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CAN SIMPLE REACTION TIME TO A VISUAL STIMULUS BE USED AS A MEASURE OF THE BALANCE TASK INTENSITY?

ALI JE LAHKO ENOSTAVEN REAKCIJSKI ČAS NA VIDNI SIGNAL MERA RELATIVNE INTENZIVNOSTI RAVNOTEŽNE NALOGE?

ABSTRACT

Correctly determining the frequency, intensity and duration of balance tasks (BT) is crucial for effective balance training. While the frequency and BT duration are well defined, understanding BT intensity remains limited. Higher BT intensity demands greater attentional capacity for postural control. To assess the role of attention in postural control the dual-task paradigm including BT with reaction time (RT) is often used, suggesting RT as a potential measure of BT relative intensity. The study aimed to determine whether simple RT can be a surrogate for the relative BT intensity. Twenty randomly selected participants performed six repetitions of two-legged and one-legged stances on firm and compliant surfaces on a force plate. During the execution of the BT, the participants had to react on illumination of the light by pressing a switch held in their dominant hand. The center of pressure (COP) velocity and the RT were investigated. The BT were categorized into low, moderate and high intensities. The results showed a significant increase in COP velocity from low to high intensity BT ($p=0.001$; $\eta2=0.79$). Moderate intensity BT resulted in a 123.6% increase in COP velocity compared to the low intensity BT. During high-intensity BT COP velocity increased by 244.2 % ($p < 0.001$). There were no differences in RT between different BT intensities ($p=0.596$; $\eta2=0.03$). The results suggest that RT may not accurately reflect the BT intensity. Therefore, it can be concluded that simple visual RT could not be used as a measure of relative intensity of BT.

Keywords: relative intensity, simple reaction time, dual tasks, FITT

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IZVLEČEK

Za optimalen učinek treninga ravnotežja je pomembno ustrezno odmeriti frekvenco, trajanje in intenzivnost BT. Medtem ko sta frekvenca in trajanje BT dobro opredeljeni, relativna intenzivnost BT še vedno ostaja neopredeljena. Višja kot je intenzivnost BT, višja je zasedenost kapacitete pozornosti, ki je potrebna za nadzor in upravljanje drže ter ravnotežja. Za oceno zasedenosti kapacitete pozornosti se najpogosteje uporabljajo dvojne naloge, ki vključujejo BT in reakcijski čas (RT). Slednji predstavlja potencialno mero relativne intenzivnosti BT. Cilj študije je bil določiti ali je lahko enostaven RČ na vidni dražljaj mera relativne intenzivnosti ravnotežne naloge (BT). V študiji je sodelovalo dvajset preiskovancev, ki so izvedli šest ponovitev sonožne in enonožne stoje na trdni in mehki površini na pritiskovni plošči. Preiskovanci so morali med BT na prižig lučke čim hitreje odreagirati s pritiskom stikala v dominantni roki. Preučevani parametri so bili hitrost oprijemališča sile reakcije podlage (COP) med BT in RT. BT so bile razdeljene na nizko, zmerno in visoko intenzivne. Rezultati analize so pokazali značilen dvig hitrosti COP od nižje proti visoko intenzivni BT ($p=0.001$; $\eta2=0.79$). Zmerna intenzivna BT je imela za 123.4 % višjo hitrost COP v primerjavi z nizko intenzivno BT. Med visoko intenzivno BT se je hitrost COP povišala za 244.2 % ($p < 0.001$). V RT med različnimi intenzivnostmi BT ni bilo razlik ($p=0.596$; $\eta2=0.03$). Na podlagi rezultatov lahko sklepamo, da RT ne odraža intenzivnosti BT. To pomeni, da enostavni RT ne more biti objektivna mera relativne intenzivnosti ravnotežnih nalog.

Ključne besede: relativna intenzivnost, enostavni reakcijski čas, dvojne naloge, FITT

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https://doi.org/10.52165/kinsi.30.2.94-104

INTRODUCTION

Balance training includes various balance tasks (BT). An evidence-based dose-response relationship of balance training is critical for maximising improvements in postural control. The dose-response relationship of balance training is determined by the frequency, intensity and duration of BT (Thompson et al., 2010). While the frequency and duration of BT have been defined in numerous studies, the intensity of BT remains uncertain. In fact, Farlie et al. (2016) found no statistically significant correlation between individual progress in balance tests and the frequency and duration of BT. Furthermore, these factors explain only 2.15 % of the variance in individual balance progress, emphasising that improvements in postural control also depend on the intensity of BT. Current BT recommendations only specify absolute intensity (Thompson et al., 2010; Tiedemann et al., 2011), while the definition of relative intensity is still unclear. Since each person has unique balance abilities, quantifying the relative intensity of BT remains crucial. Attempts have been made to determine the relative intensity of BT using the Perceived Exertion Scale (RPE) or the Perceived Stability Scale (RPS), in which people self-assess the intensity of BT (Espy et al., 2017), but their validity has not been proven yet.

The BT differ in terms of sensory conditions and stability. It was found that centre-of-pressure (COP) movement parameters increased significantly, when the use of sensory information or the support surface was gradually reduced (Muehlbauer et al., 2012). For example, a greater COP velocity in the monopedal stance compared to the two-legged stance has been observed (Muehlbauer et al., 2012). While a greater COP velocity could serve as an absolute measure of BT intensity, it is insufficient for determining the relative intensity of BT as it does not provide an indication of how much of the maximal capacity of a person's postural control system (i.e., a general name for the complex interplay of the musculoskeletal and nervous systems to control our bodies in space) was used. Although, a direct measurement of the maximum capacity of the postural control system is not yet possible, it has been shown that the attentional capacity required for postural control increases when the use of sensory information or the support surface is gradually reduced (Lajoie et al., 1993). For instance, a greater COP velocity in the monopedal stance compared to the two-legged stance was found to lead to a greater attentional capacity used for postural control (Wulf & Shea, 2007). Furthermore, it has been shown that older participants switch from an automatic to an attentional postural control strategy (Ruffieux et al. 2018) as they receive less sensory information. To assess the role of attention in postural control in healthy populations, the dual-task paradigm has often been used. The dual-task paradigm typically involves the assessment of BT with simple or choice reaction times observed following visual or auditory stimuli. (Just & Carpenter, 1992). In particular, Lajoie and colleagues (1993) found that RT increased from sitting to standing and from narrow standing to walking. An increase in RT implies that attentional capacity to respond rapidly decreases as a function of postural complexity (Just and Carpenter, 1992; Lajoie et al., 1993). Accordingly, the relative intensity of BT can be viewed as the remaining attentional capacity to respond to visual stimuli (Jehu et al., 2015).

To summarise, according to capacity sharing theory (Wickens, 1989), as the complexity, i.e., intensity, of the BT increases, both the BT and the RT task compete for the limited information processing capacity, which could lead to an increase in RT. Therefore, RT can be used as a measure of the relative intensity of the BT, but that have not been proven yet. To our knowledge, there are only few studies that systematically increase the intensity of BT and simultaneously measure the RT. However, these studies have not yet succeeded in determining the measure of relative intensity of BT (Lajoie et al., 1993; Remaud et al., 2013; Jehu et al., 2016). In their study, Jehu et al. (2016) measured simple and choice auditory RT during two-legged and semi-tandem stance in older adults. After five sessions of performing simple and choice auditory RT during the BTs, they concluded that there were no significant differences in simple RT, and furthermore the variability in choice RT remained high. Additionally, Lajoie et al. (1996) and Remaud et al. (2013) as well measured RT to auditory, rather than visual stimulus during BTs. Therefore, the aim of this study was to investigate the changes in simple RT to visual stimulus during BT of different intensities. We hypothesised that reducing the base of support and decreasing the use of sensory information would increase COP velocities. Additionally, we hypothesised that participants would increase their RT to visual stimuli during the more difficult posture and that the RT dual-task paradigm could be used as a surrogate for the relative intensity of the BT.

MATERIALS AND METHODS

Participants

In the study, 20 randomly selected healthy and uninjured students from the Faculty of Sport voluntarily participated, 12 were male and 8 were female. The average age of the participants was 23.8 ± 7.1 years, the average body weight was 71.9 ± 10.6 kg and the average height was 175.3 ± 8.8 cm. The participants did not undergo a regular training process. All participants were informed about the measurement procedures, the possible risks and the consequences of participation, and their participation was confirmed by written consent prior to the measurements.

Experimental protocol

The measurements were carried out in the Laboratory of Kinesiology at the Faculty of Sport at the University of Ljubljana. The participants took part in the measurements individually, once and in random order. The experimental protocol consisted of 3 randomly assigned BT. Two-legged stance on firm surface was determined as low intensity BT. One-legged stance on firm ground was determined as moderate intensity BT (reduced support surface). One-legged stance on compliant surface was determined as high intensity BT (reduced support surface and reduced sensory information). Before the measurements, each participant was thoroughly familiarised with the execution of the individual BTs. The participants were instructed to press the switch held in the dominant hand as quickly as possible as soon as the LED light lit up during the BT. The participants were not instructed to prioritise the RT or the execution of the BT. The Student Affairs Commission at the Faculty of Sport, University of Ljubljana, approved the study (No. 2019/20/13) to ensure that all ethical standards were met and that the study was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013).

Balance task and RT measurement

Each BT was performed for 10 seconds, followed by a 50-second rest period. Participants repeated each BT six times, with a 3-minute rest in between. During the execution of each BT, RT was measured in response to a visual stimulus triggered by a red LED light of 200 ms duration located 1.89 m from the force plate. The light illuminated at random intervals during the BT, and participants were required to respond by rapidly pressing the switch they held in their dominant hand. The switch was connected to a DAQ interface (PowerLab 16/35, ADInstruments, Bella Vista, Australia). The time elapsed from stimulus onset (illumination of the LED light) to switch press was defined as a simple RT. To avoid anticipation, the measurement was repeated if the participants' RT was less than 100 ms, as such a short time indicates anticipation of the event. LabChart v7 software (ADInstruments, Bella Vista, Australia) was used to read out all recorded signals. The recorded signals were used to measure the RT during the execution of BT. The average RT for six repetitions of each BT was then calculated and these values were used for statistical analysis.

In the two-legged stance, the participants placed their feet hip-width apart, and in the one-legged stance the participants stood on the dominant leg. Participants performed all BT barefoot and with their arms crossed on their chest on a force plate (Kistler 9286 AA, Winterthur, Switzerland). An AIREX balance cushion (50×41×6 cm) was used when participants performed the one-legged stance on a compliant surface. During all balance tasks, the analogue signal obtained from the force plate was amplified (Kistler, Winterthur, Switzerland, model 9865A), recorded and read out via a digital-analogue interface (PowerLab16/35 - ML880/P, ADInstruments, Bella Vista, Australia). The data was sampled at a frequency of 1000 Hz. The COP velocity (mm/s) one second before the light signal was calculated from the acquired signals. The average COP velocity for six repetitions of each BT was then calculated and these values were used for statistical analysis.

Statistical analysis

The statistical analysis was performed using IBM SPSS 26 (SPSS Inc., Chicago, Illinois, USA) and Microsoft Excel (version 2016, Microsoft Corporation, Redmond, Washington, USA). Mean values and standard deviations were calculated for the analysed parameters. The uniformity of the distributions was assessed using the Kolmogorov-Smirnov test for numerical variables. The intraclass correlation coefficient (ICC) and with a 95 % confidence interval was used to test the repeatability of the RT and COP velocity measurements and interpreted according to the statistical guidelines defined by Koo and Li (2016). The repeatability of the measurements was considered acceptable when the ICC > was 0.50, low when the ICC < was 0.50, moderate when the ICC > was 0.50 and < was 0.75, high when the ICC > was 0.75 and < was 0.90, and excellent when the ICC > was 0.90. A 1-way repeated measures analysis of variance (ANOVA) was used to determine the differences in RT and COP velocities between two-legged stance on firm surface and one-legged stance on firm surface and foam. In addition, $\eta 2$ (Eta – squared) was used to calculate the effect sizes (f) and divided into small (f values = 0.10), medium (f values = 0.25) and large (f values = 0.40) effects (Cohen, 1988). The significance level was set at $\alpha = 5$ %.

RESULTS

All data were normally distributed. COP velocity during BT increased from the low intensity BT (33.8 mm/s; SEM = 1.06 mm/s) i.e., two-legged stance, to the high intensity BT i.e. (116 mm/s; SEM = 9.23 mm/s), one-legged stance on the compliant surface ($F_{1.19,22.5}=75.0$; $p=0.001$; $\eta 2=0.79$; Table 1). Accordingly, the moderate intensity BT i.e., one-legged stance on a firm surface resulted in a 123.6 % increase in COP velocity compared to the two-legged stance. As expected, postural control was even more demanding during high-intensity BT, as COP velocity increased by 244.2 % ± 111 % (P < 0.001). On the other hand, there were no differences in RT measurements during BTs of different intensities ($F_{2,38}$=0.53; p=0.596; η2=0.03).

Table 1. Centre of pressure velocity and reaction time for the respective stance and sensory conditions.

	COP velocity (mm/s)	**$SEM_{COPvelocity}$ (mm/s)**	**RT (ms)**	**SEM_{RT} (mm/s)**
Low intensity BT- *two-legged stance*	33.8±4.6 [31.6, 36.0]	1.03	224.2±30.1 [238.2, 222.0]	6.73
Moderate intensity BT - *one-legged stance*	74.7±17.6*** [66.5, 83.0]	3.95	229.3±38.8 [211.2, 247.5]	8.86
High intensity BT - *one-legged stance on the compliant surface*	116.0±41.3$^{***/\#\#\#}$ [96.7,135.3]	9.23	227.2±31.8 [212.2, 241.9]	7.11

Notes. Data of COP velocity and RT are expressed in mean values ± standard deviation [confidence interval]. BT – balance task; COP – centre of pressure; RT – reaction time; SEM – standard error of the measurement. Asterisks indicate a significant difference to the low intensity BT (***P< 0.001), section signs indicate a significant difference to the moderate intensity BT ($^{\#\#\#}$P<0.001).

The repeatability of six COP velocity measurements was moderate for low intensity BT (ICC = 0.509) and high for moderate and high intensity BTs (0.75 < ICC < 0.90) (Table 2). The repeatability of six RT measurements was high for all the BTs (0.75 < ICC < 0.90).

Table 2. Intraclass correlation coefficients for centre of pressure velocity and reaction time for the respective stance and sensory conditions.

	$ICC_{COPvelocity}$	**ICC_{RT}**
Low intensity BT- *two-legged stance*	0.509 [0.079, 0.779]	0.887 [0.788, 0.949]
Moderate intensity BT - *one-legged stance*	0.821 [0.665, 0.920]	0.812 [0.648, 0.916]
High intensity BT - *one-legged stance on the compliant surface*	0.899 [0.810, 0.954]	0.814 [0.657, 0.918]

Notes. ICC for COP velocity and RT are expressed in mean values [confidence interval]. BT – balance task; COP – centre of pressure; RT – reaction time; ICC – intraclass correlation coefficient.

DISCUSSION

The aim of this study was to investigate the changes in simple RT to visual stimuli during BT of different intensities. We hypothesised and confirmed that reducing the base of support and decreasing the use of sensory information would increase COP velocities. Additionally, we hypothesised and declined that participant would increase their RT to visual stimuli during the more difficult posture and that the RT dual-task paradigm could be used as a surrogate for the relative intensity of the BT.

Although a statistically significant increase in COP velocity was observed when the support surface was reduced (i.e., two-legged stance vs. one-legged stance) and/or kinaesthetic input was restricted (i.e., firm vs. compliant), we found no significant differences in simple visual RT between BTs of different intensities ($p = 0.596$). The test-retest reliability of COP velocity and RT at different BT intensities showed that the intraclass correlation coefficients were good for all BTs tested, suggesting that the present results are not due to a lack of reproducibility of the postural or RT measurements. These results suggest that RT was not sensitive to the increase in COP movement when BTs were performed. Accordingly, the dual-task paradigm with simple RT to a visual stimulus could not be used as a surrogate for the relative intensity of BTs.

A significant increase in COP velocity during one-legged stance on firm and compliant surfaces confirmed that a progression of postural demands was achieved during the narrowing of the stance surface (one-legged stance) and/or during the limitation of kinaesthetic input (one-legged stance on compliant surfaces). Similar results were also reported in the study by Muehlbauer et al. (2012), in which 12 exercises were measured and 5 balance variables were analysed to recommend appropriate progression of BTs. The authors found that a change in support conditions and sensory information increased the COP displacement, which was also found in our study. They suggest that the one-legged stance is more demanding than the two-legged stance, probably due to the fact that the one-legged stance requires a longer lever arm to ensure the development of appropriate balance corrections to counteract the increased instability compared to the two-legged stance (Sarabon et al., 2010; Muehlbauer et al., 2012). Accordingly, the centre of mass will oscillate over the natural vertical line, resulting in increased postural sway (Muehlbauer et al., 2012). In addition, greater activation of the peroneus longus, soleus and tibialis anterior was observed to stabilise the body in the one-legged stance compared to the two-legged stance (Amiridis et al., 2003), which further supports the assumption of higher and more complex postural demands in the one-legged stance compared to the two-legged stance. The additional increase in COP velocity during one-legged stance on the compliant surface (i.e., high intensity BT) compared to one-legged stance on firm surface could be related to the greater instability caused by the compliant surface, as it causes a greater increase in anterior–posterior and mediolateral instability compared to a firm surface.

Although statistically significant differences in COP velocity confirmed an increase in the intensity of BT, this increase was not confirmed by RT measurements during BTs. On contrary, Teasdale et al. (1992, 1993) reported that young and older individuals, when asked to maintain an upright, stable posture, had slower RT to an auditory stimulus when sensory information was reduced. Similarly, Lajoie et al. (1993) confirmed a non-significant small increase in RT to a visual stimulus when the base of support was reduced during the BT. Their observation suggests that maintaining and regulation of posture requires considerable information processing capacity and that a more difficult BT may require a greater proportion of available attentional resources. However, in our study, RT remained virtually the same regardless of the BT performed. It seems that our participants were able to focus their attention on the RT so that it remained practically the same, while a significant increase in COP velocity was observed (Verghese et al., 2007; Yogev-Seligmann et al., 2010). It appears that the dual-task conditions used in our study were not demanding enough for our participants to limit attentional capacity for RT performance, regardless of the intensity of the BTs. Indeed, attentional focus has previously been shown to affect postural control and RT performance only when the dual-task conditions are demanding enough (Remaud et al., 2013). However, it is possible that our participants focused their attention on RT measures because the BT were not demanding enough. Indeed, the distribution of attentional capacity between tasks has been shown to depend on various factors, such as the complexity of the tasks, familiarity with them, and their perceived importance (Chipunza & Mandeya, 2005). On the other hand, we could speculate that the simple visual RT in our protocol did not require a sufficient load on a cognitive system, resulting in no differences in RT measured at one-legged stances. Similarly, Jehu et al. (2016) found in their study that there were no statistically significant changes in simple RT during BT, while statistically significant changes in choice RT were observed during BT. Accordingly, simple RT to a visual stimulus measured during BT could not be used as a surrogate for the relative intensity of BT.

Our study has several limitations. First, we only measured simple RT and did not include measurements of choice RT. In addition, RT was not measured in the sitting position prior to the start of the protocol. Such a measurement would serve as a baseline measurement of RT and would allow a more detailed comparison of RT between low and high intensity BT. Another limitation is that we only included young, healthy recreational athletes for whom the selected

BT were not challenging enough; therefore, it would be more optimal to increase the difficulty level of BT in further studies. Another limitation is the assumption that all participants had the same maximal balance ability and that the same balance task presented the same balance challenge for all participants. In future studies, it would also be useful to include a larger sample of participants.

In our study, we assumed that the simple RT evoked by a visual stimulus can determine the relative intensity of BT. The study results did not confirm our assumptions about the prolongation of RT with increasing BT intensity, but rather indicated a redistribution of attentional focus. This means that simple RT cannot be used as a relative measure of the intensity of BT. In future studies, it would be useful to investigate whether the choice RT can be used as a measure of the relative intensity of balance training, as it is essential for the dosage prescription and thus for the effectiveness of balance training.

CONCLUSION

When prescribing balance training, it is essential to determine the dose. For balance training, the three most commonly cited parameters are frequency (recommended: 2-3 times/week), type of tasks (static and/or dynamic task) and duration (recommended: 45-60 minutes) (Lesinski et al., 2015; Espy et al., 2017; Farlie et al., 2016), while BT intensity as a relative measure remains undetermined in the current literature. In our study, participants performed three BT, categorized into low, moderate and high intensity. COP velocity and simple visual RT elicited by a light stimulus, were evaluated. RT can be used as a baseline measure of the engaged attentional capacity required to perform the task (Yogev-Seligmann et al., 2008). Contrary to our hypothesis, RT did not prolong during higher intensities of BT, despite increased COP velocity. Therefore, our study confirmed that simple visual RT cannot be used as a surrogate for relative intensity of the BT. Future studies should examine whether the choice RT can be a surrogate for relative intensity of BT, as it is necessary for the dosage and thus the effectiveness of balance training.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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