Real-time conscious postural control is not affected when balancing on compliant surface by young adults

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Abstract

Previous research has illustrated that real-time conscious postural control (i.e., reinvestment - shifting from movement automaticity to a more consciously controlled and monitoring of movement) increased with standing task difficulties among healthy older adults. However, such association has not been investigated in the younger population. This study attempted to examine real-time conscious postural control among healthy young adults when performing different standing tasks on a compliant (foam) surface. T3-Fz EEG (electroencephalography) coherence, indicative of real-time conscious postural control, was recorded during the standing tasks (i.e., wide base on foam (WBF), narrow base on foam (NBF) and tandem stance on foam (TAF)). Body sway was also recorded by a motion capture system. Participants' perceived difficulty on the different standing tasks was evaluated by the Visual Analogue Scale (VAS). Results revealed that while body sway and perceived difficulty increased significantly with task difficulties, T3-Fz EEG coherence did not differ among standing tasks. In addition, no differences of any measures were found between young adults with high and low trait reinvestment propensity. Our findings indicate that young adults do not pose higher real-time conscious postural control when task difficulty increases. We also add support to the existing literature; the between-group effect of trait reinvestment appears to be minimal in real-time.

Keywords: Electroencephalography; reinvestment, conscious postural control, balance

Introduction

In daily life, movement execution such as balancing and walking is typically known as an automatic process which requires minimal conscious control (Malone & Bastian, 2010). However, under specific conditions such as increased movement difficulty, or within certain populations such as older fallers and patients post-stroke, individuals tend to regress from the usual automatic mode to the early stage of learning with more conscious involvement (Chu & Wong, 2018; Wong, Masters, Maxwell, & Abernethy, 2008; Orrell, Masters, & Eves, 2009). This process of shifting from movement automaticity to a more consciously controlled and monitoring of movement with the utilization of explicit knowledge has been known as “reinvestment” (Masters, 1992; Masters, Polman, & Hammond, 1993). Reinvestment has been known to disrupt movement performance and increase the likelihood of movement errors (see a review by Masters & Maxwell, 2008).

Masters et al. (1993) argued that the propensity to consciously monitor and control movement mechanics is a function of a personality trait. It can be measured by the Movement Specific Reinvestment Scale (MSRS; Masters et al., 1993), a 10-item questionnaire that is separated into two sub-scales, namely Conscious Motor Processing (CMP) and Movement Self Consciousness (MSC). The former refers to the tendency to be conscious of own bodily movements, while the latter refers to the tendency to be aware of own public image when moving. Previous studies have discovered a relatively high reinvestment propensity in certain populations, revealing a higher general conscious control to perform activities of daily living. For instance, patients post-stroke (Orrell et al., 2009) and older fallers (Wong et al., 2008) were reported to score higher in the MSRS. Higher MSRS score was also found in both old and young patients post total knee replacement when compared with their control groups (Street, Adkin, &

Gage, 2018). Moreover, an association was found between propensity of conscious control and knee pain (Selfe et al., 2015). The above literature demonstrated that certain populations exhibit higher trait reinvestment propensity than control groups in daily life.

However, MSRS is a measurement of general trait reinvestment propensity which provides insufficient information on real-time conscious control during movement execution (Chu & Wong, 2018). To address this issue, electroencephalography (EEG) T3-Fz coherence is suggested to be an objective measure for real-time reinvestment. Previous EEG studies revealed that coherence between T3 (left temporal region) and Fz (frontal midline region) may represent the contribution of verbal-analytical involvement to motor performance. The T3 region is acknowledged to be responsible for verbal-analytical processing (Haufler, Spalding, Santa Maria, & Hatfield, 2000) while Fz region is responsible for movement planning (Kaufler & Lewis, 1999). A previous study using a golf-putting motor task illustrated the effect of real-time reinvestment on motor control (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011). Novice golf players who scored higher in the MSRS (high reinvestors) were found to obtain a higher real-time reinvestment (measured by EEG T3-Fz coherence) than low reinvestors. Moreover, Chu and Wong (2018) have investigated real-time conscious postural control with different standing positions on foam (i.e., wide-base, narrow-base and tandem stance) among older adults and found a positive association between standing task difficulty and EEG T3-Fz coherence. They also categorized the participants into groups of ‘high reinvestor’ and ‘low reinvestor’ based on the split of MSRS median score but did not find any between-group significant differences. Ellmers et al. (2016) reported that young adults exhibited significantly higher EEG T3-Fz coherence when consciously controlling their movements during a postural sway task, compared to baseline condition or when attention was directed toward an external cue. These findings are in line with the predictions highlighted in the Theory of Reinvestment (see a review by Masters & Maxwell, 2008), which postulates that consciously processing movements is characterized by an increased involvement on explicit verbal-analytical or cognitive processes. As a result, since regulating postural control typically engages low levels of explicit verbal-analytical processes, attempts to consciously control or monitor posture might lead to an increased reliance on such explicit processes. Collectively, these findings suggest that conscious postural control can be characterized by heightened EEG T3-Fz coherence— a real-time measure indicating increased verbal-analytical involvement during motor planning and control of posture.

Recent literature has indicated that there are differences in conscious responses by reinvestment between young and older adults. For example, previous work observed that young adults exhibited higher real-time conscious postural control in conjunction with longer body sway path when they were instructed to direct their attention to their body movements; such effect was not apparent in older adults (Chow, Ellmers, Young, Mak, & Wong, 2019). It is therefore worthwhile investigating reinvestment with different population groups to further relate to the effect of conscious involvement on movement performance.

To the best of our knowledge, the relationship between standing task difficulty and real-time conscious postural control has only been studied among clinical populations that exhibit countless potential confounders related to either age or clinical conditions (Chu and Wong, 2018). For example, the broad concept of movement specific reinvestment has been widely associated with reported age-related increases in the attentional demands (Young, Olonilua, Masters, Dimitriadis, & Williams, 2016). Such age-related differences are likely to emerge in more dynamic and challenging tasks involving unstable support surfaces (Boisgontier et al. 2013). While Chu and Wong provided evidence that older adults increased real-time conscious postural control with task difficulties, we aim to manipulate and evaluate such association in a healthy young adult “model” unaffected by countless confounding factors (e.g., age-related decline in physical functioning, cognitive processing, etc.). We doubt the effect observed in older adults can be replicated in the younger population based on the assumption that young adults do not necessarily raise cognitive demands for conscious control to compensate for any (perceived) age-related deficits in balance ability. To explore the above notion, the current study continues the effort of Chu and Wong to investigate the potential impact of task difficulty on real-time conscious postural control during different standing balance tasks on a foam surface in healthy young adults. We hypothesize that (1) healthy young adults will respond similarly in real-time conscious postural control when task complexity increases from Wide-Base Standing on Foam (WBF), Narrow-Base Standing on Foam (NBF), and Tandem Standing on Foam (TAF); (2) high reinvestors will have similar real-time conscious postural control to low reinvestors in the three standing positions.

Method

Participants

Forty young adults (18 females, 22 males) (mean age = 20.7 years, SD = 1.1 years) from the University of Hong Kong were recruited to participate in the study. The inclusion criteria were: (i) healthy young adults aged between 18 and 25; (ii) no pervious major musculoskeletal injury and neurological problems. This study protocol was approved by the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (IRB Reference Number: UW 19-123). The Chinese version Movement Specific Reinvestment Scale (MSRS-C) was utilized to classify trait reinvestment propensity of participants (Masters et al., 1993). It includes 10 questions in a 6-point Likert scale ranging from ‘strongly disagree’ to ‘strongly agree’, where ‘strongly disagree’ scores 1 point and ‘strongly agree’ to ‘strongly agree’ scores 6 points. Higher MSRS-C score reveals a higher trait reinvestment propensity. The scale can be divided into two parts: (1) Conscious Motor Processing (CMP), representing the tendency to consciously control body movement; and (2) Movement Self-Consciousness (MSC), representing the influence of personal public image on conscious involvement in movement execution. Participants were divided into two groups; high reinvestor group (HRG) or low reinvestor group (LRG). The categorization was based on the split of median scores from the Chinese version of the Movement Specific Reinvestment Scale (MSRSC; Masters et al., 1993; Masters, Eves, & Maxwell, 2005; Wong et al., 2008; Wong, Abernethy, & Masters, 2015, 2016). Twenty young adults with mean age of 20.7 (SD = 1.2) were categorized into LRG (MSRS-C < 43) and another twenty young adults with mean age of 20.7 (SD = 1.1) were categorized into HRG (MSRS-C > 42).

Outcome measures

Visual Analogue Scale (VAS) was utilized to measure the perceived difficulty by participants on the three different standing positions (Wewers & Lowe, 1990). A horizontal line with length of 100mm was used to represent the VAS, where 0cm indicates no difficulty and 10cm is the most difficult.

Real-time EEG activity data was collected by a wireless EEG device (Brainquiry PET 4.0, Brainquiry, The Netherlands) with a sample rate of 200Hz and recorded by a biophysical data acquisition software (BioExplorer 1.5, CyberEvolution, US). Participants were equipped with six pre-gelled Ag/AgCl EEG electrodes on the scalp (Fp1, T3, T4, Fz, A1 and A2). Among the six electrodes, the reference (A1) and ground electrode (A2) were recorded at the right and left mastoid respectively. EEG signals were pre-processed to remove artifacts caused by eye blink (Fp1). Left temporal region (T3) and right temporal region (T4) are responsible for verbal-analytical processing and control of visuospatial process respectively (Deeny, Hillman, Janelle, & Hatfiled, 2003; Haufler et al., 2000), while frontal midline region (Fz) is the region for movement planning (Kaufer & Lewis, 1999). Before the measurement, an impedance test was performed to ensure an adequate signal-noise ratio. Previous research has shown that alpha2 (10–12Hz) T3-Fz coherence (but not alpha1) is sensitive at detecting within-subject changes in conscious movement processing during a postural sway task (Chu & Wong, 2018; Ellmers et al., 2016). As such, EEG alpha2 T3-Fz and T4-Fz coherences were calculated in 1Hz frequency bins by algorithms in an analysis software (BioReviewer 1.5, CyberEvolution, US). Averages for both coherences were obtained for the entire duration of each 20-second trial, and then averaged across the relevant conditions of standing positions. EEG T4-Fz coherence was obtained to ensure differences in the EEG T3-Fz coherence is not due to global activation of the brain. Higher EEG T3-Fz coherence indicates higher real-time conscious motor processing (reinvestment) (Zhu et al., 2011).

A reflective marker was placed on participants’ xiphoid process (Chow et al., 2019; Mak, Young, Chan, & Wong, 2020; Mak, Young, & Wong, 2020), which is the lowest part of the sternum, to obtain the kinematic data of balance performance. Body sway was collected using a 3-D motion capture system (ProReflex Motion Capture Unit 170 120; Qualisys, Sweden) with a frequency of 100Hz. The root-mean-square of reflective marker’s coordinates on the horizontal (X-Z) plane was calculated in the 20-second task to obtain the total length of postural sway. Data were passed through a low-pass Butterworth filter with a 5Hz cut-off and analyzed with customized Matlab scripts to obtain the amount of total body sway length (mm). Body sway measurement was implemented as an objective measurement of balancing performance in the current study since Chu and Wong (2018) proposed a potential limitation that difficulty of the standing task was perceived and thus was subjective in their study.

Procedure

The current balance tasks required participants to stand on a foam-pad (Balance Pad Elite, AIREX, Switzerland, with dimension of 19.7” x 16.1” x 2.4’””) under three different positions; Wide-Base Standing on Foam (WBF), Narrow-Base Standing on Foam (NBF) and Tandem Standing on Foam (TAF). These were chosen from the Berg Balance scale which describes an increasing difficulty (Berg, Wood-Dauphinee, Williams & Gayton, 1989). The general instruction for all participants across all three positions was ‘to stand as still as possible’. For WBF, participants were asked to stand on the foam with their feet positioned comfortably, approximately shoulder-width apart (wide stance). For NBF, participants were asked to place their feet together side by side on the foam so that they touched each other (narrow stance). For TAF, participants were asked to place one foot directly in front of the other on the foam, touching heel to toe (tandem stance). The sequence of the three standing positions was randomized. All participants were required to perform a 20-second stance twice for each standing position. After each standing position, participants were asked to determine their perceived difficulty on the task by completing the Visual Analogue Scale (VAS). Upon complete of the whole task, participants were asked to complete the MSRS-C.

Data analysis

The Shapiro-Wilk Test of Normality was first performed to investigate whether the variables are normally distributed, hence deciding whether parametric or non-parametric test should be used. Variables of VAS in NBF, alpha2 T3-Fz coherence in TAF, alpha2 T4-Fz coherence in WBF and NBF, and total body sway length in NBF and TAF were found not normally distributed ($p > .05$), thus non-parametric tests were used only when involving these variables.

For the first hypothesis of comparing real-time conscious postural control among WBF, NBF, and TAF, VAS, alpha2 T3-Fz coherence, alpha2 T4-Fz coherence and sway length with the different standing positions were compared using the Friedman test.

For the second hypothesis of comparing real-time conscious postural control between HRG and LRG in the three standing positions, independent t-test was used to compare the values that were normally distributed between the two groups: MSRS-C (MSC), MSRS-C (Total), VAS (WBF, and TAF), alpha2 T3-Fz coherence (WBF, and NBF), alpha2 T4-Fz coherence (TAF) and sway length (WBF). Mann Whitney-U test was used to compare values that are not normally distributed between the two groups: MSRS-C (CMP), VAS (NBF), alpha2 T3-Fz coherence (TAF), alpha2 T4-Fz coherence (WBF, NBF) and sway length (NBF, TAF).

Results

Visual Analogue Scale (VAS) in different standing positions

Statistically significant difference was found among the three standing positions on foam ($\chi 2 = 76.00$, $p < .001$, Kendall’s W = 1.00). Wilcoxon Signed Ranks Tests revealed that VAS increased significantly from WBF to NBF ($Z = -5.443$, $p < .001$, $r = 0.87$), NBF to TAF ($Z = -5.443$, $p < .001$, $r = 0.87$), and WBF to TAF ($Z = -5.374$, $p < .001$, $r = 0.87$).

EEG alpha2 T3-Fz coherence in different standing positions

No statistically significant overall difference was discovered in alpha2 T3-Fz coherence among different standing positions on foam ($\chi2 = 3.15$, $p = .207$, Kendall's W = .039) (Figure 1).

Figure 1 near here

EEG alpha2 T4-Fz coherence in different standing positions

No statistically significant overall difference was discovered in alpha2 T4-Fz coherence among different standing positions on foam ($\chi2 = 0.05$, $p = .974$, Kendall's W = .001) (figure 2).

Figure 2 near here

Total body sway length in different standing positions

Statistically significant difference was found among the three standing positions on foam ($\chi2 = 56.42$, $p < .001$, Kendall's W = .742). Wilcoxon Signed Ranks Tests revealed that total body sway length increased significantly from WBF to NBF (Z = -5.401, $p < .001$, r = 0.86), NBF to TAF (Z = -3.949, $p < .001$, r = 0.63), and WBF to TAF (Z = -5.373, $p < .001$, r = 0.87).

HRG versus LRG

The only significant between-group differences were found in MSRS-C (CMP) (Mann-Whitney U = 56.000, Z = -3.906, $p < .001$ $d = 1.56$), MSRS-C (MSC) ($t_{38} = -5.899$, $p < .001$, $d = 1.35$) and MSRS-C (Total) ($t_{38} = -7.636$, $p < .001$, $d = 2.41$) (Table 1). There were no between-group differences in VAS in all standing positions (WBF: $t_{37} = 0.023$, $p = .982$, $d = 0.01$; NBF: Mann-Whitney U = 176.000, Z = -0.650, $p = .516$, $d = 0.21$; TAF: $t_{37} = 0.288$, $p = .775$, $d = 0.09$). The between-group difference in alpha2 T3-Fz coherence was larger when the difficulty was higher, albeit not statistically significant (WBF: $t_{38} = -0.131$, $p = .896$, $d = 0.04$; NBF: $t_{38} = -0.252$, p

= .802, *d* = 0.08; TAF: Mann-Whitney U = 167.000, Z = -0.893, *p* = .372, *d* = 0.29). There were no between-group differences in alpha2 T4-Fz coherence (WBF: Mann-Whitney U = 179.000, Z = -0.568, *p* = .570, *d* = 0.18; NBF: Mann-Whitney U = 174.000, Z = -0.703, *p* = .482, *d* = 0.22; TAF: t_{36} = -0.407, *p* = .687, *d* = 0.13) and total body sway length (WBF: t_{37} = -0.126, *p* = .900, *d* = 0.04; NBF: Mann-Whitney U = 188.000, Z = -0.325, *p* = .745, *d* = 0.10; TAF: Mann-Whitney U = 159.000, Z = -0.871, *p* = .384, *d* = 0.36) in all standing positions.

Table 1 near here

Discussion

This study aimed at examining real-time conscious postural control (measured by EEG alpha2 T3-Fz coherence) in standing balance tasks among healthy young adults, and hypothesized that there would be no differences in real-time conscious postural control when the difficulty of standing task increases from Wide-Base Standing on Foam (WBF) to Narrow-Base Standing on Foam (NBF), and to Tandem Standing on Foam (TAF). We also hypothesized that HRG would have similar real-time conscious postural control to LRG in the three standing positions.

The results first revealed VAS together with total body sway length increased significantly from WBF to NBF and from NBF to TAF, which collectively supported the increase in task difficulties from WBF to NBF and to TAF. However, as predicted, no significant difference was found in EEG alpha2 T3-Fz coherence when task difficulty increases. Our findings indicate that the current task difficulty did not contribute to an increase in real-time reinvestment among healthy young adults, which is different from Chu and Wong (2018)'s findings which discovered that T3-Fz coherence increased with task difficulties among older adults. The difference between the response of young and older adults might be due to the age-related changes; healthy young adults typically have a better physical performance and require lower attentional demands during postural control than older adults, who generally encounter deterioration of somatosensory, visual and vestibular systems (Baloh, Jacobson & Socotch, 1993; Enrietto, Jacobson & Baloh 1999; Skinner, Barrack & Cook, 1984). Previously, Chan et al. (2016) did not find any significant difference in EEG T3-Fz coherence among different standing tasks when older adults was performing on firm ground until they were performing identical standing tasks on a foam surface (Chu & Wong, 2018). Taken together, it is suggested that task difficulty might still contribute to the difference in real-time reinvestment, but healthy young adults are relatively less susceptible to elicit significant changes in conscious postural control.

Moreover, it was found that psychological pressure/stress contributes to higher conscious control and monitoring of movements (Pijpers, Oudejans & Bakker, 2005; Master, 1992). However, the current task difficulty does not necessarily contribute to the expression of stress, and hence the real-time reinvestment. Indeed, stress is dependent on how nerve impulse is interpreted in the central nervous system (CNS) (Rylander, 2004). Therefore, although the tasks were documented to be increasingly challenging, the overall difficulty might not be necessarily translated to stress interpretation in the CNS among health young adults, thus contributing to the non-significant change in real-time conscious motor processing.

When looking at between-group differences for trait reinvestment, the non-significant association with real-time conscious postural control that we observed were actually consistent with Chu and Wong (2018)'s findings, where the difference in real-time conscious postural control between older high and low reinvestors was statistically insignificant. Recent evidence by Ellmers et al. (2016) and Chow et al. (2019) also demonstrated a lack of between-group differences in real-time conscious postural control in young and older adults. The collective argument is that the standing balance tasks do not seem to be physically and/or cognitively demanding for individuals with high trait reinvestment propensity to induce real-time changes in conscious postural control. Our evidence, nevertheless, reinforce the view that the MSRS-C might not be sensitive enough to reflect differences in conscious control during postural movements in healthy young adults.

There are several limitations in this study. First, stress might play a role in real-time reinvestment. Future work can monitor stress level and investigate its association with task difficulty, as well as real-time reinvestment. Second, the difficulty of standing positions appears to be physically and cognitively unchallenging for young adults to elicit any significant increase in real-time reinvestment. Future work could utilize a standing or dynamic balancing task with higher difficulty, or add another task that requires more attention or is known to increase cognitive load, which is expected to observe the potential increase in real-time reinvestment among healthy young adults. For example, performing a Stroop task while standing may increase attention and lead to greater alterations in posture and real-time conscious control. Apart from the potential of differentiating HRG and LRG within young adults, this would provide further evidence about postural adjustments during more cognitively demanding tasks that have been shown to attenuate sway in certain instances (Wollesen, Voelcker-Rehage, Regenbrecht, & Mattes, 2016). Collecting force/pressure measurements (i.e., center of pressure, sample entropy, etc.) may also generate more information about postural control during these tasks. Additionally, investigating gaze behavior in future studies could potentially enhance our understanding of the link or mechanism between reinvestment and postural control. After all, existing evidence indicate that attempts to consciously process movements, but not trait reinvestment propensity

(Uiga et al., 2020), resulted in changes in gaze behavior during locomotor tasks (Ellmers, Cocks, Kal, & Young, 2020; Ellmers & Young, 2019).

Conclusion

The current findings evaluate behaviors in young adults and demonstrate a mild real-time conscious response (represented alpha2 T3-Fz coherence) to different standing task difficulties, contrary to the responses observed in related work in the older population. No differences were found between individuals with high and low trait reinvestment propensities. By studying a population that is unaffected by countless potential confounding factors, the current study indicate that we cannot assume that basic concepts associated with reinvestment and task difficulties are easily transferrable to different cohorts/populations, particularly those affected by age-related changes. Future work could use balancing tasks with higher difficulty with additional measurements (e.g., force data, gaze behavior) to consolidate the contemporary knowledge on real-time conscious involvement in postural control.

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Conflict of interest

There is no commercial interest between the authors and the subject of the manuscripts. The authors declare no conflict of interest.

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Table 1. Mean (SD) values of different variables between LRG and HRG.

	Group	
Variables	Low reinvestors (LRG)	High reinvestors (HRG)
Age (years)	20.70 (1.17)	20.70 (1.08)
MSRS-C (CMP) **	18.20 (3.19)	23.80 (2.80)
MSRS-C (MSC) **	16.95 (5.64)	23.55 (4.01)
MSRS-C (Total) **	35.15 (5.99)	47.85 (4.40)
VAS (WBF)	1.02 (0.85)	1.02 (0.81)
VAS (NBF)	3.50 (1.69)	3.16 (1.52)
VAS (TAF)	6.72 (2.26)	6.54 (1.62)
Sway length (mm) (WBF)	152.97 (36.24)	154.49 (39.22)
Sway length (mm) (NBF)	218.02 (44.92)	225.42 (41.19)
Sway length (mm) (TAF)	261.78 (86.99)	284.45 (76.05)

Notes: MSRS-C (CMP) = Chinese version of the Movement Specific Reinvestment Scale (Conscious Motor Processing); MSRS-C (MSC) = Chinese version of the Movement Specific Reinvestment Scale (Movement Self Consciousness); MSRS-C (Total) = Chinese version of the Movement Specific Reinvestment Scale (Total); VAS = Visual Analogue Scale; WBF = Wide-Base Standing on Foam; NBF = Narrow-Base Standing on Foam; TAF = Tandem Standing on Foam; $^{**}p < .01$.

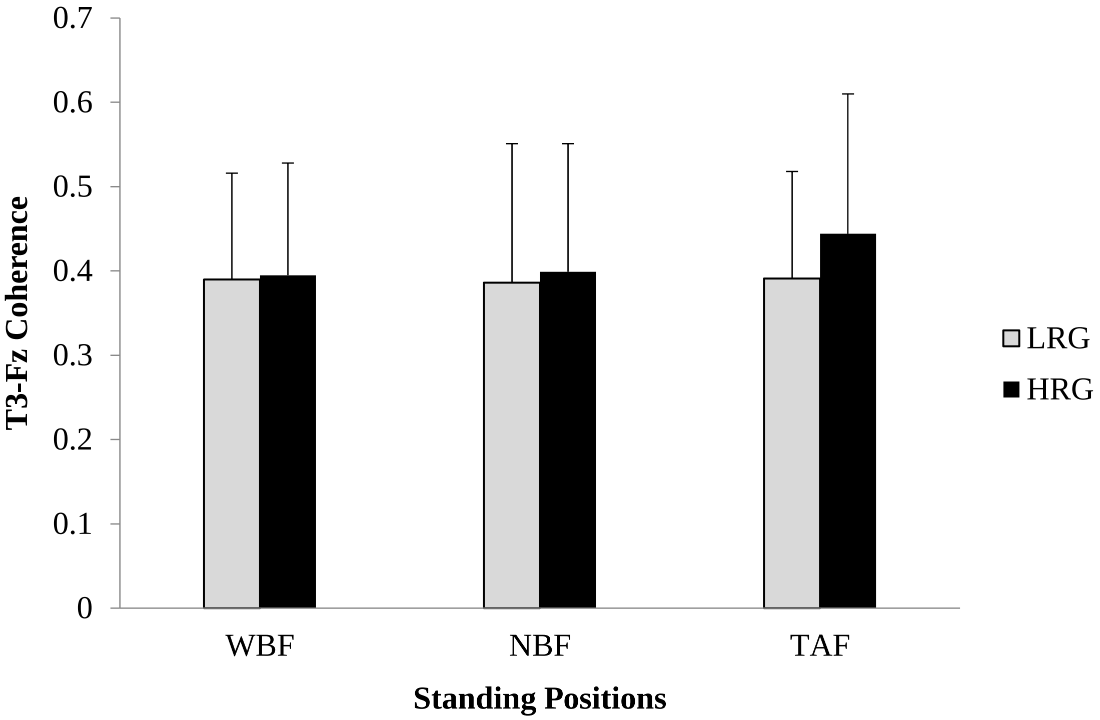
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
T3-Fz Coherence
WBF
NBF
TAF
Standing Positions
LRG
HRG

Figure 1.

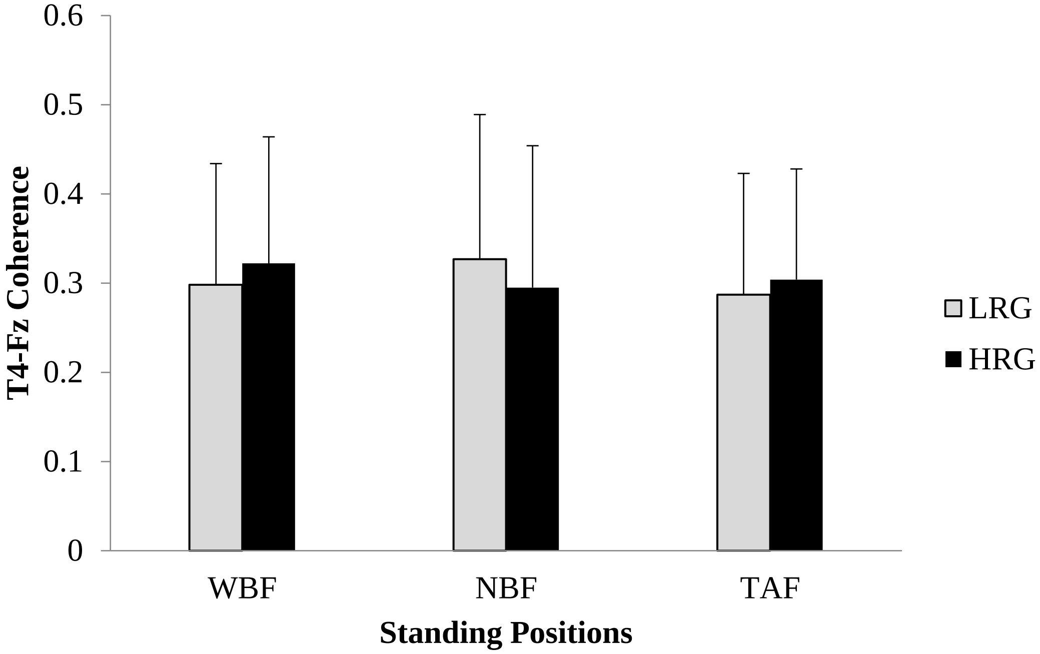
0.6
0.5
0.4
0.3
0.2
0.1
0
T4-Fz Coherence
WBF
NBF
TAF
Standing Positions
LRG
HRG

Figure 2.

Figures captions

Figure 1. EEG alpha2 T3-Fz coherence of LRG and HRG in different standing positions. Error bars represent standard deviations of the data.

Figure 2. EEG alpha2 T4-Fz coherence of LRG and HRG in different standing positions. Error bars represent standard deviations of the data.