Full length article

Examining changes in corticospinal excitability and balance performance in response to social-comparative feedback

Stephanie A. Reischl[a], Syed Z. Raza[b], Allan L. Adkin[a,b], Jae T. Patterson[a,b], Craig D. Tokuno[a,b,*]

[a] Department of Kinesiology, Brock University, St. Catharines, ON, Canada
[b] Centre for Neuroscience, Brock University, St. Catharines, ON, Canada

ABSTRACT

Background: Social-comparative feedback informs an individual that their performance was better or worse than the group. Previous studies have found that compared to knowledge of results alone, social-comparative feedback produces a valence response that results in larger improvements in balance performance. However, the neural processes contributing to these motor improvements have not yet been examined.

Research question: Does social-comparative feedback alter corticospinal excitability and consequently, balance performance?

Methods: Thirty-six healthy young adults stood and maintained their balance on a stabiliometer for eight trials. After three of the trials, the neutral (i.e., only knowledge of results) group received their performance feedback (i.e., time on balance) while the other two groups also received positive (i.e., performed better than the group) or negative (i.e., performed worse than the group) social-comparative feedback. To measure corticospinal excitability, soleus motor-evoked potentials were elicited using transcranial magnetic stimulation at the beginning of the experiment, after the presentation of feedback, and at the end of the experiment. Pre- and post- ratings of confidence, perceived skill, motivation, and anxiety were also collected.

Results: The negative feedback group reported decreases in perceived skill (43 ± 29%) and balance confidence (26 ± 28%), while the positive group reported a 13 ± 17% increase in perceived skill. Despite these group differences in feedback perception, all three groups improved their balance performance by ≈35% (p < 0.001) by the eighth trial. However, this improvement in balance performance was not matched by any changes in corticospinal excitability over time (19.2 ± 55.9% change; p = 0.340) or between groups (p = 0.734).

Significance: Our findings suggest that social-comparative feedback, as presented in this study, does not affect corticospinal excitability and balance performance differently than knowledge of results (neutral feedback) alone. More arousing and more frequent forms of social-comparative feedback may be necessary for observing larger changes in the functional or neural control of balance.

1. Introduction

Social-comparative feedback informs an individual of their performance outcome relative to a peer group's (false) average score to indicate whether they performed better or worse than their peers. Positive social-comparative feedback, informing an individual that they have performed better than the group, leads to individuals reporting higher self-efficacy and motivation as well as more positive self-reactions, while opposite effects are observed following negative social-comparative feedback [1–4].

Valent responses that accompany social-comparative feedback are thought to influence balance performance. When social-comparative feedback is provided to individuals learning a novel balance task,

positive feedback results in greater improvements in balance performance, as reflected by a reduction in root mean square error (RMSE) and an increase in mean power frequency (MPF), than negative or neutral feedback [5]. It is speculated that these balance improvements reflect the adoption of a more automatic control of balance [5,6] but the underlying neural processes that are altered in response to social-comparative feedback have not been directly examined.

One neurophysiological measure that might be altered in response to social-comparative feedback is corticospinal excitability. This can be assessed by eliciting motor-evoked potentials (MEPs) using transcranial magnetic stimulation (TMS). Specifically, larger MEP amplitudes reflect an increased excitability of the neural structures within the corticospinal pathway, including the motor cortical neurons, spinal interneurons

or motor neurons [7]. Monitoring how corticospinal excitability is up- or down-regulated is useful for understanding how the central nervous system responds to different stimuli. For example, previous studies have observed an increase in corticospinal excitability when individuals encounter more difficult balance tasks (e.g., standing on a wobble board compared to a stable surface) [8–10]. However, when individuals gain more experience through a short-term balance training program, there is a reduction in corticospinal excitability [11–13]. Those who demonstrate the largest improvements in stability (i.e., reduction in ground reaction forces) to platform perturbations have the greatest decreases in excitability [11]. This training-induced decrease is believed to reflect a lesser motor cortical involvement and a more reliant "automatic" balance control strategy [11,12]. In contrast to these aforementioned effects, research has also shown that independent of balance control, corticospinal excitability increases following exposure to negative or unpleasant images or auditory scenarios compared to neutral stimuli [14–17]. This change is likely a result of a priming or facilitation of the neuromuscular system in preparation for future motor action [17].

Considering the opposing effects that balance training and emotion have on corticospinal excitability, investigating whether changes in excitability explains how social-comparative feedback affects balance performance is warranted. It is possible that the elevated level of corticospinal excitability due to the negative valence associated with social-comparative feedback undermines any potential down-regulation of corticospinal excitability observed with balance training and improvements in balance performance. This lesser ability to decrease excitability may then explain why individuals exposed to negative social-comparative feedback do not perform as well as those receiving positive feedback.

The purposes of this study were to examine whether social-comparative feedback alters balance performance, and to determine whether the effects of this feedback could be explained by changes in corticospinal excitability. It was hypothesized that positive social-comparative feedback would lead to greater improvements in balance performance than negative social-comparative or neutral feedback. Further, it was hypothesized that this differential improvement of balance performance would be explained by corresponding changes in corticospinal excitability. Exposure to the negative valence associated with negative social-comparative feedback was expected to result in a lesser ability for individuals to reduce their MEP amplitude over time.

2. Methods

2.1. Participants

Thirty-six young adults (18 males) participated in this study (Table 1). All participants provided informed consent. The experimental protocol was approved by the university research ethics board and performed in accordance with the Declaration of Helsinki.

2.2. Experimental set-up

Pairs of Ag/AgCl electrodes (30 mm, Covidien Kendall, Minneapolis,

Table 1
Participant characteristics for the three experimental groups. Unless otherwise stated, values represent the mean ± 1 SD for each group.

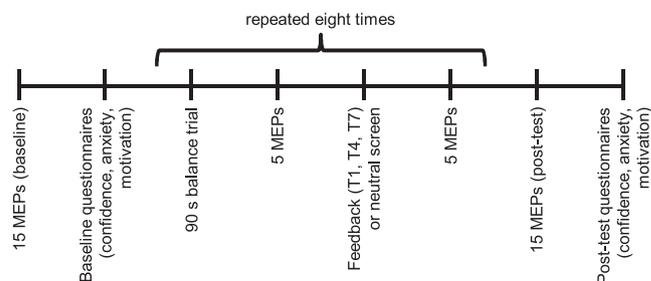|	Neutral Feedback (n = 12)	Positive Feedback (n = 12)	Negative Feedback (n = 12)
Male/Female (#)	6/6	6/6	6/6
Age (y)	24.5 ± 2.4	23.4 ± 3.1	22.4 ± 2.5
Height (m)	174.8 ± 9.4	175.5 ± 10.9	172.9 ± 1.0
Weight (kg)	75.9 ± 8.4	72.0 ± 11.7	70.8 ± 9.0

Fig. 1. A timeline overview of the experimental protocol. The questionnaires completed after the baseline MEPs and after the eight trial were the same except that participants were to refer to the upcoming (pre-test) or the eight preceding trials (post-test).

MN, USA) were placed on the skin over the right soleus (SOL) and tibialis anterior (TA) with an interelectrode distance of 2 cm while a single reference electrode (same material as above) was placed over the lateral aspect of the knee. All skin sites were shaved, cleansed with alcohol, and abraded with a conductive gel prior to electrode placement. All EMG recordings were sampled at 2000 Hz (micro1401 and Spike2 software, Cambridge Electronic Design, Cambridge, UK).

Participants were seated while determining the optimal coil position for stimulating the SOL. The TMS coil (110 mm double-cone coil with Super Rapid² stimulator, Magstim Company, Dyfed, UK) was gradually moved around the vertex while single TMS pulses were applied over the left motor cortex until the largest SOL EMG response was observed for a given stimulation intensity. This position was marked to ensure a consistent coil position throughout the experiment. Participants then stood while motor threshold (MT), defined as the minimum intensity that elicited SOL MEPs of at least 100 µV in three of six consecutive stimuli, was determined.

2.3. Experimental protocol

An overview of the experimental protocol is illustrated in Fig. 1. Prior to the first experimental trial, participants stood on the ground with their feet hip-width apart, arms by their sides, and their gaze fixed ahead. The TMS coil was positioned to the previously-identified hotspot and 15 stimuli (interstimulus interval of 4–7 s) were applied at 120% MT to determine the baseline level of corticospinal excitability. Next, participants were given instructions regarding the upcoming balance trials and verbally responded to a questionnaire rating their balance confidence [18] and perceived skill [5] on the stabiliometer, as well as their anxiety [19] and motivation [5] for the balance task using a 9-point scale (1 = low; 9 = high).

Participants completed eight experimental trials. Each trial consisted of a 90-s balance task followed by two blocks of five MEPs, which were separated by a feedback or neutral screen. Each balance task began with participants standing with their feet hip-width apart on top of a stabiliometer (16030 Stability Platform, Lafayette Instrument, Lafayette, IN, USA) that could tilt in the roll plane. The goal of this task was to keep the platform horizontal for as long as possible. The TMS coil was not positioned on the participants' head and TMS was not applied during the balance trials due to difficulties in maintaining coil position and ensuring neuromuscular factors (e.g., joint angles) remain consistent between stimuli. Instead, TMS was delivered following each balance trial and with the participant standing on the ground. One block of five TMS pulses was applied while participants stood quietly with their gaze fixed on a monitor positioned 2 m in front. This was followed by performance feedback [after the first (T1), fourth (T4) and seventh (T7) balance trial] or a blank screen (remaining five balance trials) that was shown on the monitor before a second block of five TMS pulses was collected. The content of the feedback was dependent on the group for which the participant was assigned.

Table 2
Mean ± 1 SD responses to the questionnaires delivered before and after the experimental trials. Asterisks (*) indicate a significant time effect (from pre- to post-test), while hashtags (#) denote a significant group difference between the positive compared to both the neutral and negative feedback groups.

	Neutral Feedback		Positive Feedback		Negative Feedback	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Confidence	7.3 ± 0.8	6.8 ± 1.3	6.7 ± 1.4	7.0 ± 1.3	6.3 ± 1.2	4.8 ± 2.0*
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*
Perceived 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
Valence	–	4.8 ± 1.5	–	7.1 ± 0.8#	–	4.3 ± 1.1
Arousal	–	5.2 ± 1.7	–	5.5 ± 1.0	–	5.2 ± 2.0

After T8, a final block of 15 TMS pulses was applied and participants rated their balance confidence, perceived skill, anxiety and motivation using the same 9-point scales as those administered prior to T1. Participants also rated the valence and arousal of their feedback using the 9-point Self-Assessment Manikin scale [20].

2.4. Feedback

Participants were randomly assigned to the neutral, positive, or negative feedback groups based on their T1 performance score (i.e., amount of time spent within ± 1.5° from the horizontal). This ensured a similar distribution of initial performance scores between groups. On the three trials when feedback was provided, participants in the neutral group were only provided their performance score. In contrast, participants in the positive and negative social-comparative groups were given their performance score as well as a group score that was 15–20% lower and higher, respectively, than the participant's score. This numeric feedback was accompanied by a valent statement. Participants were informed that their performance was either "terrific" (Affective Norms for English Words valence rating of 8.2 ± 1.1 out of nine) or "terrible" (valence rating of 1.9 ± 1.4) to provide a stronger valence component to the social-comparative feedback [21]. Feedback was not provided every trial to avoid participants becoming desensitized to the valent terms. Similarly, feedback was made more believable by using a range of normative scores so that the group score could improve even if the participant performed worse on a given trial.

2.5. Data analyses

Balance performance on each 90 s trial was quantified using the angular position signal of the stabiliometer, 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 stabiliometer was within ± 1.5° from the horizontal, the RMSE and MPF for each trial were determined. Corticospinal excitability was determined from the TMS-evoked electromyographical (EMG) response from the SOL. The peak-to-peak amplitude of each SOL MEP was averaged separately within each block of five MEPs before and after feedback, as well as the block of 15 MEPs prior to T1 and after T8. The SOL and TA background EMG (bEMG) activity were calculated as the RMSE for the 100 ms prior to each stimulus and averaged within each block of trials.

2.6. Statistical analyses

Since positive and negative emotional stimuli may act over different time courses [16], two analyses were performed. The long-term effects of social-comparative feedback on balance performance (i.e., time on balance, RMSE and MPF) and SOL MEPs were assessed by separate group (neutral, positive, negative) x trial (T1, T8 for performance; baseline, post-test for MEPs) mixed ANOVAs. The immediate effects of feedback for these same measures were examined by separate group x

feedback trial (1st, 2nd, 3rd) and time (pre-, post-feedback trials for performance; pre-, post-feedback blocks for MEPs) mixed ANOVAs. Since MEPs are influenced by bEMG activity, SOL and TA bEMG values were also compared using the same statistical methods as those used to examine MEP amplitudes. Responses to questionnaires (i.e., balance confidence, perceived skill, anxiety and motivation) were assessed using separate group x time (pre, post) mixed ANOVAs. The valence and arousal ratings for the provided feedback were assessed using separate one-way ANOVAs.

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). Unless stated otherwise, data are reported as the mean ± one standard deviation.

3. Results

3.1. Questionnaires

Differences in balance confidence ($F_{2,33} = 6.778$; $p = 0.003$), perceived skill ($F_{2,33} = 21.284$; $p < 0.001$) and motivation ($F_{2,33} = 3.716$; $p = 0.035$) between groups over time were confirmed by two-way interaction effects (Table 2). Over the course of the experiment, balance confidence decreased by 26 ± 28% for the negative group ($p = 0.006$) but did not change for the positive ($p = 0.266$) or the neutral group ($p = 0.241$). Similarly, perceived skill decreased by 43 ± 29% for the negative group ($p = 0.001$) and increased by 13 ± 17% for the positive ($p = 0.039$) but did not change for the neutral group ($p = 0.220$). Motivation increased by 72 ± 168% for the neutral group ($p = 0.021$) but there was no change in motivation for the positive ($p = 0.096$) or negative groups ($p = 1.000$). Lastly, changes in perceived anxiety over time were confirmed by a time main effect, with anxiety increasing by 35 ± 73% throughout the experiment ($F_{1,33} = 6.270$; $p = 0.017$).

Differences in perceived valence ($F_{2,33} = 18.152$; $p < 0.001$) between groups was confirmed by a group main effect. At the end of the experiment, the positive feedback group rated the feedback more positively than both the negative ($p < 0.001$) and neutral groups ($p < 0.001$) (Table 2). There was no difference in the perceived arousal of the feedback between groups ($F_{2,33} = 0.126$; $p = 0.882$).

3.2. Balance performance

Changes in the duration that the platform was ± 1.5° of the horizontal over the course of the experiment (i.e., from T1 to T8) was confirmed by a trial main effect ($F_{1,33} = 46.784$; $p < 0.001$). Across all groups, participants spent 49 ± 49% more time with the platform in a horizontal position from T1 (35.9 ± 16.7 s) to T8 (48.5 ± 15.1 s) (Fig. 2). Likewise, the RMSE of the platform position was also found to decrease, by 37 ± 29% across all groups, over time ($F_{1,33} = 59.973$; $p < 0.001$). These aforementioned long-term changes could be primarily attributed to the first instance of feedback. When the immediate
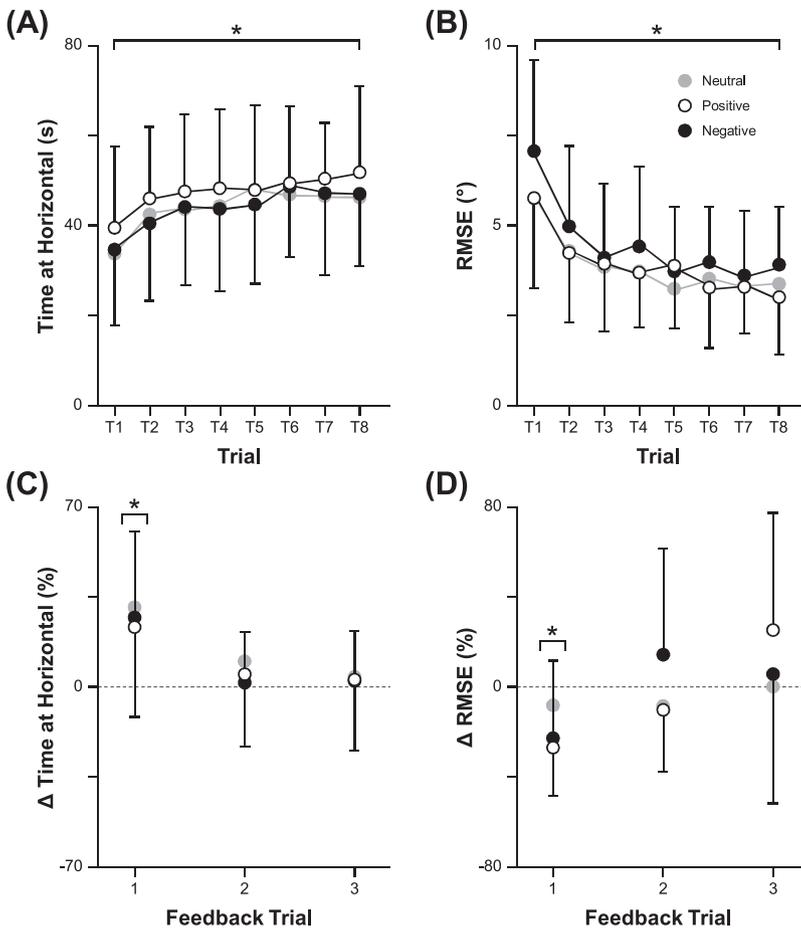
Fig. 2. Mean ± 1 SD (A) time spent with the stabiliometer in the horizontal position and (B) root mean square error (RMSE) for the eight balance trials. The immediate effect of feedback on time in the horizontal position and RMSE for the three instances of feedback are plotted in (C) and (D), respectively. Data represents the mean ± 1 SD percent change, with positive percentages representing an increase in time or RMSE during the trial immediately after feedback (i.e., T2, T5, or T7) compared to the trial before feedback (i.e., T1, T4, T7). The grey, white, and black circles represent the neutral, positive, and negative feedback groups, respectively. For clarity, error bars are not included for the neutral group. Asterisks (*) indicate a significant difference from T1 to T8, or from T1 to T2.

effects of feedback were considered, significant changes in both the duration ($F_{2,66} = 7.183$; p = 0.002) and RMSE ($F_{2,66} = 12.139$, p < 0.001) were only observed from T1 to T2 for all three groups (Fig. 2). In contrast to the time and RMSE measures, the MPF of the platform position did not change from T1 (0.29 ± 0.07 Hz) to T8 (0.29 ± 0.06 Hz; $F_{1,33} = 0.229$; p = 0.636) and there were no differences in MPF between groups ($F_{2,33} = 2.014$; p = 0.150).

3.3. Electromyographical recordings

The SOL MEP amplitude did not change over the course of experiment (i.e., from baseline to post-test) ($F_{1,33} = 0.939$; p = 0.340) or immediately following each instance of feedback ($F_{2,66} = 0.813$; p = 0.448) (Fig. 3). Corticospinal excitability was not significantly correlated with performance (r = -0.015, p = -.931), perceived skill (r = -0.097, p = 0.572), or feedback valence (r = 0.201, p = 0.239). This lack of change in SOL MEP amplitude is unlikely to be explained by bEMG activity. Neither the SOL bEMG (p = 0.134) nor the TA bEMG (p = 0.919) changed throughout the experiment (Table 3). However, the TA bEMG was different between groups ($F_{2,33} = 3.998$; p = 0.028), where a larger bEMG activity was observed in the positive (3.32 ± 2.79 μV) compared to the negative group (1.42 ± 0.64 μV; p = 0.021).

4. Discussion

Social-comparative feedback provided in this study altered participants' psychological state. Similar to previous studies [1,5,6,22], when participants received negative social-comparative feedback, they reported a significant decrease in balance confidence and perceived skill over the course of the experiment. However, negative feedback was not
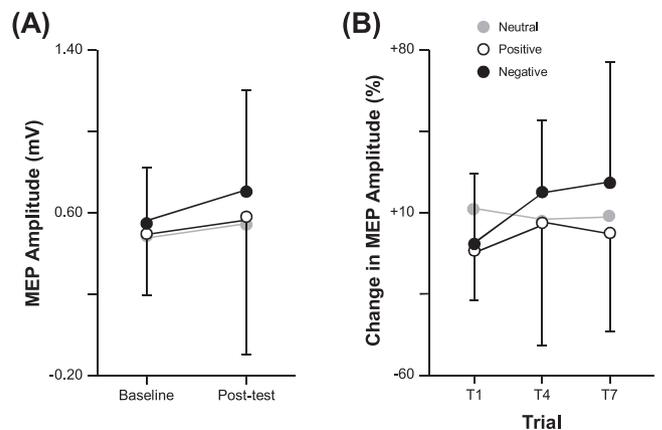

Fig. 3. (A) Mean ± 1 SD soleus (SOL) MEP amplitude from the block of 15 stimuli at baseline compared to post-test. (B) The immediate change in MEP amplitude following each instance of feedback. Data represents the mean ± 1 SD percent change, with positive percentages representing an increase in MEP amplitude during the block of five stimuli after compared to before the feedback. For both figures, the grey, white, and black circles represent the neutral, positive, and negative feedback groups, respectively. For clarity, error bars are not included for the neutral group.

entirely adverse, as participants did not report any decreases in motivation to perform the balance task across trials and perceived the feedback as neutral rather than negative (valence of 4.3 ± 0.3). This may have occurred due to participants seeing their own performance score improve across trials, producing an unintended positive element to the feedback. In contrast to the negative social-comparative feedback group, the positive feedback group considered their feedback as more

Table 3

Mean ± 1 SD background EMG (bEMG) of the SOL and TA for the baseline and post-test trials. No differences in bEMG were observed from pre- to post-test.

	Neutral Feedback		Positive Feedback		Negative Feedback	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
SOL bEMG (µV)	11.47 ± 7.37	12.01 ± 7.43	9.89 ± 4.59	10.08 ± 5.98	11.71 ± 6.20	13.23 ± 7.71
TA bEMG (µV)	3.18 ± 4.26	1.97 ± 1.85	2.96 ± 2.68	3.68 ± 3.50	1.29 ± 0.52	1.56 ± 0.84

positive (valence of 7.1 ± 0.8) and reported an increase in perceived skill. However, no changes in balance confidence or motivation were reported by participants in the positive social-comparative group. These results are consistent with others who have reported no changes in perceived balance efficacy [1,18,22] or self-efficacy [6] following positive social-comparative feedback and suggest that it is easier to undermine rather than enhance self-efficacy with feedback [2].

Despite the aforementioned psychological and valent changes in response to social-comparative feedback, no differential effects on balance performance were observed. All groups improved their time spent on balance by ≈35% and their RSME by ≈43%. Most of these improvements occurred after the first instance of feedback, but this can be attributed to a first-trial effect. The long-term effects contrast with the previously reported findings that positive social-comparative feedback leads to a reduction in RMSE and a more automatic control of movement when standing on a stabiliometer [5]. Since this study used the same balance task as the prior study, other factors may have contributed to these conflicting results, including the fewer number of trials, feedback presentation method (e.g., group compared to individual score vs. a top/bottom 10% ranking), and the frequency of feedback presentation (e.g., every trial vs. every three trials) [5]. However, it is important to note that our results are also supported by studies that have also failed to observe an influence of social-comparative feedback during quiet standing [1,18] or while standing on a stabiliometer [6]. Since the benefits of social-comparative feedback appear more consistent for non-balance motor tasks (e.g., throwing) [23–26], intrinsic feedback related to balance control may outweigh information provided through social-comparative feedback.

Due to balance performance changing similarly across the three groups, it is not surprising that there were no between-group differences in corticospinal excitability. However, since all groups still demonstrated improvements in balance performance, an overall decrease in neural excitability would have still been expected [11]. Furthermore, since the positive social-comparative feedback was rated positively and the negative feedback reduced their balance confidence and perceived skill, a change in corticospinal excitability due to a change in emotional state might have still been expected [14,17]. Several factors related to this study's experimental protocol may explain the lack of change in corticospinal excitability over time. First, corticospinal excitability was assessed while participants were quietly standing rather than during the task itself to minimize coil movement and to control for measures known to influence MEP amplitudes (e.g., limb position and muscle activity). However, this may be disadvantageous because training-induced adaptations of corticospinal excitability are commonly task-specific [13,27]. Second, it is possible that the social-comparative feedback presented in this study produced a similar valence response as previous studies, but the magnitude of the response was not sufficient to observe an change in corticospinal excitability. Previous studies suggest that high arousal in response to valent stimuli is needed to elicit changes in corticospinal excitability [17,28]. However, this study observed no differences in anxiety and arousal between the three groups.

Despite the minimal differential effects of social-comparative feedback, a resulting discord between balance perception and performance was observed. Individuals in the positive feedback group reported higher levels of confidence yet did not perform any better than the negative group who reported lower levels of confidence. This situation

may be similar to what is observed in older adults, where 20–42% of older adults are categorized as being over-confident in their balance ability (i.e., have a high fall risk yet report high balance confidence) [29,30] and is a predictor of falls [31]. Thus, the use of social-comparative feedback to manipulate one's perceived balance abilities may yield stronger effects if conducted in individuals with poorer balance control.

5. Conclusion

Social-comparative feedback altered psychological and valence responses but did not lead to any differential changes in balance performance or corticospinal excitability. This study cannot determine whether this indicates that social-comparative feedback has minimal influence on balance control and/or that the corticospinal excitability measure is not appropriate or sensitive enough to detect differences in the underlying neural processes. Thus, future studies should investigate whether more arousing and more frequently presented social-comparative feedback to a more balance-impaired population leads to greater changes in the functional and neural control of balance.

References

[1] L. Lamarche, K.L. Gammage, A.L. Adkin, Can balance efficacy be manipulated using verbal feedback? Can. J. Exp. Psychol. 65 (2011) 277–284.
[2] A. Bandura, Self-efficacy: The Exercise of Control, Freeman, New York, 1997.
[3] J.C. Hutchinson, T. Sherman, N. Martinovic, G. Tenenbaum, The effect of manipulated self-efficacy on perceived and sustained effort, J. Appl. Sport Psychol. 20 (2008) 457–472.
[4] D.S. Johnson, D.B. Turban, K.F. Pieper, Y.M. Ng, Exploring the role of normative- and performance-based feedback in motivational processes, J. Appl. Soc. Psychol. 26 (1996) 973–992.
[5] R. Lewthwaite, G. Wulf, Social-comparative feedback affects motor skill learning, Q. J. Exp. Psychol. 63 (2010) 738–749.
[6] N.T. Ong, N.J. Hodges, Balancing our perceptions of the efficacy of success-based feedback manipulations on motor learning, J. Mot. Behav. (2017) 1–17.
[7] N.T. Petersen, H.S. Pyndt, J.B. Nielsen, Investigating human motor control by transcranial magnetic stimulation, Exp. Brain Res. 152 (2003) 1–16.
[8] I.A. Solopova, O.V. Kazennikov, N.B. Deniskina, Y.S. Levik, Y.P. Ivanenko, Postural instability enhances motor responses to transcranial magnetic stimulation in humans, Neurosci. Lett. 337 (2003) 25–28.
[9] C.D. Tokuno, W. Taube, A.G. Cresswell, An enhanced level of motor cortical excitability during the control of human standing, Acta Physiol. (Oxf) 195 (2009) 385–395.
[10] C.D. Tokuno, M. Keller, M.G. Carpenter, G. Marquez, W. Taube, Alterations in the cortical control of standing posture during varying levels of postural threat and task difficulty, J. Neurophysiol. 120 (2018) 1010–1016.
[11] W. Taube, M. Gruber, S. Beck, M. Faist, A. Gollhofer, M. Schubert, Cortical and spinal adaptations induced by balance training: correlation between stance stability and corticospinal activation, Acta Physiol. (Oxf) 189 (2007) 347–358.
[12] F. Penzer, J. Duchateau, S. Baudry, Effects of short-term training combining strength and balance exercises on maximal strength and upright standing steadiness in elderly adults, Exp. Gerontol. 61 (2015) 38–46.
[13] M. Schubert, S. Beck, W. Taube, F. Amtage, M. Faist, M. Gruber, Balance training and ballistic strength training are associated with task-specific corticospinal adaptations, Eur. J. Neurosci. 27 (2008) 2007–2018.
[14] A. Baumert, C. Sinclair, C. MacLeod, G. Hammond, Negative emotional processing induced by spoken scenarios modulates corticospinal excitability, Cogn. Affect. Behav. Neurosci. 11 (2011) 404–412.
[15] G. Hajcak, C. Molnar, M.S. George, K. Bolger, J. Koola, Z. Nahas, Emotion facilitates

action: a transcranial magnetic stimulation study of motor cortex excitability during picture viewing, Psychophysiology 44 (2007) 91–97.

[16] D.J. Schutter, D. Hofman, J. Van Honk, Fearful faces selectively increase corti-cospinal motor tract excitability: a transcranial magnetic stimulation study, Psychophysiology 45 (2008) 345–348.

[17] S.A. Coombes, C. Tandonnet, H. Fujiyama, C.M. Janelle, J.H. Cauraugh, J.J. Summers, Emotion and motor preparation: a transcranial magnetic stimulation study of corticospinal motor tract excitability, Cogn. Affect. Behav. Neurosci. 9 (2009) 380–388.

[18] L. Lamarche, J.A. Shaw, K.L. Gammage, A.L. Adkin, Manipulating balance per-ceptions in healthy young adults, Gait Posture 29 (2009) 383–386.

[19] A.L. Phanthanourak, T.W. Cleworth, A.L. Adkin, M.G. Carpenter, C.D. Tokuno, The threat of a support surface translation affects anticipatory postural control, Gait Posture 50 (2016) 145–150.

[20] P.J. Lang, Behavioral treatment and bio-behavioral assessment: computer applica-tions, in: J.B. Sidowski, J.H. Johnson, T.A. Williams (Eds.), Technology in Mental Health Care Delivery Systems, Ablex, Norwood, 1980, pp. 119–137.

[21] M.M. Bradley, P.J. Lang, Affective Norms for English Words (ANEW): Instruction Manual and Affective Ratings. The Center for Research in Psychophysiology, University of Florida, 1999.

[22] L. Lamarche, A.M. Gionfriddo, L.E. Cline, K.L. Gammage, A.L. Adkin, What would you do? The effect of verbal persuasion on task choice, Gait Posture 39 (2014) 583–587.

[23] L.A. Pascua, G. Wulf, R. Lewthwaite, Additive benefits of external focus and en-hanced performance expectancy for motor learning, J. Sports Sci. 33 (2015) 58–66.

[24] G. Wulf, S. Chiviacowsky, P.L. Cardozo, Additive benefits of autonomy support and enhanced expectancies for motor learning, Hum. Mov. Sci. 37 (2014) 12–20.

[25] L.T.G. Ávila, S. Chiviacowsky, G. Wulf, R. Lewthwaite, Positive social-comparative feedback enhances motor learning in children, Psychol. Sport Exerc. 13 (2012) 849–853.

[26] G.S. Gonçalves, P.L. Cardozo, N.C. Valentini, S. Chiviacowsky, Enhancing perfor-mance expectancies through positive comparative feedback facilitates the learning of basketball free throw in children, Psychol. Sport Exerc. 36 (2018) 174–177.

[27] S. Beck, W. Taube, M. Gruber, F. Amtage, A. Gollhofer, M. Schubert, Task-specific changes in motor evoked potentials of lower limb muscles after different training interventions, Brain Res. 1179 (2007) 51–60.

[28] T. Baumgartner, M. Willi, L. Jancke, Modulation of corticospinal activity by strong emotions evoked by pictures and classical music: a transcranial magnetic stimula-tion study, Neuroreport 18 (2007) 261–265.

[29] R.H. Fortinsky, V. Panzer, D. Wakefield, F. Into, Alignment between balance con-fidence and fall risk in later life: has over-confidence been overlooked? Health Risk Soc. 11 (2009) 341–352.

[30] K. Delbaere, J.C. Close, H. Brodaty, P. Sachdev, S.R. Lord, Determinants of dis-parities between perceived and physiological risk of falling among elderly people: cohort study, BMJ 341 (2010) c4165.

[31] A.A. Butler, S.R. Lord, J.L. Taylor, R.C. Fitzpatrick, Ability versus hazard: risk-taking and falls in older people, J. Gerontol. A Biol. Sci. Med. Sci. 70 (2015) 628–634.