The effect of social-comparative feedback on corticospinal excitability and balance performance.

Stephanie Reischl

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Faculty of Applied Health Sciences, Brock University
St. Catharines, Ontario

Abstract

Social-comparative feedback informs individuals about their performance relative to a falsified group score. Providing positive ("performed better than the group") social-comparative feedback enhances motivation, self-efficacy and balance performance, while negative ("worse than the group") social-comparative feedback has the opposite effect. A possible mechanism explaining the motor benefits of social-comparative feedback is it produces a valent (emotional) response that subsequently, alters corticospinal excitability. This is based on studies observing correlations between valence, corticospinal excitability and balance performance. However, the neural processes contributing to the motor and cognitive benefits of social-comparative feedback have not yet been examined. Thus, the purpose of this study was to examine whether social-comparative feedback alters corticospinal excitability and consequently, balance performance. Thirty-six young adults (18 males) completed a balance task (i.e., standing on a stabilometer) eight times. After three of these trials, the control group received their performance outcome (i.e., time on balance) while the other two groups received positive or negative social-comparative feedback. Before and after each instance of feedback, corticospinal excitability was assessed using transcranial magnetic stimulation. Participants rated their perceived skill on the task as well as provided ratings of valence and arousal for the feedback as a manipulation check. Results indicated that by the end of the eight trials, participants in the negative group reported lower perceived skill (i.e., comparative balance ability) than those in the control and positive feedback groups ($p<0.001$). Despite this difference in feedback perception, all groups improved their balance performance by ~35% across all trials ($p<0.001$). This change in performance was not matched by changes in corticospinal excitability ($p=0.340$). These findings suggest that social-comparative feedback has minimal or no influence on corticospinal excitability and balance performance.

Keywords: social-comparative feedback, balance performance, transcranial magnetic stimulation, corticospinal excitability, emotional stimuli

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1. Introduction

Feedback is information that is provided about an individual's performance on a task. When feedback is provided throughout and/or after their performance, it enables the individual to modify their performance on future attempts of the movement (McGill, 2001; Winstein, Wing, & Whitall, 2003). Individuals use feedback to determine how appropriate their behaviour is to achieve their goal (Ashford, 1986). Feedback generating positive consequences motivates the individual to maintain their behaviour. In contrast, negative consequences encourage corrections of behaviour to adapt appropriately to goals (Forsyth & Schlenker, 1977; Payne & Hauty, 1955). When an individual's own perception of their performance is unclear, feedback is sought out by observing others, situational cues, other's responses to their behaviour, or directly inquiring about other's evaluations of their behaviour (Ashford & Cummings, 1983).

Feedback can come from one's self and other individuals. Feedback originating from one's self is termed *intrinsic feedback* and is provided in the form of sensory perceptual information when performing a movement (Sharma, Chevidikunnan, Khan, & Gaowgzeh, 2016). In contrast, feedback provided by others is known as *external feedback* and can be presented during the action or right after the movement is complete (McGill, 2001). This latter type of feedback provides additional information beyond the constraints of the sensory system and can be presented in two forms. When the feedback is related to performance outcome, it is known as knowledge of results (KR). In contrast, feedback related to specific movement characteristics is known as knowledge of performance (KP) (Keogh & Hume, 2012; Magill, 1998; McGill, 2001).

The difference between KP and KR can be differentiated when considering a balance task. An individual may receive KP as video playback of them performing the task so they can

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see which strategy or technique was used during the balance task. Alternatively, KR could be provided in terms of the amount of time spent in a balanced position. For more simple tasks, such as standing on one leg with the eyes open, KR is sufficient to motivate participants to continue practicing and provide them with additional information when their intrinsic feedback is insufficient at determining performance outcome. However, for more complex balance tasks, such as balancing on an unstable or narrow surface, KP is advantageous over KR. When the task requires specific movement characteristics or strategies to be used, receiving feedback of how the task was performed is more informative. For example, a gymnast performing their routine on a balance beam can benefit from KP by making specific corrections to improve their competition scores (Sharma *et al*., 2016).

1.1 Social-Comparative Feedback

One way to contextualize and present external feedback is to provide social-comparative feedback. This type of feedback informs the individual about their performance outcome relative to an 'average' or normative score. The average score is used to indicate whether the individual is better or worse than the group (Bandura & Jourden, 1991; Johnson, Turban, Pieper, & Ng, 1996; Klein, 1997). It has been suggested that positive social-comparative feedback ("performed better than the group") has the potential to improve motor performance and increase an individual's self-efficacy [i.e., an individual's belief of their capabilities to perform the required actions to meet a performance goal (Bandura & Cervone, 1986)], motivation to practice the task, and the generation of more positive self-reactions (Bandura, 1997; Hutchinson, Sherman, Martinovic, & Tenebaum, 2008; Johnson, Turban, Pieper, & Ng, 1996; Weinburg & Jackson, 1979).

Although social-comparative feedback results in consistent psychological changes, studies focusing on the relationship between social-comparative feedback and motor performance have yielded conflicting results. For example, positive social-comparative feedback can lead to improvements in motor performance on force (Hutchinson *et al*., 2008) and timing tasks (Wulf, Chiviacowsky, & Lewthwaite, 2010). The same can be said for balance tasks (Lewthwaite & Wulf, 2010; Wulf, Chiviacowsky, & Lewthwaite, 2012), which are of interest for this thesis. When positive social comparative feedback was given, performance on a 90 s stabilometer balance task improved by 55% across seven trials compared to a 25% improvement by the control group (Lewthwaite & Wulf, 2010).

Negative social-comparative feedback ("performed worse than the group") can also improve motor performance on timing (Wulf *et al*., 2010) and balance tasks (Lewthwaite & Wulf, 2010) but the observed improvement is not as large as receiving positive feedback. Lewthwaite and Wulf (2010) observed a significant improvement (35%) in performance on the stabilometer task for the negative social-comparative feedback group. Although this was greater than the 25% improvement achieved by the KR only group, the improvement in the negative social-comparative feedback group was still less than the improvement by the positive group (Lewthwaite & Wulf, 2010).

In contrast to the aforementioned studies, others have found that social-comparative feedback is ineffective in altering balance performance. Ong and Hodges (2017) found that there was no difference between the groups; all groups improved 45% across seven trials of the 90 s balance task. While Wulf *et al.* (2012) found a 95% improvement for all groups on a 30 s stabilometer balance task across 10 trials. Additionally, Lamarche *et al*. (2009) had healthy young adults complete two balance tasks (i.e., standing with eyes open and closed) and were told they were better or worse than individuals of the same gender and age. On the eyes open task all groups improved 10%, while the eyes closed task all groups improved 20% from the pre- to post-feedback trials. Similarly, Lamarche *et al*. (2011) incorporated a more challenging balance task (i.e., standing on one leg with the eyes closed) so that participants had to rely more heavily on the social-comparative feedback to gauge their performance (Bandura, 1997). No change in balance performance was observed between the pre- and post-feedback trials (Lamarche *et al.*, 2011). Interestingly, the lack of effects on motor performance were not strongly related to the amount of psychological change induced by the feedback. For example, when participants were told they were better/worse than their peers, they reported more/less perceived stability even though they did not demonstrate any change in balance performance (Lamarche *et al*., 2009; Lamarche *et al.*, 2011). Despite no change in balance performance, participants in the negative social-comparative feedback group also reported lower levels of success (Ong & Hodges, 2017).

1.2 Proposed Mechanisms of Social-Comparative Feedback on Performance

It is unclear why social-comparative feedback has an inconsistent effect on performance. Previous studies have suggested that feedback works through changes in self-efficacy and motivation, which may produce an emotional response (Bandura, 1997; Weinburg & Jackson, 1979). However, it is unclear how this would lead to a change in performance. One neurophysiological mechanism that could explain the interaction between social-comparative feedback and performance is that social-comparative feedback produces an emotional response that results in changes in corticospinal excitability, which in turn, aids in performance (Figure 1).

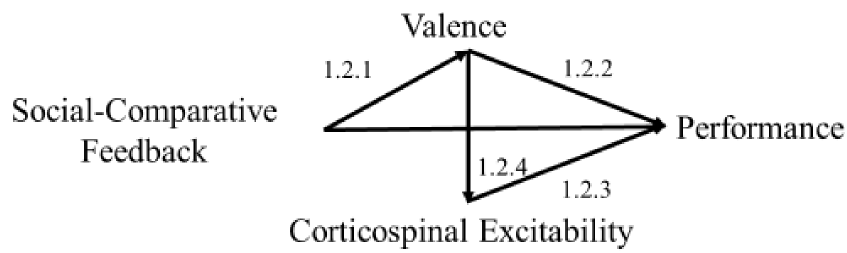

Figure 1. The effect of social-comparative feedback on performance: Possible mechanisms. The arrows are labelled with the sections of the document outlining the relationship between those variables.

1.2.1 Feedback and Valence

Valence is measured as an emotional response, often alongside measurements of arousal (i.e., magnitude of the response). The simplest and most cost-effective method to measure valence is through self-report (Baumert, Sinclair, MacLeod, & Hammond, 2011; Cheetham, Lingdan, Pauli, & Jancke, 2015; Coombes, Janelle, & Duley, 2005; Hajcak *et al*., 2007). Researchers can generate self-report scales to measure the participant's ratings of their self-efficacy and motivation (Lamarche *et al*., 2009; Lamarche *et al*., 2011; Lewthwaite & Wulf, 2010). Individuals report enhanced self-efficacy and motivation when the presented feedback indicates successful performance (Lamarche *et al*., 2009; Wulf, Shea, & Lewthwaite, 2010). However, individuals may also be motivated, thereby enhancing their efforts, by negative feedback because of a negative discrepancy between external feedback and intrinsic feedback (Bandura & Cervone, 1983; Chiviacowsky & Wulf, 2002; Moorthy, Munz, Adams, Pandey, & Darzi, 2006).

A limitation of this work is that many of the previously used self-report measures have not been validated or shown to be reliable (Cheetham *et al*., 2015). Although validated and reliable measures, such as the Self-Assessment Manikin (SAM) scale are available to collect valence and arousal ratings (Hajcak *et al*., 2007; Lang, 1980), more objective measures of valence and arousal can be obtained using heart rate variability (HRV) and electrodermal activity (EDA), respectively (Baumert *et al*., 2011; Coombes *et al*., 2005; Hajcak *et al*., 2007). HRV provides a continuous measure of the sympathetic and parasympathetic influences on HR that reflects autonomic flexibility (Appelhans & Luecken, 2006). This is regulated by physiological arousal, subjective feeling, and motor expression which are reflected in emotional responses (Caicedo & van Beuzekom, 2006). Although this has led to HRV being used as a physiological measure of emotion regulatory ability (Appelhans & Luecken, 2006), it has not been used to assess the emotional response to feedback. However, decreases in HRV have been demonstrated with exposure to valent film clips compared to neutral clips (Lane *et al*., 2009).

In contrast to HRV, EDA demonstrates sympathetically innervated changes in sweat gland activity (Bernstein, 1969). In the presence of pleasant and unpleasant stimuli, EDA increases with reports of increasing arousal (Greenwald, Cook, & Lang, 1989; Lang, Greenwald, Bradley, & Hamm, 1993). Researchers measure EDA when trying to discern whether changes in behaviour following exposure to valent stimuli occur because of the arousal or valence. For example, when exposure to pleasant and unpleasant images result in different changes in motor performance but EDA was comparable between images then it can be assumed that the changes are from differences in valence and not arousal (Coombes *et al*., 2005).

Similar to valent images, social-comparative feedback could be categorized as positive and negative when individuals are told they are better or worse than the norm, respectively.

However, previous studies examining social-comparative feedback have used customized self-report measures without the use of validated scales or objective measures. Therefore, it can only be assumed that social-comparative feedback generates an emotional response. This could explain why self-reports of psychological state in response to social-comparative feedback do not necessarily correspond with changes in performance.

1.2.2 Valence and Performance

Valent images alter motor performance (Coombes *et al*., 2005; Coombes *et al*., 2009). Previous studies have shown images from the International Affective Picture System, which is a collection of images with normative valence and arousal ratings (Lang, Bradley, & Cuthbert, 2005), to demonstrate the differential effects of valence on task performance. Coombes *et al*., (2005) showed that participants make more errors on a square-tracing task following prolonged exposure to unpleasant compared to pleasant images. With brief exposure to unpleasant images, participants performed the task faster, without compromising accuracy, compared to trials with exposure to pleasant images.

In the context of balance control, valent images have no effect on measures of postural control during a more stable (i.e., feet shoulder width apart) standing task (Horslen & Carpenter, 2011). Conversely, with more complex balance tasks, such as feet together or one-legged stance, exposure to unpleasant images leads to reduced body sway compared to neutral and pleasant images (Azevedo *et al*., 2005; Stins & Beek, 2007). Since balance is controlled via spinal and supraspinal pathways, including those involving M1 (Taube *et al*., 2007; Tokuno, Garland, Carpenter, Throstensson, & Cresswell, 2008; Tokuno, Taube, & Cresswell, 2009), it may be suggested that the central nervous system (CNS) control for the performance of a balance task could be altered by valence.

1.2.3 Corticospinal Excitability and Performance

The involvement of the CNS in balance control can be assessed by measuring corticospinal excitability using a technique called transcranial magnetic stimulation (TMS). TMS is a non-invasive brain stimulation technique that produces a volley of action potentials down the descending corticospinal pathways (Brasil-Neto *et al.*, 1992; Guzman-Lopéz, Selvie, Solá-Valls, Casanova-Molla, & Valls-Solé, 2015; Hallett, 2007). When the TMS pulse is strong enough and directed over the motor cortex, it generates a synchronous muscle response in the target muscle, referred to as a motor-evoked potential (MEP). The peak-to-peak amplitude of a MEP is often used as a measure of corticospinal excitability because it reflects how easily a muscle can be activated via the stimulation of the cortical neurons within the corticospinal pathway (Hallett, 2007; Nielsen, Petersen, Deuschl, & Ballegard, 1993; Ugawa, Terao, Hanajima, Sakai, & Kanazawa, 1995).

TMS has been used to detect changes in corticospinal excitability during various motor tasks, including those involving balance. When learning to perform a balance task, there is an initial increase in corticospinal excitability during skill acquisition and as the skill becomes more automatic, corticospinal excitability decreases. The changes in corticospinal excitability can differ based on the parameters and complexity of the task (McDonnell & Ridding, 2006; Muellbacher, Ziemann, Boroojerdi, Cohen, & Hallett, 2001; Perez, Lungholt, Nyborg, & Nielsen, 2004; Taube *et al*., 2007). Interestingly, both increases and decreases in corticospinal excitability can have a meaningful influence on skill acquisition (Smyth, Summers, & Garry, 2010). Across six weeks of practice, improvements in performance on a balance task corresponded with a decrease in corticospinal excitability (Taube *et al*., 2007). However, others have found that an increase in corticospinal excitability is associated with improvements in force, reaction time, acceleration, and skill based tasks (Ávila, Chiviacowsky, Wulf, & Lewthwaite, 2012; Jensen *et al*., 2005; Muellbacher *et al*., 2001; Perez *et al*., 2004).

When given feedback during the initial practice of a balance task there are changes in the movement representation of the muscles in the primary motor cortex (M1) and this increases the excitability of the movement representation of the muscles used for that movement (Elbert, Pantey, Wienbruch, Rockstroh, & Taube, 1995). With more practice of a task, it becomes more automatic and there is a decrease in corticospinal excitability (Taube *et al.*, 2007). Since changes in corticospinal excitability occur with practice, this could explain why there were different results between studies using multiple trials (Lewthwaite & Wulf, 2010; Ong & Hodges, 2007; Wulf *et al*., 2012) and those only repeating the task once (Lamarche *et al*., 2009; Lamarche *et al*., 2011). Specifically, Lamarche *et al*., (2009, 2011) may not have seen a very large change in performance because participants were not provided enough practice trials to induce changes within the CNS.

1.2.4 Valence, Corticospinal Excitability, and Performance

The effects of both corticospinal excitability and valence on motor performance may not act independent of one another, as changes in valence can also alter corticospinal excitability. Negative (unpleasant) and positive (pleasant) valent stimuli contribute to action preparation but across differing time courses (Baumert *et al*., 2011). For example, when individuals are exposed to short durations (i.e., random order) of unpleasant images, an immediate increase in corticospinal excitability, as reflected by an increase in MEP amplitude, is observed (Baumert *et al*., 2011; Coombes *et al*., 2009; Oathes, Bruce, & Nitschke, 2008; Schutter, Hofman, & van Honk, 2008). This increase in MEP amplitude occurs in tandem with improvements in force production and reaction time to a greater degree when exposed to unpleasant compared to pleasant stimuli (Coombes *et al*., 2009). In contrast, when valent stimuli, in the form of pleasant or unpleasant images, are presented over a longer duration (e.g. a full testing session), there is a similar amount of increase in MEP amplitude in response to both positive and negative stimuli (Baumgartner *et al*., 2007; Hajcak *et al*., 2007). This suggests that a longer duration of exposure to the emotional stimuli is required to enhance action preparation with pleasant emotional states. This makes sense from an evolutionary perspective since there are more immediate consequences with inaction following exposure to unpleasant stimuli than pleasant stimuli.

Since studies have shown a difference in performance improvements and changes in corticospinal excitability between pleasant and unpleasant stimuli (Coombes *et al*., 2009; Hajcak *et al*., 2007), it is possible that the underlying mechanism behind changes in performance following social-comparative feedback is a change in the emotional state of the individual.

1.3 Rationale

Social-comparative feedback has been shown to produce changes in motivation and self-efficacy (Lamarche *et al*., 2009; Lewthwaite & Wulf, 2010). When individuals receive positive social-comparative feedback, they demonstrate improved self-efficacy and motivation compared to those who receive negative feedback (Lamarche *et al*., 2009). Although the effects on balance performance are not consistent between studies (Lamarche *et al.*, 2009; Lamarche *et al.*, 2011; Ong & Hodges, 2017) it has also been shown that positive social-comparative feedback can lead to greater gains in motor performance than individuals receiving negative feedback or knowledge of results (Lewthwaite & Wulf, 2010). These changes elicited in motor performance could be a result of the emotional context of the social-comparative feedback and the corresponding changes in corticospinal excitability. Studies using TMS have shown an increase in corticospinal excitability following short term exposure to negative stimuli and long-term exposure to both negative and positive stimuli (Baumert *et al*., 2011; Baumgartner, Willi, & Jäncke, 2007; Coombes *et al*., 2009; Hajcak *et al*., 2007; Schutter *et al*., 2008). In addition to emotional stimuli evoking changes in corticospinal excitability, changes have been demonstrated with motor performance measures such as reaction time and force production. Exposure to unpleasant images shortened reaction time and increased force production in comparison to pleasant images (Coombes *et al*., 2009). However, since the emotional stimuli used in these studies were impersonal and did not relate to an individual's performance, it is not known whether these effects of valent stimuli will transfer to feedback provided during the acquisition of a motor skill.

The purpose of this thesis is to examine the effects of social-comparative feedback on corticospinal excitability and balance performance.

This project aims to address three research questions:

i) **Does social-comparative feedback produce a valence response?** Since social-comparative feedback has been shown to alter psychological measures, it is hypothesized that positive social-comparative feedback group will rate their feedback higher on the SAM scale than the negative and control group. Negative social-comparative feedback group will rate their feedback lower on the SAM scale than the control group. It is also hypothesized that HRV, EDA and self-report measures of arousal will not be different between the social-comparative feedback groups but greater than the control group.

ii) **Does social-comparative feedback alter balance performance?** If social-comparative feedback leads to a valence response, it would be hypothesized that there will be greater improvements in performance scores for the negative and positive feedback groups compared to the control group. Based on the work by Lewthwaite & Wulf (2010), it is expected that the positive feedback group will demonstrate greater improvements in performance than the negative feedback group.

iii) **Does social-comparative feedback alter corticospinal excitability?** Since negative stimuli have a more immediate effect on action preparation than positive stimuli (Baumert *et al*., 2011), it is hypothesized that the negative feedback group will demonstrate an increase in corticospinal excitability, as measured by the MEP amplitude, after each instance of feedback as well as upon conclusion of all trials. The positive group will demonstrate an increase in MEP amplitude for the final block of MEPs that is comparable to the negative group, but no changes will be seen in MEP amplitude between trials.

2. Materials and Methods

2.1 Participants

Thirty six healthy young adults (18 males) with a mean ± one standard deviation (SD) age of 23±3 y, height of 1.7±0.1 m, and mass of 72.9±9.8 kg participated in this study. None of the participants reported any current musculoskeletal, neurological, sensory, or orthopaedic disorders or injuries that could affect their balance. All participants provided informed consent and passed a TMS screening questionnaire (Appendix A) prior to participating in the study. The experimental protocol was performed in accordance with the Declaration of Helsinki and was approved by the university research ethics board.

2.2 Experimental Setup

An overview of the experimental setup and procedure can be seen in Figure 2.

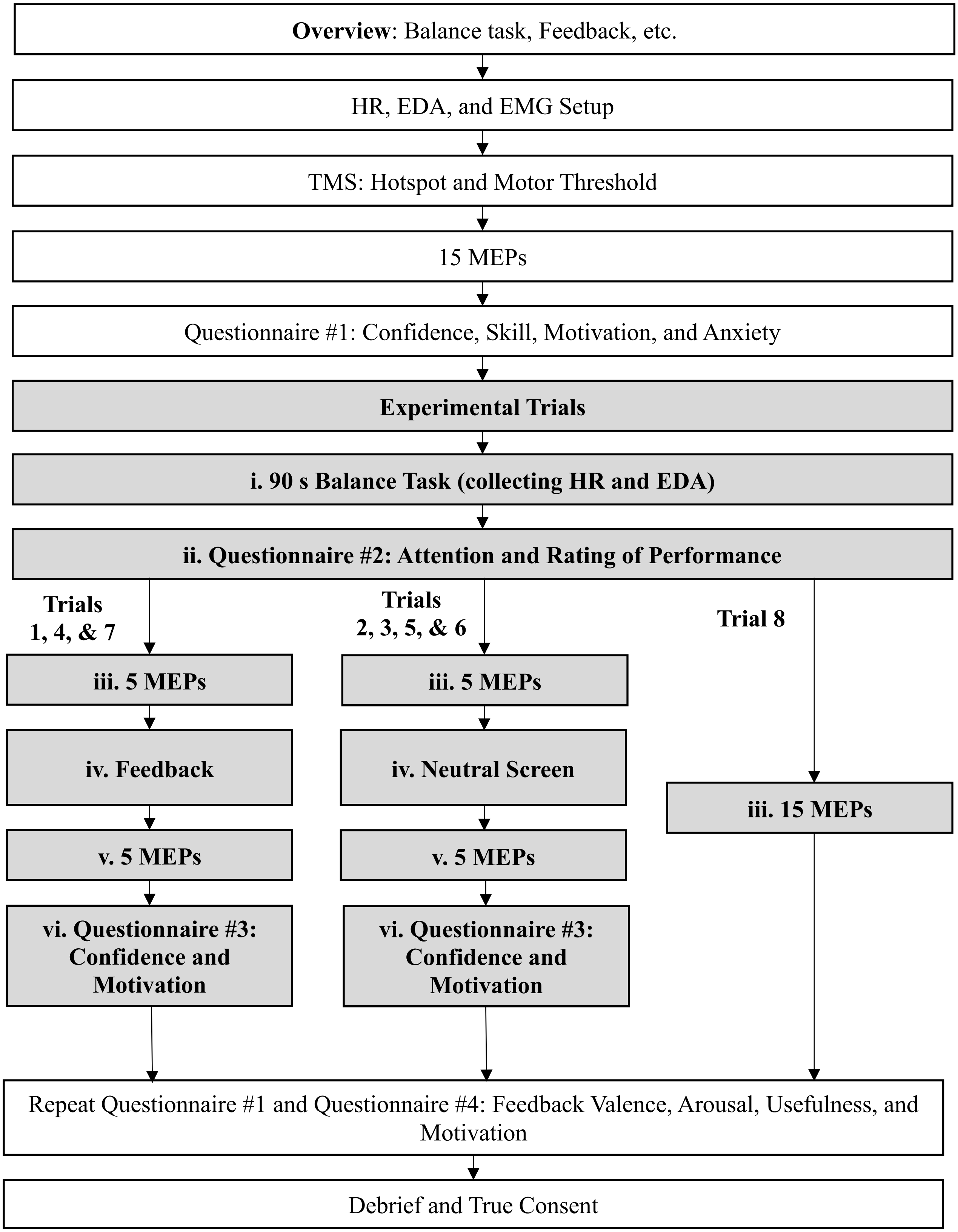

Figure 2. Overview of experimental setup and procedure.

Participants initially completed the 14-question Sport Mental Toughness Questionnaire (SMTQ; Sheard, Golby, & van Wersch, 2009) since an individual's level of mental toughness may alter their response to feedback (Appendix B). Next, participants put a Polar H7 heart rate monitor (Polar Electro Oy, Kempele, Finland) around their chest. Participants were then seated while the right soleus (SOL), tibialis anterior (TA), and bony protuberance on the lateral side of the knee were prepared for electromyography (EMG). The skin of each area was shaved, cleansed with alcohol, and abraded with a conductive gel (NuPrep, Weaver and Company, Aurora, CO, USA). Pairs of disposable silver/silver chloride electrodes (31112496, Covidien Kendall, Minneapolis, MN, USA) were placed on the prepared muscle regions with an inter-electrode distance of 2 cm. A single electrode was placed on the bony protuberance of the right knee. Isotonic recording electrode gel (BIOPAC Systems Inc., Goleta, CA, USA) was applied to the skin of the distal phalanx of the index and middle fingers of the non-dominant hand. The gel was also applied to the reusable electrodes (TSD203, BIOPAC Systems Inc., Goleta, Canada) that were placed around the two fingers.

While remaining in the seated position, the TMS parameters were determined. First, the vertex of the participants' head was marked with a non-toxic washable marker. The vertex was defined as the midpoint of the head length measured from the nasion to the inion, and breadth measured from tragus to tragus of both ears. A double-cone TMS coil was placed over the vertex so that the center of the coil was located directly over the marked location on the scalp. Single-pulse TMS stimuli was delivered every 8-10 s in the area surrounding the vertex to determine the motor hotspot for the right SOL. The motor hotspot was considered the location where the largest muscle response to a single TMS pulse at a given intensity can be elicited. Once the motor hotspot was identified, it was marked with a non-toxic washable marker and this was the TMS stimulation location for the remainder of the session.

Next, participants stood with the double-cone coil placed over the hotspot so that active motor threshold (AMT) could be determined. AMT was considered to be the minimum stimulation intensity at which MEPs with an peak-to-peak amplitude greater than 100 μV could be evoked in the right SOL in three out of six consecutive trials. The stimulation intensity for the remainder of the session was set to 120% AMT.

Baseline measures for heart rate and EDA were collected simultaneously over 90 s of sitting quietly without any external distractions. Participants then stood with their feet shoulder width apart, hands resting by their sides, and gaze straight ahead while a block of 15 baseline MEPs were obtained using TMS. Participants were instructed of the balance task goal and outline of the procedure described below prior to completing a balance confidence questionnaire (Appendix C).

2.3 Procedure

Participants stood on a 65 x 105 cm wooden stabilometer (Model 16030L, Lafayette Instrument, Lafayette, IN) that when released, could rotate ± 27 degrees from the horizontal in the roll orientation. Participants stood centered on the platform, with their feet hip width apart. This foot position was marked so that foot placement was consistent across all trials. Participants were required to keep the platform in a horizontal position for as long as possible over the 90 s trial while standing with their hands resting at their sides and looking straight ahead. At the end of the 90 s trial, the platform was slowly tipped so that the participant could step off the platform onto the surrounding foam and sit on chair.

For the next two minutes after each balance trial, participants remained seated while they wrote what they were focused on during the trial (Appendix D). During the 2 min, the time on balance (s) was calculated in Spike2 (Cambridge Electronic Design, Cambridge, UK) and an error range was selected that provided a score of approximately 45 s for trial one (T1). Error ranges from 0.7 to 5.5˚ were used with an average of 2.6±1.3˚. Error ranges were catered to the skill of the individual so that the feedback was more believable. The error range used on T1 for a participant was the error range used for the remainder of the trials (T2-T8). Based on the participant's error range, they were assigned to one of the three experimental groups (i.e., control, positive, and negative) so there was a relatively equal distribution of balance ability and an equal number of participants between groups. Participants were unaware of the study's purpose and their group assignment throughout the study but were debriefed upon conclusion of the session.

After the 2 min rest period and attention questionnaire were completed, participants were instructed to stand 2 m in front of a television screen. In bold Arial black font (size 44), a question appeared on the screen that asked participants to rate their performance for the previous trial on a 9-point scale (1=terrible, 9=terrific) (Appendix D). Participants shared their rating with the experimenter verbally. Participants remained in front of the monitor while the double-cone TMS coil was placed over the hotspot. Participants were instructed to keep their gaze at the blank TV screen while five MEPs were collected at 120% AMT.

Next, feedback of the participant's balance performance, consisting of the duration that they kept the platform in the horizontal position throughout the 90 s trial, was shown on the monitor. The feedback was presented in Arial black font, size 44 with a white background. Feedback was only provided for T1, T4 and T7 while a neutral screen was displayed in its place on the other trials. On the three trials when feedback was provided, participants in the control group were only provided their performance score. In addition, participants in the positive social-comparative group were given their performance score as well as a group score that was 15-20% lower than the participant’s performance score. While participants in the negative social-comparative group were given their performance score as well as a group score that was 15-20% higher than their score. The social-comparative feedback groups also received a statement of context to compare their score to the expected score. To encourage the intended emotional reaction, the statements included the word “terrific” and “terrible” for the positive and negative groups respectively. These words were selected from the Affective Norms for English Words list, since they were rated as a positive word, with “terrific” rated 8.2±1.1 (out of nine) for valence and 6.2 ±2.7 (out of nine) for arousal, and a negative word, with “terrible” rated 1.9±1.4 for valence and 6.3±2.4 for arousal (Bradley & Lang, 1999). Thus, the statement of feedback for the positive group followed the format “Your score: <participant’s actual score>. Group score: <participant’s actual score minus 15-20%>. Your performance was terrific (<15-20%> better) compared to the group.” (Figure 3A). For the negative feedback group, the statement of feedback followed the format “Your score: <participant’s actual score>. Group score: <participant’s actual score plus 15-20%>. Your performance was terrible (<15-20%> worse) compared to the group.” (Figure 3B). For the control group, the statement of feedback will indicate “Your score: <participant’s actual score>” (Figure 3C). Once the participant indicated that they had read the feedback, another five MEPs were collected at 120% AMT. The MEPs collected after the provision of feedback were used to examine the immediate effect of feedback on corticospinal excitability. In contrast, the MEPs collected before the provision of feedback were primarily being collected as a control (back-up) measure in the event that MEPs were found to change throughout the experiment in the control group. To complete the experimental trial, the participant continued to stand in front of the monitor while two questions were presented, and the participant verbally rated their confidence and motivation to improve leading into the next trial (Appendix D).

This procedure (i.e., balance task, questionnaires, feedback, and MEPs) was repeated for seven more trials. Following the completion of the 8th trial participants reported what they were paying attention to during the task and rated their performance. Then a final block of 15 MEPs were collected at 120% AMT. The purpose of these MEPs was to determine the long-term effects of feedback on corticospinal excitability. After feedback was displayed, participants were not asked to rate their confidence or motivation to improve since that was the final trial.

Participants then completed one questionnaire to assess their balance confidence, perceived skill with the task, as well as their anxiety and motivation to perform the task (Appendix E). Another questionnaire was given to assess how motivating and useful the participants found the feedback, as well as their ratings of valence and arousal for the feedback using the 9-point SAM scale (Bradley & Lang, 1994) (Appendix F/G).

Upon completion of the study, participants were debriefed about the purpose of the study and the false nature of the performance feedback for the positive and negative groups. The participants read and signed a second consent form (Appendix H) outlining the true purpose and deceptive nature of the feedback.

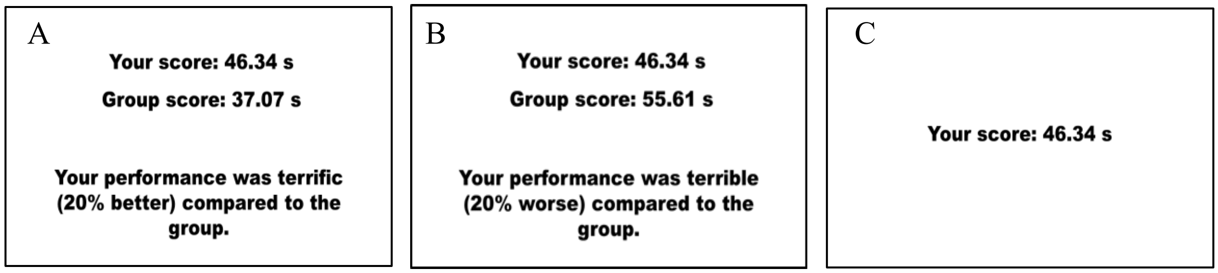

Figure 3. Feedback screens for each group with an example time on balance of 46.34 s for the A) positive, B) negative, and C) control groups.

2.4 Data Collection and Analyses

Balance performance on each 90 s trial was quantified based on the angular position signal of the stabilometer, which was analog-to-digitally converted at 1000 Hz (micro1401 and Spike2 software, Cambridge Electronic Design, Cambridge, UK). From this signal, the duration of time that the stabilometer was within ±1.5˚ from the horizontal, the root mean square error (RMSE) and mean power frequency (MPF) for each 90 s trial were determined.

The effect of social-comparative feedback on corticospinal excitability was determined from the TMS-evoked electromyography (EMG) response from the right SOL. The peak-to-peak amplitude of each SOL MEP was averaged for each block of five MEPs before and after each feedback, as well as the baseline block of 15 MEPs prior to T1 and the final block of 15 MEPs after T8. The SOL and TA background EMG (bEMG) activity were calculated as the RMSE for the 100 ms prior to the magnetic stimuli and averaged for each block.

Data recorded from the Polar H7 heart rate monitor was used as an additional measure of valence. HR data was exported from the Elite HRV recording software to Kubios HRV Standard software (BSAMIG, Kuopio, Finland) to analyze the “normal-to-normal” (NN) interval. The NN interval, also known as the inter-beat interval, is the temporal distance between the R spikes of consecutive heartbeats and reflects when the ventricles of the heart contract (Figure 3). The standard deviation of the NN intervals (SDNN), a measure of overall HRV, and the square root of the mean squared difference of successive NN intervals (RMSSD), a measure thought to represent parasympathetically mediated HRV (Task Force, 1996), were determined for each trial. HRV measurements were averaged across the eight trials and compared between the groups.

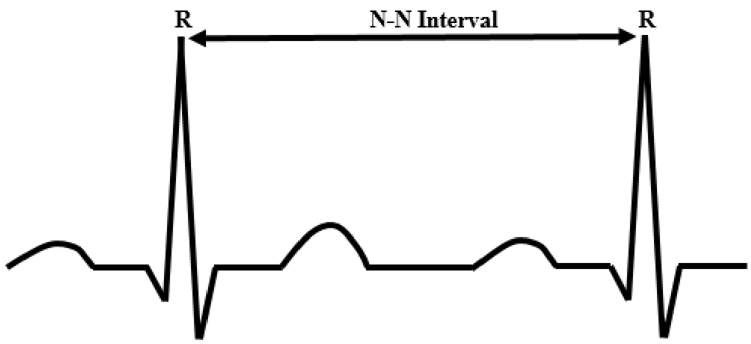

Figure 4. Schema of heart rate trace and corresponding HRV measurement.

EDA was recorded (EDA100C, BIOPAC Systems Inc., Goleta, Canada) and sampled at 1000 Hz (micro1401, Cambridge Electronics Design, Cambridge, UK). This is a physiological measure that can be looked at in conjunction with the self-reported arousal ratings. This measure was used to identify whether arousal levels were the same between the three feedback groups.

2.5 Statistical Analyses

The overall effect of social-comparative feedback on balance performance, as reflected by time on balance, RMSE and MPF, were assessed by separate 3 (group: control, positive, negative) × 2 (trial: T1, T8) mixed ANOVAs with trial as a repeated measure. In contrast, the immediate effect of social-comparative feedback on balance performance was examined using separate 3 (group: control, positive, negative) × 3 (trial: T1, T4, T7) × 2 (time: pre/post) mixed ANOVAs with trial and time as repeated measures.

Similarly, the overall effect of social-comparative feedback on corticospinal excitability, as reflected by the SOL MEP amplitude, was examined using a 3 (group: control, positive, negative) × 2 (trial: baseline, T8) mixed ANOVAs with trial as a repeated measure. The immediate effect on corticospinal excitability was analyzed using a 3 (group: control, positive, negative) × 3 (trial: T1, T4, T7) × 2 (time: pre/post) mixed ANOVAs with trial and time as repeated measures. For both analyses, since corticospinal excitability can be influenced by the level of bEMG activity, both SOL and TA bEMG were also compared using the same statistical methods as those used to compare MEP amplitudes. The effect of social-comparative feedback on heart rate, HRV, and EDA was assessed using separate 3 (group: control, positive, negative) × 9 (trial: baseline, T1-T8) mixed ANOVAs with trial as a repeated measure.

Balance confidence, perceived skill, as well as anxiety and motivation to perform the task were assessed using separate 3 (group: control, positive, negative) × 2 (time: pre, post) mixed ANOVAs with time as a repeated measure. The valence and arousal ratings for the provided feedback were assessed using separate one-way ANOVAs. Separate one-way ANOVAs were used to assess how motivating and useful the feedback was.

Trial by trial motivation and confidence ratings for the upcoming trial were assessed using separate 3 (group: control, positive, negative) × 7 (trial: T1-T7) mixed ANOVAs with trial as a repeated measure. A 3 (group: control, positive, negative) × 8 (trial: T1-T8) mixed ANOVAs with trial as a repeated measure was used to assess ratings of performance on the previous trial.

Pearson correlations were completed to assess the overall relationship between performance (time on balance) and corticospinal excitability, perceived skill, feedback valence and feedback arousal ratings. Correlations were also used to assess the overall relationship between corticospinal excitability and perceived skill, feedback valence and feedback arousal ratings.

For all analyses, post hoc one-way ANOVAs or Bonferroni-corrected paired *t* tests were conducted when appropriate. A significance value of $p \leq 0.05$ was used for all tests and all statistical analyses were completed using IBM SPSS Statistics, version 23, (Armonk, NY, USA). The Greenhouse-Geisser correction was used when the assumption of sphericity was violated (i.e. $p<0.05$ for Mauchly's statistics). All data presented in the Results section are reported as the mean ± one SD.

3. Results

A summary of the statistical analyses can be seen in Appendix I. There was no difference between the groups for age ($F_{2,33}=1.846$; $p=0.174$), height ($F_{2,33}=1.204$; $p=0.313$), weight ($F_{2,33}=0.866$; $p=0.430$), or mental toughness ($F_{2,33}=1.069$; $p=0.355$).The error range, determined after T1 and used to calculate time on balance scores for all trials, was not different between groups ($F_{2,33}=0.057$; $p=0.944$)(Table 1).

Table 1. Mean±1 SD age (y), height (m), weight (kg), SMTQ score (out of 56), and error range (˚) for the three groups.

	Control	**Positive Feedback**	**Negative Feedback**
Age (y)	24.50±2.35	23.42±3.06	22.42±2.50
Height (m)	174.84±9.43	175.47±10.91	172.93±0.9
Weight (kg)	75.90±8.35	71.97±11.73	70.84±9.02
SMTQ Score (/56)	38.33±5.43	34.83±4.28	34.25±3.52
Error Range (˚)	2.56±1.03	2.46±1.56	2.65±1.43

3.1 Questionnaires

Balance confidence was influenced by a group × time interaction effect ($F_{2,33}$=6.778; p=0.003). Post-hoc analyses revealed that from the beginning to the end of the experimental trials, balance confidence decreased 25±67% for the negative group (p=0.006) but did not change for the positive (p=0.266) or the control group (p=0.241) (Table 2). Similarly, perceived skill was influenced by a group × time interaction effect ($F_{2,33}$=21.284; p<0.001). Post-hoc tests indicated that while there was no difference in the level of perceived skill at the start of the experiment between groups ($F_{2,33}$=0.223; p=0.801), the negative group reported a lower perceived skill compared to the control (47% difference; p<0.001) and positive (51% difference; p<0.001) groups upon completion of the trials (Table 2). No differences in perceived skill were observed between the positive and control groups at the end of the experimental trials (p=1.000). Participants' ratings of anxiety during the experimental trials significantly increased by 23±17% across all groups ($F_{1,33}$=6.270; p=0.017; Table 2). Finally, motivation to perform the task was influenced by a group × time interaction effect ($F_{2,33}$=3.716; p=0.035). While motivation to perform the task increased 22±21% for the control group and 6±2% for the positive group from the start to the end of the experimental trials, there was no change in motivation for the negative group (Table 2).

Table 2. Mean ± 1 SD balance confidence, perceived skill, anxiety and motivation prior to the first balance trial (Pre) and after the last balance trial (Post) for each group. Responses to each question were rated on a 9-point scale, where 1 represented "not confident", "not skilled", "not anxious", and "not motivated", while a 9 represented "very confident", "very skilled", "very anxious", and "very motivated".

	Control		**Positive Feedback**		**Negative Feedback**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
Balance confidence	7.3±0.8	6.8±1.3	6.7±1.4	7.0±1.3	6.3±1.2	4.8±2.1
Perceived skill	6.0±1.4	6.3±1.3	6.2±1.0	6.8±0.8	5.8±1.3	3.3±2.0
Anxiety	2.7±2.0	3.5±2.4	3.6±2.3	3.8±2.6	3.3±2.0	4.3±2.4
Motivation	5.7±2.8	6.9±2.2	7.2±1.3	7.6±1.2	7.2±1.3	7.2±1.3

Participants perceived the valence of the feedback differently depending on the group ($F_{2,33}$=18.152; p<0.001). The positive social-comparative feedback group rated the feedback as more positive (7.1±0.8) than the negative (4.3±1.1; p<0.001) and control groups (4.8±1.5; p<0.001). There was no difference between the negative and control groups (p=0.746) (Figure 4). In contrast, no differences in the perceived arousal of the feedback were reported between groups ($F_{2,33}$=0.126; p=0.882). The control, positive and negative feedback groups rated the level of arousal as 5.2±1.7, 5.5±1.1, and 5.2±2.0, respectively (Figure 4). There was no difference in how motivating ($F_{2,33}$=2.940; p=0.067) or useful ($F_{2,33}$=0.865; p=0.430) the groups rated the feedback.

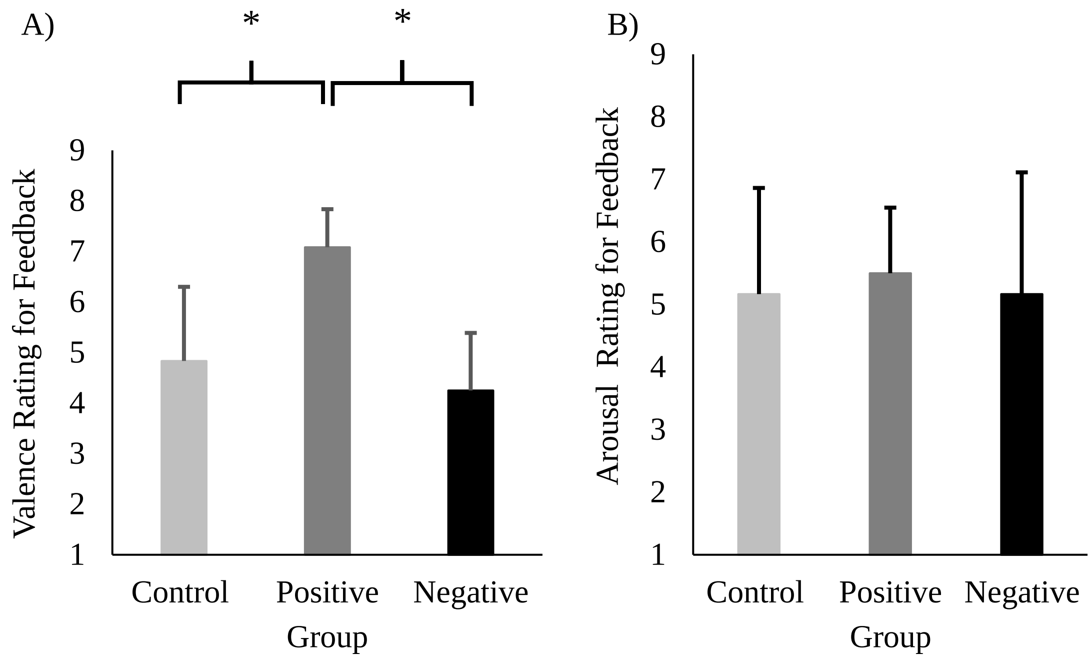

Figure 5. Mean+1 SD A) valence and B) arousal ratings for the feedback using the SAM Scale. Asterisks (*) indicate a group main effect, with the positive group rating the feedback as more positive than the negative and control groups.

For T1 through T7, participants rated their confidence and motivation to improve leading into the next trial. There was a difference in confidence for the groups ($F_{2,33}$=9.826; p=0.001) and across trials ($F_{3.523,116.253}$=23.891; p=<0.001) (Figure 5). The negative group reported lower confidence than the control (29% difference; p=0.002) and positive (30% difference; p=0.001) groups. Confidence levels across all groups were lower on T1 (5.4±1.8) than T2 (6.0± 1.7; p=0.002) and the rest of the trials (p<0.001). T2 was also lower than T4 (6.5±1.8; p=0.043), T5 (6.6±1.8; p=0.005), T6 (6.8±1.6; p<0.001), and T7 (6.6±1.8; p=0.005) (Figure 5). There was no difference in motivation between the groups ($F_{2,33}$=1.214; p=0.310) across trials ($F_{3.146,103.806}$=0.569; p=0.645).

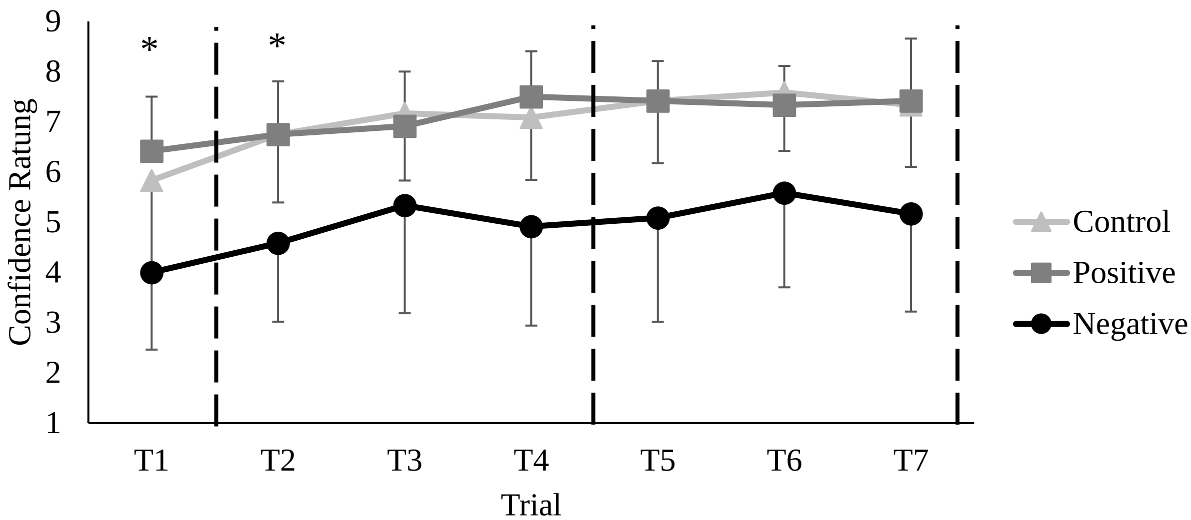

Figure 6. Mean confidence ratings for the upcoming trial using a 9-point scale (1=not confident, 9=very confident). Asterisks (*) show a main effect for trial, with lower confidence ratings on T1 than the rest of the trials and lower ratings for T2 than T4 to T7. The vertical dashed lines indicate when feedback was given to the participants. Error bars represent 1 SD.

Ratings of performance were different between the groups ($F_{2,33}$=6.140; p=0.005). The negative social-comparative feedback group rated their performance as being worse than the control (p=0.008) and positive (p=0.026) groups. The ratings of performance differed across trials ($F_{7,231}$=30.885; p<0.001) with perceived performance worse on T1 (3.3±1.8) than T2 (5.7±1.6) to T8 (6.3± 1.6; p<0.001) (Figure 6).

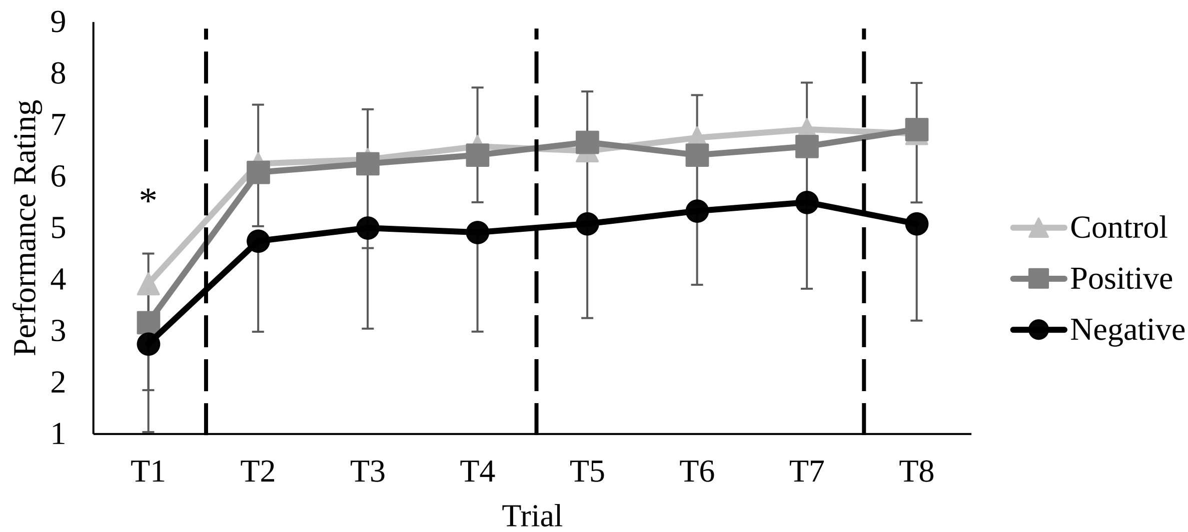

Figure 7. Mean trial-by-trial ratings for perceived performance using a 9-point scale (1=terrible, 9=terrific). The asterisk (*) shows a main effect for trial, with worse perceived performance on T1 than the rest of the trials. The vertical dashed lines indicate when feedback was given to the participants. Error bars represent 1 SD.

3.2 Performance

The overall change in performance, as measured by the amount of time when the platform was within 1.5° of the horizontal, was influenced by a trial main effect ($F_{1,33}$=46.784; p<0.001). Across all groups, participants spent 35.0±9.5% more time with the platform in a horizontal position from T1 (35.9±16.7 s) to T8 (48.5±15.1 s) (Figure 7). When the immediate effect of feedback was examined, time at horizontal was influenced by a trial × time interaction effect ($F_{2,66}$=7.183; p=0.002). Post-hoc analyses indicated that across all groups, there was a 20.2±9.4% immediate improvement in performance following the first instance of feedback (i.e., from T1 to T2) but not after the second (3.4±18.5% change in performance) or third feedback trial (0.8±5.1% change in performance) (Figure 8).

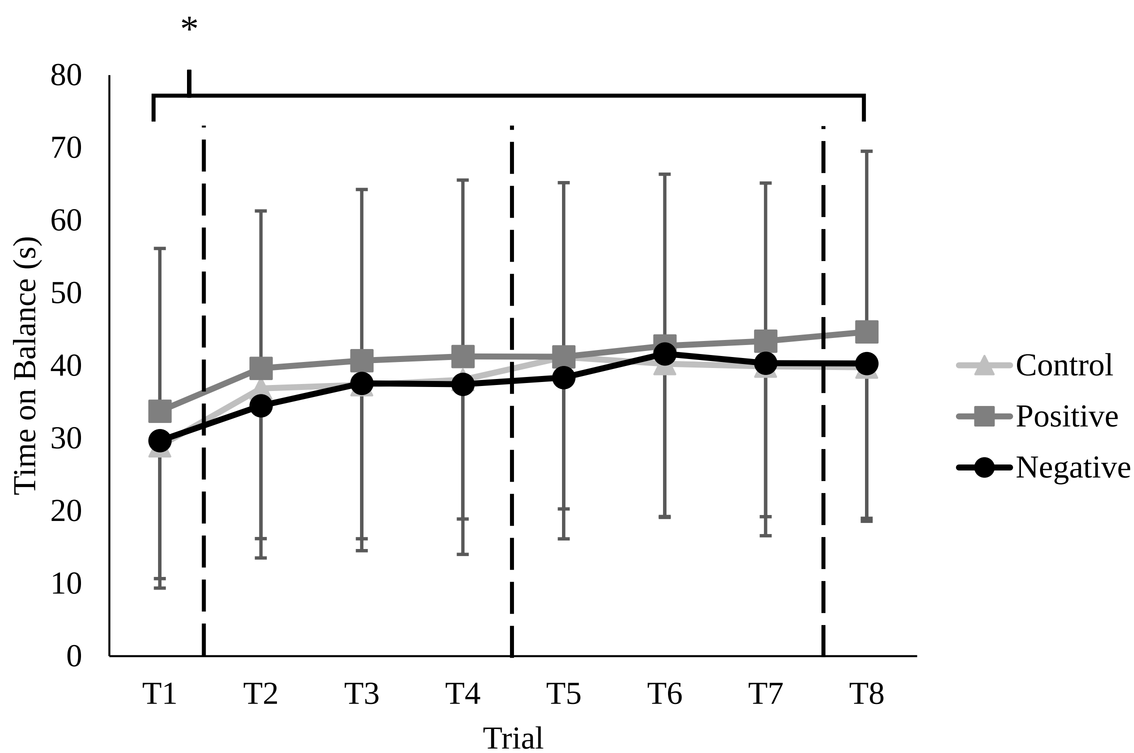

Figure 8. The mean time on balance, as measured by the time spent within 1.5˚ of the horizontal, for each 90 s balance trial. The vertical dashed lines indicate when feedback was given to the participants. Time on balance was significantly higher for T8 than T1 as noted by the asterisk. Error bars represent 1 SD.

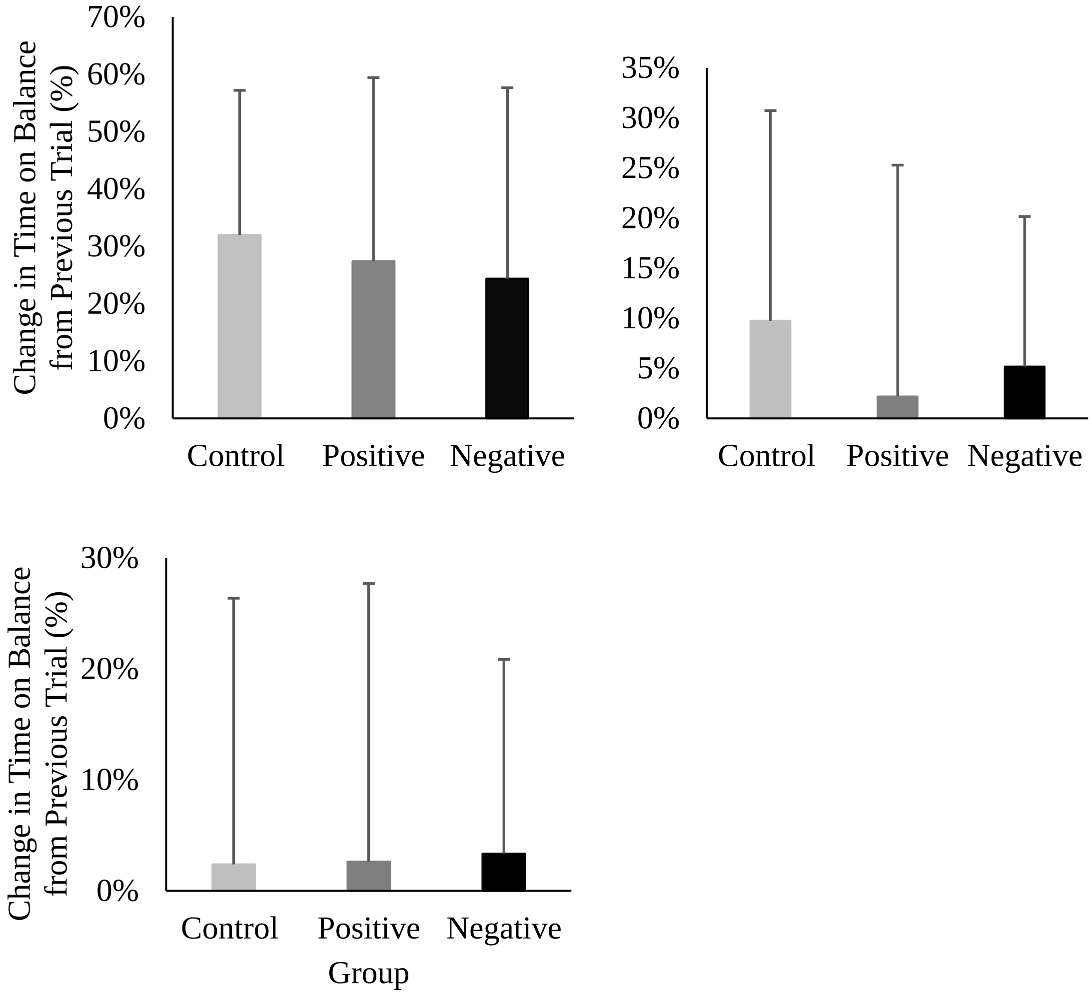

Figure 9. Mean +1 SD improvement in time on balance for trials immediately after feedback. The percent improvement from A) T1 to T2, B) T4 to T5, and C) T7 to T8 are shown. There was a greater improvement across all groups in response to the first (A) compared to the second and third feedback trials (B and C).

When RMSE of the platform position was considered, overall performance was influenced by a trial main effect ($F_{1,33}$ =59.973; $p<0.001$), with the RMSE decreasing by 43.1±36.3% across all groups (Figure 9). The RMSE on trials immediately following feedback were influenced by a trial × time interaction ($F_{2,33}$=0.404; $p=0.671$), with post-hoc analyses indicating a greater reduction in RMSE following the first (27.0±27.6%) compared to the second (8.6±9.8%) and third (increased 1.9±10.0%) instances of feedback.

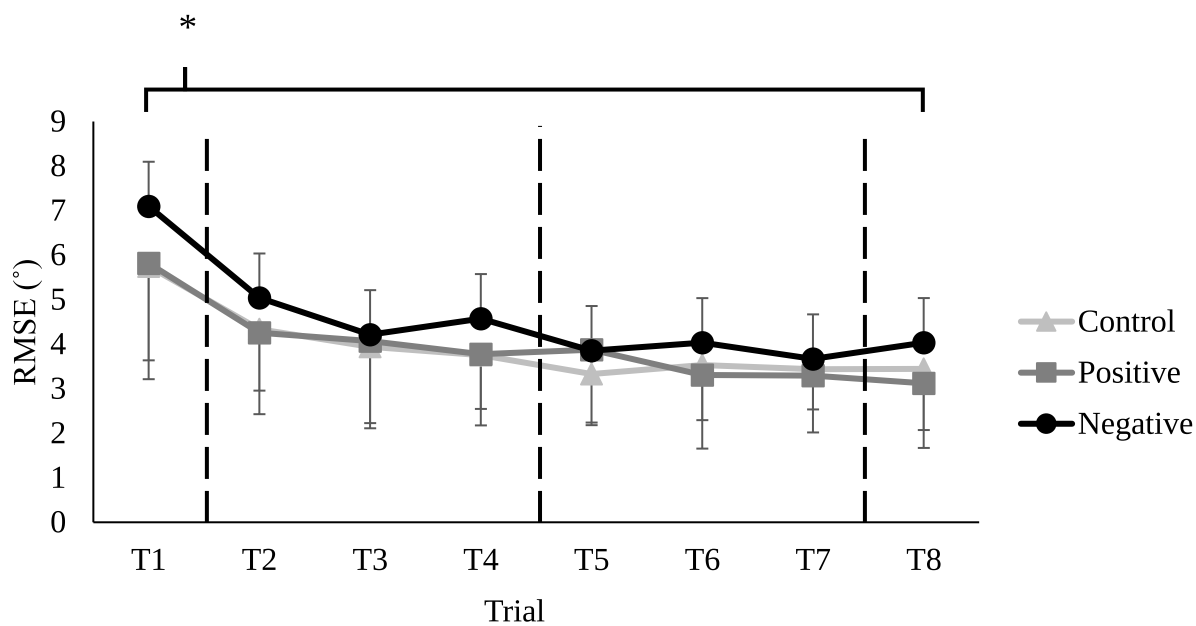

Figure 10. The mean RMSE for each 90 s balance trial. All groups improved from T1 to T8. The vertical dashed lines indicate when feedback was given to the participants. As indicated by the asterisk (*), T1 was significantly greater than T8. Error bars represent 1 SD.

In contrast to the other balance performance outcome measures, MPF was 0.3 ± 0.1 Hz at T1 and did not change by T8 (0.3 ± 0.1 Hz; $F_{1,33}$=0.229; p=0.636) (Figure 10). Similarly, the MPF following feedback ($F_{1,33}$=2.674; p=0.111) was not different. There were no differences in MPF between the groups ($F_{2,33}$=2.014; p=0.150). There was no correlation between performance and perceived skill (r=-0.216, p=0.206), feedback valence (r=0.092, p=0.593), or feedback arousal ratings (r=0.200, p=0.242).

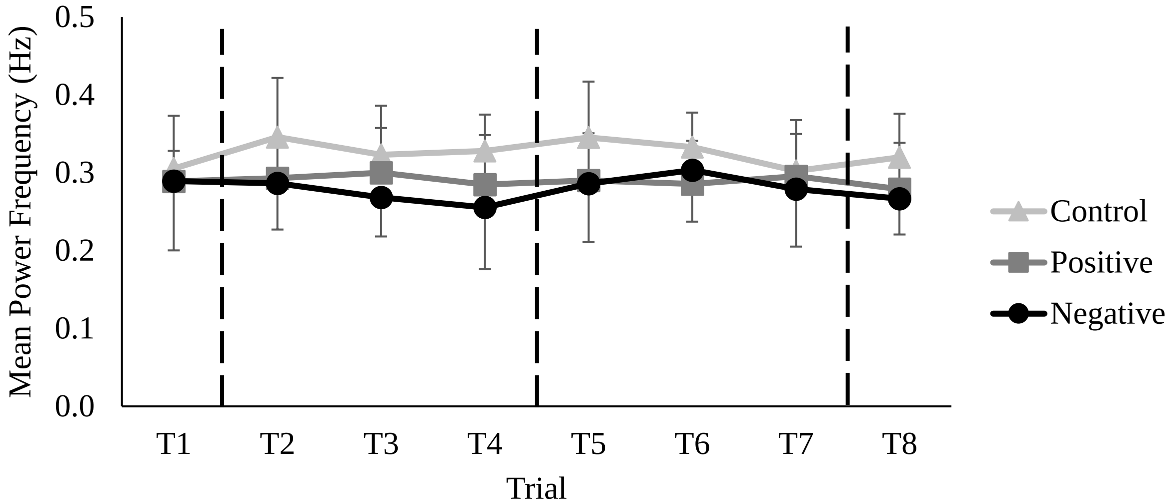

Figure 11. The mean MPF for each 90 s trial. The vertical dashed lines indicate when feedback was given to the participants. Error bars represent 1 SD.

3.3 Electromyographical Recordings

As shown in Figure 11A, the SOL MEP amplitude was not different from baseline (11.6±5.9 μV) to T8 (12.8±8.3 μV; $F_{1,33}$=0.939; p=0.340) and it did not change immediately following any instance of feedback ($F_{1,66}$=0.218; p=0.644) (Figure 11B). There was no correlation between corticospinal excitability and performance (r=-0.015; p=-0.931). Similarly, there was no correlation between corticospinal excitability and perceived skill (r=-0.097; p=0.572), feedback valence (r=0.201; p=0.239), or feedback arousal ratings (r=-0.150; p=0.384).

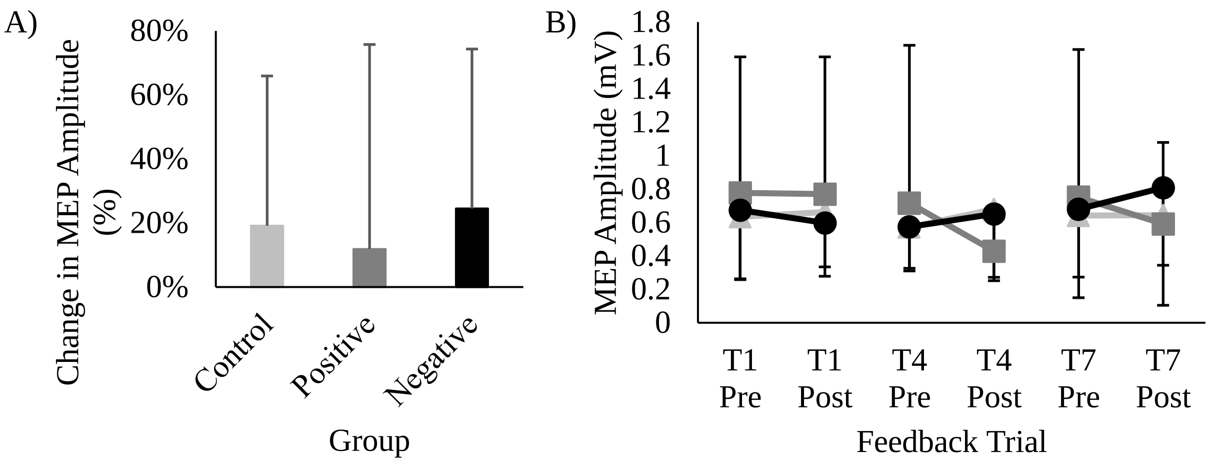

Figure 12. A) Mean+1 SD change in SOL MEP amplitude from baseline to after T8. B) Mean SOL MEP amplitude before and after the three instances of feedback. Error bars represent 1 SD.

The lack of change in SOL MEP amplitude was unlikely a result of changes in bEMG activity, as both the SOL and TA bEMG did not differ from T1 to T8 (trial main effect of p=0.134 and p=0.871 for the SOL and TA, respectively). However, there was a significant difference in the TA bEMG between groups ($F_{2,33}$=4.567; p=0.018), where a larger bEMG activity was observed in the positive (4.4±4.6 μV) compared to the negative feedback group (1.5±0.9μV; p=0.021).

When examining the immediate effect of feedback, the SOL bEMG was influenced by a group × trial interaction effect ($F_{2,66}$=3.344; p=0.048). Post-hoc analyses indicated that the SOL bEMG decreased 20±13% following the second and 16±9% following the third instance of feedback for the positive feedback group (p=0.035) but not for the negative feedback (p=0.548) or control groups (p=0.467). In contrast, no differences in the TA bEMG activity were observed from pre- to post-feedback ($F_{1,32}$=0.138; p=0.713).

3.4 Heart Rate Variability

Heart rate was influenced by a main effect for trial ($F_{2.814,92.851}$=14.155; p<0.001). Post hoc tests revealed heart rate was lower at baseline (77.2±17.4 bpm) than from T1 (100.0±19.2 bpm) to T8 (90.2±13.7 bpm; p<0.001) and T8 was lower than T2 (97.5±15.3 bpm; p=0.031) (Figure 12). There was no main effect for group ($F_{2,33}$=0.976; p=0.387).

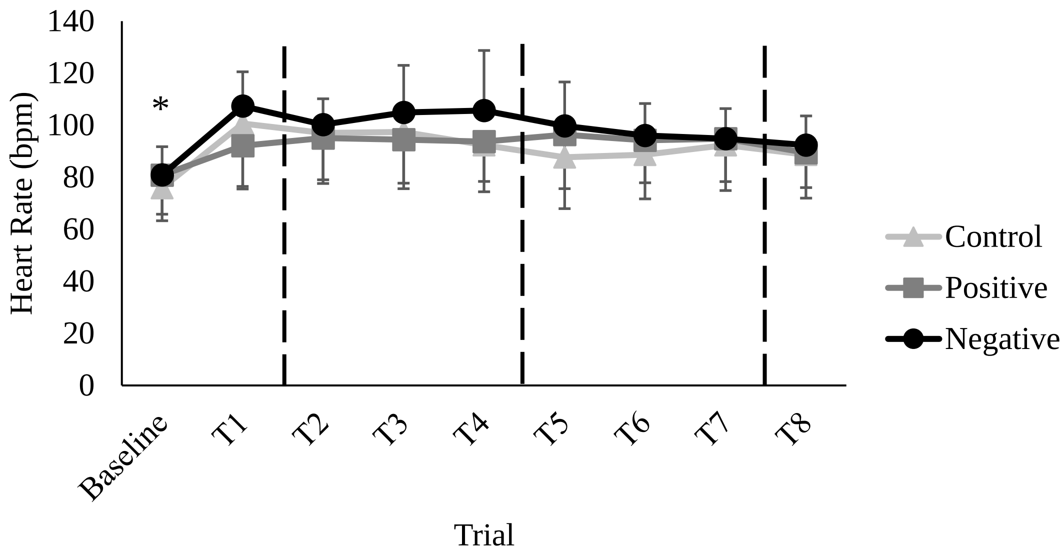

Figure 13. Mean heart rate for each 90 s balance trial for each of the three groups. The vertical dashed lines indicate when feedback was given to the participants. As noted by the asterisk (*), the baseline heart rate was lower than T1 to T8. Error bars represent 1 SD.

When analysing SDNN, there was a main effect for trial ($F_{4.483,147.933}$=11.270; p<0.001) but not for group ($F_{2,33}$=0.351; p=0.707). SDNN was higher at baseline (75.7±33.9 ms) than T1 (55.1±25.9 ms; p=0.012), T2 (46.3±25.4 ms; p<0.001), T3 (49.3±29.4 ms; p=0.009), T4 (45.7±29.6 ms; p=0.001), T5 (47.2±28.3 ms; p<0.001), T7 (45.5±23.1 ms; p=0.001) and T8 (47.1±23.8 ms; p<0.001) (Figure 13A). RMSSD was influenced by main effect for trial

($F_{4.559,150.458}$=10.487; p<0.001) but no difference between groups ($F_{2,33}$=0.484; p=0.621). RMSSD was higher at baseline (63.1±29.6 ms) than T2 (38.7±20.5 ms; p=0.002), T4 (37.5±22.3 ms; p<0.001), T5 (40.1±26.0 ms; p=0.001), T6 (37.9±20.8 ms; p<0.001), T7 (36.3±18.7; p<0.001), and T8 (39.5±20.3 ms; p<0.001) (Figure 13B).

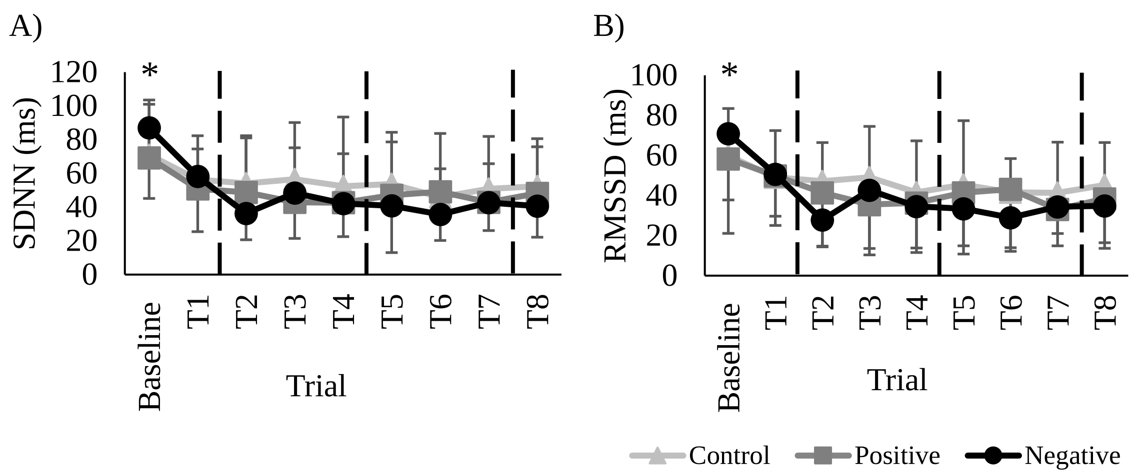

Figure 14. Mean heart rate variability, as represented by A) SDNN and B) RMSSD, for each 90 s balance trial for each of the three groups. The vertical dashed lines indicate when feedback was given to the participants. Significantly higher baseline SDNN and RMSSD values are noted with an asterisk (*). Error bars represent 1 SD.

3.5 Electrodermal Activity

EDA decreased from T1 (10.4±2.8 μS) to T8 (8.9±2.6 μS) ($F_{8,264}$=10.303; p<0.001). There was no difference between baseline (9.5±2.6 μS) and T8 (p=1.000) and no difference between the groups ($F_{2,33}$=0.332; p=0.720) (Figure 14). There was a main effect for trial ($F_{2.388,78.804}$=10.303; p<0.001) where EDA was higher on T1 than T2-T8 (p<0.001). EDA was greater on T2 (9.7±2.6 μS) than T4 (9.3±2.6 μS; p=0.002), T5 (9.1±2.4 μS; p=0.008), T6 (9.1±2.4 μS; p=0.039), T7 (9.0±2.4 μS; p=0.006), and T8 (8.9±2.6 μS; p=0.026). It was also higher on T3 (9.5±2.6 μS) compared to T4 (p=0.002), T5 (p=0.049), T7 (p=0.006), and T8 (p=0.026).

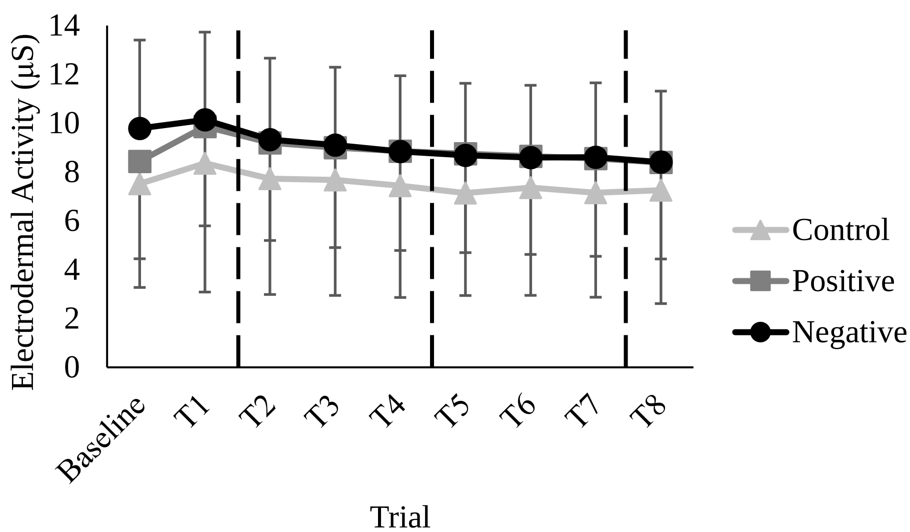

Figure 15. The mean electrodermal activity for each 90s trial and baseline for the control, positive, and negative groups. The vertical dashed lines indicate when feedback was given to the participants. Error bars represent 1 SD.

4. Discussion

The purpose of this study was to examine whether social-comparative feedback influences balance performance and whether changes in balance performance could be attributed to differences in corticospinal excitability. Although the provision of social-comparative feedback induced the intended psychological and valent effects (e.g., decreased perceived skill and balance confidence following negative social-comparative feedback), no differential effects of feedback type on balance performance and corticospinal excitability were observed.

Therefore, the results of the current study do not support the original hypothesis. Instead, results suggest that social-comparative feedback does not lead to any greater or lesser improvements in balance performance as knowledge of results feedback and that social-comparative feedback does not alter corticospinal excitability.

4.1 Feedback

The specific form of social-comparative feedback provided in this current study was modified from previous studies. In previous studies, the participants' score and a comparative score were used for feedback or the percentage better/worse than the group were provided but both were included in this study. In addition, a statement of context including valent terms was used to encourage the participants to interpret the feedback as intended. Despite these alterations, it can be argued that the current study was successful in altering psychological processes of the participants through the use of social-comparative feedback. For example, when participants were informed that they were performing worse than the group, they reported a 16% decrease in balance confidence and a 43% reduction in perceived skill over the course of the experiment. These changes are similar to what has been reported in previous studies. Lamarche *et al*. (2011, 2014) reported a 10-20% decrease in balance efficacy in their negative social-comparative feedback groups, while a 21-45% decrease in perceived skill has been previously reported following negative feedback (Lewthwaite & Wulf, 2010; Ong & Hodges, 2017). Interestingly however, these robust responses to negative feedback did not lead to any reported changes in motivation to perform the balance task and participants perceived the feedback in a neutral rather than a negative tone (4.3±1.1). It is possible that these participants did not perceive their feedback as wholly negative because seeing their own performance score improve across trials may have produced a positive element to the feedback.

In contrast to the negative feedback group, no changes in balance confidence or perceived skill were reported by participants in the positive social-comparative group from the beginning to the end of the experiment. These results are not surprising, as other researchers have reported similar findings. For example, positive social-comparative feedback was unable to change perceived balance efficacy (Lamarche *et al*., 2009; Lamarche *et al*., 2011; Lamarche *et al*., 2014) or self-efficacy (Ong & Hodges, 2017) in previous studies. These effects may reflect the suggestion it is easier to undermine self-efficacy with feedback than it is to enhance it (Bandura, 1997). Despite no changes in the reported balance confidence or perceived skill, participants in the positive feedback group indicated that they became slightly (6%) more motivated to perform the balance task and considered their feedback with a more positive affect than both the control and negative feedback groups.

4.2 Balance Performance

Although social-comparative feedback elicited psychological and valence responses, no differential effects of social-comparative feedback on balance performance were observed, which produced a mismatch between perception of abilities and actual performance abilities. This was the case when the overall effect of social-comparative feedback was examined, where the negative group perceived their performance to be worse than the positive and control groups despite all three groups improving their time spent on balance and RSME from T1 to T8 by ~35% and ~43%, respectively. Further, none of the groups demonstrated a change in MPF across trials. When assessing the immediate effects on balance performance, all experimental groups demonstrated the largest improvement in balance performance after the first instance of feedback. This first trial effect, where larger postural reactions occur during the untrained first trial and generally habituate over subsequent trials (Nanhoe-Mahabier *et al*., 2012; Oude Nijhuis, Allum, Valls-Solé, Overeem, & Bloem, 2010) appears to have a similar influence regardless of feedback type. While others have also found social-comparative feedback to have little or no influence on balance performance with training (e.g., Wulf (2013) and Ong & Hodges (2017)), this contrasts with the frequently assumed benefits of social-comparative feedback. For example, greater reductions in RMSE have previously been reported for the positive compared to the negative feedback group (Lewthwaite & Wulf, 2010).

It is not clear why the effects of social-comparative feedback on a stabilometer balance task have produced such variable effects, particularly when the elicited psychological and valent responses appear to be similar between studies. One factor may be the level of task difficulty, which was increased in this study by increasing the range of motion of the stabilometer platform (27˚ compared to the 18˚ used by Wulf (2012)) and the probable use of fewer resistance bands than previous studies. When a more difficult balance task is encountered, this requires an increased involvement of the motor cortex to maintain movement coordination (Solopova, Kazennikov, Deniskina, Levik, & Ivanenko, 2003). Consequently, individuals may require more practice trials before the task can be controlled through automatic processes. Had participants of this study completed more trials, such as 14 over two days (Lewthwaite & Wulf, 2010; Wulf, 2013), a differential effect of social comparative feedback may have emerged. Further, it may also be important to examine the effects of social-comparative feedback on balance performance during a delayed retention test. When participants were assessed one day after their training, Wulf (2012) found the positive group improved more than the control group while Lewthwaite and Wulf (2010) observed that the positive group performed better than both the negative and control groups. Thus, providing time for consolidation to occur may help maximize the benefits of social-comparative feedback on balance performance.

Another factor that may explain the varied results between studies is the form of social-comparative feedback that has been provided to participants. Social-comparative feedback of performance has previously been presented as a group score and individual score (Lewthwaite & Wulf, 2010), percentage of time on target (Ong & Hodges, 2017), and top/bottom 10% ranking (Lamarche *et al.*, 2009). Differences in the way an individual is interpreting the feedback, rather than the content of the feedback itself, is known to influence EMG activity, motor cortical activation and muscle endurance time (Lauber *et al.*, 2012, 2013). For example, when following a live feedback trace during a fatiguing protocol, there is a longer time to fatigue when participants are told it is a force trace rather than a position trace (Lauber, Leukel, Gollhofer, & Taube, 2012; Lauber *et al*., 2013) even when a position trace is presented (Lauber *et al*., 2013).

4.3 Corticospinal Excitability

The current study also investigated whether the valence of social-comparative feedback influences corticospinal excitability. It was hypothesized that differences in corticospinal excitability might help to explain some of the previously reported improvements in balance performance. Results of this study revealed no changes in corticospinal excitability immediately after each instance of feedback or at the end of the experiment for all three experimental groups.

The lack of between-group difference in corticospinal excitability is perhaps not surprising due to the similar changes in balance performance across groups. However, an overall increase in neural excitability from T1 to T8 would still be expected given the 35% improvement in balance performance across trials. Pascual-Leone *et al.* (1995) reported an increase in corticospinal excitability during the practice and skill acquisition phases when learning a new motor task. Similarly, as a skill is learned, researchers have reported a decrease in corticospinal excitability with less active control of balance and more automatic control (Taube *et al.*, 2007).

When a task is being learned, the motor system is actively developing a ‘model’ for that particular task to correct for errors in execution for better performance. As the task becomes learned, the ‘model’ allows for modifications of appropriate magnitude automatically because the conditions become more predictable (Nashner, 1976). Neither of these were supported by the results of the current study.

Another limitation of this study that might explain the lack of change in corticospinal excitability is the timing of measurement. MEPs were collected prior to and upon completion of the experimental trials, as well as immediately before and after each instance of feedback or neutral screen. This was done to assess the immediate and prolonged effects of the valent stimuli on corticospinal excitability since positive and negative stimuli influence corticospinal excitability across differing time courses (Baumert *et al.*, 2011). However, the disadvantage is that corticospinal excitability rapidly changes in response to a stimulus or movement. This can take place within 50 ms of initiating a voluntary movement to 150 ms of terminating muscle activity (Chen, Yaseen, Cohen, & Hallett, 1998). Changes to M1 excitability can also last for 5 min, as shown by increased MEP amplitude in the first dorsal interosseus muscle after training a finger abduction task, while the trained skill can be maintained for 45 min (Bologna *et al.*, 2015). Since the amount of time that occurred between balance trial completion and the blocks of MEPs was of several minutes in this study, it is possible that EMG activity had already returned to baseline by the time of TMS application.

Even though participants perceived the social-comparative feedback as valent and the negative social-comparative feedback reduced an individual’s balance confidence and perceived skill, social-comparative feedback did not differentially alter corticospinal excitability. This is surprising based on previous studies examining how individuals respond to emotional stimuli.

Previous studies have found that when individuals are exposed to negative stimuli (e.g., IAPS images, music, images of faces), there is an immediate increase in MEP amplitude (Baumert *et al*., 2011; Coombes *et al*., 2009; Oathes *et al*., 2008; Schutter *et al*., 2008). These changes in corticospinal excitability are proposed to be through enhanced intracortical inhibition which has been shown in response to negative images, resulting in improved performance on reaction time tasks (Koganemanu, Domen, Fukuyama, & Mima, 2012). Increases in corticospinal excitability have also been observed when individuals experience a prolonged exposure to positive stimuli (Baumgartner *et al*., 2007; Hajcak *et al*., 2007).

One potential reason for why the current study did not observe a change in corticospinal excitability is the strength of the valent stimulus. Baumgartner *et al*. (2007) found that increased arousal is needed to increase the activation in the motor system but to alter motor output there may need to be a valent component to the stimuli which lead to increased arousal. This was supported by Coombes *et al*. (2009), who observed an increased corticospinal excitability with increased arousal for the valent stimuli while there were no changes in corticospinal excitability or arousal for the neutral stimuli. In the current study, individuals in the negative social-comparative feedback group rated their feedback as less positive than the positive feedback group but otherwise, there were no between-group differences in how arousing individuals perceived their feedback and all groups demonstrated similar levels of anxiety, as reflected by comparable fluctuations in HRV and EDA, throughout the experiment. It is possible that social-comparative feedback, as presented in this study, produced the intended valent response as studies that have used negative images, but the magnitude of the emotional response may not have been sufficient for increased activation in the motor system. A stronger emotional response could also lead to a greater differentiation in how motivating the feedback was to the individual.

Since motivation, separate from valence and arousal, is also known to influence corticospinal excitability (Radel *et al.*, 2016) through alterations in intracortical inhibition in the motor cortex (Kapogiannis *et al.*, 2011), a more motivating form of social-comparative feedback may have also yielded larger effects on corticospinal excitability and subsequently, balance performance.

4.4 Conclusions

In conclusion, this study found that the provision of social-comparative feedback did not lead to any differential improvements in balance performance or changes in corticospinal excitability. Since the feedback still elicited selected valent responses, such as decreased confidence and perceived skill for the negative group as well as the positive group rating the feedback as more positive than the negative and control groups, it is suggested that social-comparative feedback has minimal or no influence on the corticospinal and functional control of balance. However, future studies are needed to confirm these conclusions. This could include (i) examining different presentations of social-comparative feedback to determine the optimal form of feedback to increase motor activation and alter balance performance, and (ii) collecting neurophysiological measures during the actual performance of the task to better assess the immediate and task-specific influence of social-comparative feedback.

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Appendix A

TMS Screening Questionnaire

Please answer the following questions:

1. Do you have epilepsy or have you ever had a convulsion or a seizure?	
2. Have you ever had a fainting spell or syncope? If yes, please describe the situation(s).	
3. Have you ever had severe head trauma?	
4. Have you experienced a concussion in the past six months?	
5. Do you experience headaches or migraines on a regular basis? If yes, how frequently? When was the last occurrence?	
6. Do you have any hearing problems or ringing in your ears?	
7. Are you pregnant or is there any chance that you might be?	
8. Do you have metal (e.g., splinters, fragments, clips, etc.) in the brain/skull?	
9. Do you have cochlear implants?	
10. Do you have an implanted neurostimulator? (e.g., DBS, epi-dural/subdural, VNS)	
11. Do you have a cardiac pacemaker or intracardiac lines or metal in your body?	
12. Do you have a medication infusion device?	
13. Are you currently taking any medications/supplements (including vitamins)? If yes, for what condition? (Note: It is especially important to indicate if you are currently taking anti-depressant or anti-convulsant medication as they are associated with a higher risk of injury from TMS.)	
14. Have you ever had a surgical procedure to your spinal cord?	
15. Do you have spinal or ventricular derivations?	
16. Have you ever undergone MRI in the past? If so, were there any problems?	
17. Have you ever undergone TMS in the past? If so, were there any problems?	

Appendix B

1. How confident are you in your balance abilities?

1	2	3	4	5	6	7	8	9

Not confident Very confident

2. Relative to other people, how skilled do you think you will be on the balance task (wobble board)?

1	2	3	4	5	6	7	8	9

Not skilled Very skilled

3. How anxious are you to perform the balance task?

1	2	3	4	5	6	7	8	9

Not anxious Very anxious

4. How motivated are you to perform the balance task?

1	2	3	4	5	6	7	8	9

Not motivated Very motivated

Appendix C

Between trial questionnaire. Question one answered on a slip of paper on each trial. The last three questions were presented on the television screen and responses provided verbally.

1. What were you focused on/thinking about during the balance task? (Ex., task instructions, feedback, thoughts unrelated to the task, etc.)

How would you rate your balance performance for the last trial?

1	2	3	4	5	6	7	8	9
Terrible								Terrific

FEEDBACK & MEPS

How confident are you in your ability to perform the balance task?

1	2	3	4	5	6	7	8	9
Not confident								Very confident

How motivated are you to improve your performance on the balance task?

1	2	3	4	5	6	7	8	9
Not motivated								Very motivated

Appendix D

1. How confident are you in your balance abilities?

   1 2 3 4 5 6 7 8 9

   Not confident Very confident

2. Relative to other people, how skilled do you think you were on the balance task (wobble board)?

   1 2 3 4 5 6 7 8 9

   Not skilled Very skilled

3. How anxious were you performing the balance task?

   1 2 3 4 5 6 7 8 9

   Not anxious Very anxious

4. How motivated were you to improve on the balance task?

   1 2 3 4 5 6 7 8 9

   Not motivated Very motivated

Appendix E

*Questionnaire for the social-comparative feedback groups.

Please answer the following questions based on your experience throughout all seven trials.

1. How useful did you find the feedback for the subsequent trial?

1 2 3 4 5 6 7 8 9

Not useful Neither Very useful

2. How motivating did you find the feedback for the subsequent trial?

1 2 3 4 5 6 7 8 9

Not motivating Neither Very motivating

3. How did seeing that your score was better/worse than the expected score make you feel? The first picture (1) shows someone distressed (e.g., irritated, defeated) while the last picture (9) shows someone elated (e.g. delighted, satisfied).

SAM SCALE PROVIDED (Lang, 1980)

4. How did seeing that your score was better/worse than the expected score make you feel? The first picture (1) shows someone very calm (e.g., relaxed, bored) while the last picture (9) shows someone bursting with arousal (e.g. excited, angered).

SAM SCALE PROVIDED (Lang, 1980)

Appendix F

*Questionnaire for the control group.

Please answer the following questions based on your experience throughout all seven trials.

1. How useful did you find the feedback for the subsequent trial?

1 2 3 4 5 6 7 8 9

Not useful Neither Very useful

2. How motivating did you find the feedback for the subsequent trial?

1 2 3 4 5 6 7 8 9

Not motivating Neither Very motivating

3. How did seeing your score make you feel? The first picture (1) shows someone distressed (e.g., irritated, defeated) while the last picture (9) shows someone elated (e.g. delighted, satisfied).

SAM SCALE PROVIDED (Lang, 1980)

4. How did seeing your score make you feel? The first picture (1) shows someone very calm (e.g., relaxed, bored) while the last picture (9) shows someone bursting with arousal (e.g. excited, angered).

SAM SCALE PROVIDED (Lang, 1980)

Appendix G

Department of Kinesiology, Brock University
Debrief and Informed Consent

August 2017

Title of Study:	Examining corticospinal excitability following a balance task.
Principal Investigator:	Dr. Craig Tokuno, Associate Professor, Department of Kinesiology, Brock University
Principal Student Investigator:	Stephanie Reischl, Faculty of Applied Health Sciences, Brock University
Co-Investigator:	Syed Raza, Centre for Neuroscience, Brock University

The true purpose of the study was to determine whether positive (e.g., "you did terrific") or negative (e.g., "you did horrible") feedback alters motor performance and the responsiveness of your nervous system.

To examine this question, participants were randomly divided into three groups:

- Participants in the positive group always received feedback that their actual performance was better than the group average on every trial.
- Participants in the negative group always received feedback that their actual performance was worse than the group average on every trial.
- Participants in the control group were only informed of their actual performance value.

If you were in the positive or negative group, the feedback you were provided relative to the group average was not necessarily indicative of your actual performance and should not shape your opinion of your balance capabilities.

We needed to provide deceiving feedback in order to elicit a genuine emotional (positive or negative) response. If you were aware of the true purpose of the study prior to participation, it may have altered your perception of the feedback. This may have generated less of an emotional response or caused you to ignore the feedback entirely, which would have prevented us from being able to address our research question.

I am aware of the true purpose of the study and the use of deception. I have been told which of the feedback groups I was assigned. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I consent to the use of my data collected.

Name: ____________________________ (please print)

Signature: _____________________________ Date: ________________________

Appendix H

Tables reporting the F and p values for all statistical analyses.

Table 3. Demographics: F and *p* values from one-way ANOVAs.

	Group (G)	
	F	***p***
Age	1.846	0.174
Height	1.204	0.313
Weight	0.866	0.430
SMTQ	1.069	0.355
Error Range (°)	0.057	0.944

Table 4. Questionnaires: F and *p* values for 3 (group: control, positive, negative) × 2 (time: pre/post) mixed ANOVAs with time as a repeated measure to assess confidence, perceived skill, motivation and anxiety before and after the experimental trials (Appendix C vs Appendix E). F and *p* values for separate 3 (group: control, positive, negative) × 7 (trial: T1-T7) to assess trial by trial changes in motivation and confidence (Appendix D) and a 3 (group: control, positive, negative) × 8 (trial: T1-T8) to assess ratings of performance on the previous trial (Appendix D).

	Group (G)		Time (T)		Trial (Tr)		G × T		G × Tr	
	F	***p***	**F**	***p***	**F**	***p***	**F**	***p***	**F**	***p***
Overall										
Balance Confidence	5.323	0.010	6.728	0.014	-	-	6.778	0.003	-	-
Perceived Skill	9.011	0.001	5.272	0.028	-	-	21.284	<0.001	-	-
Anxiety (perform)	0.401	0.673	6.270	0.017	-	-	0.773	0.488	-	-
Motivated (perform)	1.336	0.277	8.494	0.006	-	-	3.716	0.035	-	-
Trial by Trial										
Confidence	9.826	0.001	-	-	23.891#	<0.001	-	-	1.499#	0.174
Motivation	1.214	0.310	-	-	0.569#	0.645	-	-	0.752#	0.699
Performance	6.140	0.005	-	-	30.885	<0.001	-	-	0.504	0.930

# indicates where a Greenhouse-Geisser correction was made.

Table 5. Feedback: F and *p* values from one-way ANOVAs assessing the participants' interpretation of the feedback (Appendices F and G).

	Group (G)	
	F	***p***
Valence	18.152	<0.001
Arousal	0.126	0.882
Motivating	2.940	0.067
Useful	0.865	0.430

Table 6. Performance: F and *p* values for separate 3 (group: control, positive, negative) × 2 (trial: T1, T8) mixed ANOVAs with trial as a repeated measure to assess overall performance and separate 3 (group: control, positive, negative) × 3 (trial: T1, T4, T7) × 2 (time: pre/post) mixed ANOVAs with trial and time as repeated measures to assess the immediate effects on performance.

	Group (G)		Time (T)		Trial (Tr)		G × T		G × Tr		T × Ti		G × T × Tr	
	F	***p***	**F**	***p***	**F**	***p***	**F**	***p***	**F**	***p***	**F**	***p***	**F**	***p***
Overall														
Time on Balance	0.484	0.621	-	-	46.784	<0.001	-	-	0.003	0.997	-	-	-	-
RMSE	1.429	0.254	-	-	59.973	<0.001	-	-	0.404	0.671	-	-	-	-
MPF	2.014	0.150	-	-	0.229	0.636	-	-	0.835	0.443	-	-	-	-
Immediate														
Time on Balance	0.318	0.730	16.505	<0.001	39.677	<0.001	0.505	0.515	0.677	0.732	7.183	0.002	0.388	0.816
RMSE	0.881	0.424	28.325	<0.001	60.308#	<0.001	0.409	0.668	0.903	0.467	12.126	<0.001	0.750	0.561
MPF	3.247	0.052	2.674	0.111	1.482	0.235	2.058	0.144	1.240	0.303	1.485	0.234	0.828	0.512

Table 7. Electromyography: F and *p* values for separate 3 (group: control, positive, negative) × 2 (trial: T1, T8) mixed ANOVAs with trial as a repeated measure to assess overall effects on EMG amplitudes and separate 3 (group: control, positive, negative) × 3 (trial: T1, T4, T7) × 2 (time: pre/post) mixed ANOVAs with trial and time as repeated measures to assess the immediate effects on EMG amplitude.

	Group (G)		Time (T)		Trial (Tr)		G × T		G × Tr		T × Ti		G × T × Tr	
	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*
Overall														
SOL EMG Amplitude	0.312	0.734	-	-	0.939	0.340	-	-	0.267	0.768	-	-	-	-
bEMG SOL	0.928	0.405	-	-	2.364	0.134	-	-	1.926	0.162	-	-	-	-
bEMG TA	4.567	0.018	-	-	0.027	0.871	-	-			-	-	-	-
Immediate														
SOL EMG Amplitude	0.586	0.562	0.218	0.644	1.025	0.364	2.259	0.120	0.563	0.691	0.035#	0.936	1.307	0.277
bEMG SOL	1.090	0.348	0.415	0.524	1.138	0.327	3.344	0.048	0.246	0.911	1.879	0.161	0.726	0.577
bEMG TA	4.339	0.022	0.138	0.713	0.023	0.978	2.391	0.108	1.147	0.343	0.379	0.686	0.125	0.973

Table 8. HR, HRV, and EDA: F and *p* values for separate 3 (group: control, positive, negative) × 9 (trial: baseline, T1-T8) mixed ANOVAs with trial as a repeated measure.

	Group (G)		Trial (Tr)		G × Tr	
	F	*p*	F	*p*	F	*p*
HR	0.976	0.387	14.155#	<0.001	1.371	0.156
HRV - SDNN	0.351	0.707	11.270#	<0.001	1.431	0.127
HRV - RMSSD	0.484	0.621	10.487#	<0.001	1.414	0.135
EDA	0.332	0.720	10.303#	<0.001	0.940	0.524

# indicates where a Greenhouse-Geisser correction was made.