aFB) and inducing an external focus of attention (EF) through instructions or feedback are effective tools to improve immediate motor performance and motor learning (for reviews see Lauber & Keller, 2014; Wulf, 2013). A study, which compared the two strategies with each other revealed a more beneficial effect on motor performance and motor learning, when aFB was provided than when instructions were given to induce EF or an internal focus of attention (Keller et al., 2015). A further study then combined the two strategies EF and aFB for guidance in countermovement jumps (CMJ) and found evidence that this combination enhances performance even more compared to just aFB. In the present study, the first aim was to combine aFB and EF instructions to further investigate the behavioral effects on performance and short-term learning of a ballistic force production task compared to when only aFB or no feedback is provided. Based on the existing literature, it was hypothesized that a combination of EF and aFB would result in greater maximum rate of force development (mRFD) and greater maximum voluntary contraction (MVC) after a short ballistic training period than when providing only aFB or no aFB and EF. The results in the presented study showed no differences in MVC and mRFD between pre-, post- and retention-test within the three groups neutral, aFB and EF+aFB. Therefore, the presented results do not support the predictions made and are in contrast to other training studies showing that aFB as well as the combination of EF and aFB have a beneficial effect on performance and retention of force production (Hopper et al., 2003; Keller et al., 2014; Wälchli et al., 2015). A second aim of this study was to investigate the effects on the neurophysiological adaptions of the corticospinal and intracortical excitability (MEPs and SICI) when providing aFB or a combination of EF and aFB for a plantar foot flexion task. Based on the existing literature we hypothesized that a short ballistic training period would increase TMS-evoked MEP amplitude in the target muscle compared to the baseline values, whereby the combination of providing aFB and promoting EF results in higher MEP values than when just providing aFB or no aFB and EF. The results in the present study showed no difference in TMS-evoked MEP amplitude between pre-, post- and retention-test for neither of the three groups neutral, aFB or EF+aFB and are therefore in contrast to our predictions and other studies providing evidence that a short ballistic period of training facilitates MEP in the trained muscle (Lundbye-Jensen et al., 2011; Muellbacher et al., 2001; Rogasch et al., 2009). The reasons for these contradictory results are discussed in the following paragraphs.

Behavioral Aspects. It has been suggested that results of experiments are based on different determinants (e.g. task, skill level of participants, feedback frequency etc.) and that therefore the results have to be seen within the specific context of the study (Lauber & Keller, 2014; Magill, 1994; Wulf & Shea, 2002). Wulf and Shea (2002) claimed in their review, that principles of motor skill learning differ between simple skills and complex skills. They defined a simple skill as a task, which has only one degree of freedom and can be learnt within one practice session, whereas a complex skill has several degrees of freedom and needs different practice sessions to be learnt. With respect to aFB and EF, Wulf and Shea (2002) stated that certain practice variables enhancing motor learning for simple skills do not seem to be beneficial for learning complex skills and vice versa. For example, while a reduced feedback frequency might be beneficial for learning simple tasks, it was shown that a high feedback frequency enhances learning of complex skills (Wulf & Shea, 2002). Additionally, since complex skills require more information-process demands than simple skills, certain practice variables like providing instructions and feedback inducing an EF might enhance complex skill learning, but might not influence simple skill learning (Wulf & Shea, 2002). Many of the earlier presented and cited studies about aFB and EF used complex skills like jumping (countermovement jumps (Keller et al., 2015; Wälchli et al., 2015); drop jumps (Keller et al., 2014); standing long jumps (Porter et al., 2010)), balancing (Taube et al., 2008; Wulf et al., 2001) or sport specific skills (soccer passes and volleyball services (Wulf et al., 2002); tennis services (Moran et al., 2012)) to investigate the effects of aFB and EF on motor learning and immediate performance. In contrast, the present study used a plantar foot flexion task, a simple skill, to examine effects of aFB and a combination of EF and aFB on motor performance and motor learning. Keller et al. (2014) and Wälchli et al. (2015) concluded in their study that the main reason for the immediate improvement in performance of participants is that aFB stimulates their intrinsic motivation. Both studies suggest, that short-term learning did not affect performance since performance only improved when aFB was provided but decreased immediately after aFB was withdrawn. Therefore the intrinsic motivation is suggested to be the main factor for the positive effect of aFB. The present results indicate that short-term learning did also not affect performance in the present study but do not provide evidence that motivation could have been a factor influencing the performance outcome since no difference was found between mean mRFD without aFB and mean mRFD when aFB was provided (exception: retention-test of the EF+aFB group ($p = 0.006$)). The lack of improvement in MVC and mRFD is speculated to be due to the simplicity of the plantar foot flexion task used in the present study. According to the energisation theory (Brehm & Self, 1989) mobilization of energy is dependent on the task difficulty. Hence, a simple task like a plantar foot flexion might not sufficiently arouse participants' motivation to improve their performance with every trial, unlike a complex task. This notion is further supported by Wulf and Shea (2002), who mentioned that "…learning of a simple task might be enhanced by making practice more "difficult" or challenging for the learner (e.g., by reducing feedback frequency or providing serial/random feedback),…" (p. 194). Furthermore, Wälchli et al. (2015) proposed that the combination of EF and aFB can, compared to just providing aFB, further improve performance of a complex task because instructions inducing an EF foster a greater movement efficiency additionally to the motivational effect of aFB. Wulf and Shea (2002) stated that while certain principals, like inducing an EF through instructions or feedback, enhance learning of a complex skill, these variables might not affect simple skill learning since there is only one degree of freedom. Simple tasks are thought to be learnt in just one training session (Wulf & Shea, 2002). Therefore, it is suggested that participants had already achieved a high level of automaticity of the plantar foot flexion movement so that the positive effects of EF mentioned could not influence performance of participants. Additionally, aFB could have obfuscates any additional enhancement effect of the EF instruction since it seems to already induce an EF when performing an isolated simple motor task by drawing the attention to the computer screen. Thus, the lack of performance improvement in the present study might be due to the fact that aFB and EF might not have the same positive impact on performance and learning of a simple task as shown for a complex task.

Finally, contradictory training and post-test performances of all groups could also be explained with task dependent movement kinematics. A study by Lundbye-Jensen et al. (2011) focused on the same muscle group (plantar foot flexors) and had a comparable experimental procedure (producing torque through plantar foot flexion to a force pedal), showed improvement in achieved torque during three training periods of eight minutes. However, subjects in this study were sitting in a chair seat and there is no evidence that the knee joint of the leg to be tested was immobilized to inhibit knee extenders involvement in the torque production. Hence, when performing plantar foot flexion movements to the force pedal other muscle groups than solely the plantar foot flexors could have contributed to the constant increase in force production. In contrast, subjects in the present study were in a supine position with the knee joint of the working leg strapped to the chair seat to prevent an engagement of other muscles groups than plantar foot flexors to produce force (Fig. 1). Therefore it is argued, that the differences in improvement of force production during and after the training period between the two studies are due to differences in movement kinematics.

Neurophysiological Aspect. Different studies have observed an increase in MEP in the trained muscles immediately after a short period of ballistic training (Giesebrecht et al., 2012; Lundbye-Jensen et al., 2011; Muellbacher et al., 2001; Rogasch et al., 2009). When comparing the cited studies with the present one, which did not detect an increase in MEP after practice, a significant difference can be seen between the amount of ballistic movement repetitions performed during the training session. While in the present study sixty ballistic foot flexion movements were executed during practice, in other experiments 105 repetitions (Lundbye-Jensen et al., 2011), 300 repetitions (Giesebrecht et al., 2012; Rogasch et al., 2009) and sixty minutes of practice (Muellbacher et al., 2001) were performed. Additionally, three of the above mentioned studies focused on different finger muscles (Giesebrecht et al., 2012; Muellbacher et al., 2001; Rogasch et al., 2009), whereas the present study investigated the plantar foot flexors SOL and GASm. Therefore, it is speculated that the training period might not have consisted of enough movement repetitions in order to impact MEP in the plantar foot flexors SOL and GASm.

Another aspect to be considered is that repetitive transcranial magnetic stimulation (rTMS) to the primary motor cortex can interfere with the consolidation of the acquisition of a ballistic motor skill and performance after training (Baraduc et al., 2004; Lundbye-Jensen et al., 2011; Muellbacher et al., 2002). A study by Muellbacher et al. (2002) investigated the learning effects of a short practice period on maximum pinch force and pinch acceleration. Participants practiced their pinch force and acceleration in two periods of five minutes and one period of ten minutes. There was a break of fifteen minutes in between each practice period, in which rTMS at 115% of resting motor threshold (rMT) was applied immediately after each practice period. The results showed that subjects were able to improve performance during the practice sessions, although applying suprathreshold rTMS to the motor cortex inhibited the retention of behavioral improvement in peak pinch force and peak pinch acceleration. It was concluded that suprathreshold rTMS applied to the motor cortex interferes with early motor consolidation. A second study by Baraduc et al. (2004) supported these findings. In their study participants had to perform two sessions of 150 rapid ballistic finger abduction with the goal to improve acceleration speed. In between the two sessions rTMS at 120% of rMT was applied for fifteen minutes to the primary motor cortex representing the trained finger muscle. Again, participants were able to increase the finger abduction acceleration speed within both training session. But the positive training effect on the performance was almost completely abolished after suprathreshold rTMS was applied. Early trials of rapid ballistic finger abductions had almost the same speed at the beginning of both practice sessions. Therefore, rTMS showed a severe degradation of the retention of a learned ballistic force task. Finally, in the study by Lundbye-Jensen et al. (2011) participants engaged in three short periods (eight minutes) of practices, in which they performed maximum voluntary plantar foot flexion torque. At the end of each practice period 1Hz rTMS at either 115% rMT, 90% rMT or sham rTMS was applied to the primary cortex area evoking the plantar foot flexors for twenty minutes. The result showed again a performance increase during each of the short practice period, but that performances significantly decreased after suprathreshold rTMS (115% rMT) was applied, although this was not the case when a subthreshold rTMS (90% rMT) or sham rTMS was applied. It was concluded that suprathreshold rTMS interferes with consolidation of motor skills and abolishes retention of ballistic learning and is in line with the other two presented studies (Baraduc et al., 2004; Muellbacher et al., 2002). Furthermore, the study of Lundbye-Jensen et al. (2011) showed a suppressing effect of suprathreshold rTMS on MEPs of the trained muscle. Despite a significant increase in MEP after the practice period, MEP decreased significantly followed by an application of suprathreshold rTMS to the motor cortex. These three studies presented above provide evidence, that despite a positive learning effect on performances after a short period of practice of a ballistic task, suprathreshold rTMS applied to the motor cortex representing the trained muscle interferes with the consolidation process of motor skill learning, which hinders the retention of an improved skill performance and MEP facilitation. In the present study, ten suprathreshold single-pulse TMS (120% of rMT) alternating with ten paired-puls TMS (80% rMT and 120%rMT) were applied to the primary motor cortex immediately preceding the measurements of MVC and mRFD of plantar foot flexion movements. Considering, that improvements in force production are due to neuronal changes (Giesebrecht et al., 2012; Muellbacher et al., 2001), these findings could be an explanation for the lack of improvement in MVC, mRFD and MEP facilitation in the retention-test in the present study, irrespectively of the training method. Although, it is pointed out, that the rTMS application time was significantly lower in our study compared to the three presented ones. Additionally, rTMS were applied immediately after practice in the three presented studies, whereas a ten minutes break between practice and retention-test measurements was held in the current study. Since the three studies presented were all relatively homogenous in their experimental protocol, the amount of rTMS (e.g. duration) applied as well as the time in between training cessation, rTMS-application and retention-measurements should be further examined and specified in order to better understand interference of rTMS on subsequent immediate performance.

Short latency intracortical inhibition (SICI). There exists an inconsistency among the studies regarding the influence of ballistic training on SICI. Therefore, no hypothesis was made about the change in SICI for the present study. The results present no significant change in SICI immediately after the short ballistic plantar foot flexion training in the target muscles (SOL and GASm) in all groups. These findings are in line with the study of Rogasch et al. (2009). In their study SICI also remained unchanged after a short period of ballistic training as well as during follow up measurements thirty minutes after training. These findings are in contrast to other studies, which observed a reduction in SICI after a short training period (Liepert et al., 1998; Perez et al., 2004; Rosenkranz et al., 2007; Stinear & Byblow, 2003). Liepert et al. (1998) argued that these inconsistent findings of training on SICI in a given muscle are due to their task specific role. Findings of different studies also disagreed about the influence of timing of the application of paired-pulse TMS. While Garry and Thomson (2009) found smaller SICI measurements in the target muscle when paired-pulse TMS was applied during task performance compared to at rest, Stinear and Byblow (2003) showed the opposite, that paired-pulse TMS result in smaller amount of SICI in the target muscle when applied during rest rather than task performance. Another factor contributing to the inconsistent findings could be the difference in test TMS-pulse intensity. Different studies (Liepert et al., 1998; Rosenkranz et al., 2007; Stinear & Byblow, 2003) adjusted their test stimulus in order to keep MEP amplitudes constant throughout the study, to cross out influence on estimates of SICI. The results of all three studies showed a reduction in SICI after a short period of training. However, Garry and Thomson (2009) suggested that test TMS intensity should remain constant to elicit SICI throughout the study since an alteration of TMS intensities confound the estimates of SICI. In the present study as well as in the study of Rogasch et al. (2009) test TMS intensity remained the same throughout the experiment, with the result that no change in SICI could be observed in the targeted muscle after a ballistic plantar foot flexion training. Further experiments using the same motor task but different protocols (TMS intensity, timing) should be done in order to clarify inconsistencies.

It has to be mentioned, that the present study revealed one significant decrease in SICI between pre-test and retention-test of the neutral group ($p = 0.02$) in the control muscle (TA). However, these differences are mostly affected by the results of one subject (participant nr. 27), which showed that paired-pulse TMS applied to this subject resulted in an intracortical inhibition of MEP in TA during pre-test, but subsequently changed to an intracortical facilitation of MEP in TA during the retention-test. Differences in SICI between pre- and post-test as well as post- and retention-test remained unchanged in the control muscle (TA).

6 Conclusion

The present study investigated the behavioral and neurophysiological effects of augmented feedback (aFB) compared to a combination of instructions inducing an external focus of attention (EF) and aFB. The results presented no significant differences in maximum voluntary contraction (MVC), maximum rate of force development (mRFD) and motor evoked potential (MEP) in the target muscle after a short ballistic force production training for all groups. These findings are in contrast to a majority of studies, which provided evidence that firstly aFB has an enhancing behavioral effect and secondly a short ballistic training period can facilitate cortical excitability. While many studies examined the effects of aFB and EF on complex skill learning, the present study investigated these effects on a simple skill. The contradictory behavioral results are therefore speculated to be due to task specific differences. Additionally, variances could also derive from different movement kinematics. Thus it is concluded that aFB and EF might have smaller effects on the performance and learning of simple tasks compared to complex tasks.

Furthermore, the lack of neurophysiological adaptions in the form of MEP facilitation is speculated to be attributed to an insufficient training load and the application of repeated transcranial magnetic stimulation (rTMS) immediately preceding force production tests, which might have interfered in early consolidation of motor skill learning. The underlying determinants of rTMS interference with performance and motor excitability (duration of TMS application, TMS intensity, timing of TMS application) should be further investigated and specified in order to exclude obfuscation of experimental results.

Finally, no differences could be detected in short-latency intracortical inhibition (SICI) in the resting plantar foot flexors after a short training period in all groups, when test transcranial magnetic stimulation (TMS) intensities remained constant throughout the experiment.

Since there is an inconsistency in findings concerning the effect of short training period on SICI, it is suggested that further studies using more comparable study designs (identical target muscles, TMS intensities and timing of TMS stimulation) should be done to better understand this context.

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