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Abstract

Young adults reduce their sway in both light touch (LT) and anchor systems (AS), however, the cognitive involvement in these tasks is unknown. This study investigated postural control in young adults standing upright using either LT or AS, concomitantly with a cognitive task (counting). Nine adults (26 ± 7.4 years) stood in the upright tandem stance with eyes closed, with/without LT, AS (force <2N), and a cognitive task. The mean sway amplitude of the trunk, right wrist, and shoulder ellipse area, as well as the mean force during LT and AS were obtained. The cognitive task did not influence the magnitude of trunk sway or the mean force in the LT and AS conditions. The trunk sway magnitude was reduced in the AS and even further in LT. Wrist and shoulder variability was larger in the AS than in the LT. Based on these results, we conclude that enhanced sensory cues provided by LT and AS reduce trunk sway with little or no attentional demands.

Keywords: Posture control; sensory cues; cognitive task

Introduction

Maintaining an upright posture is a daily task that humans perform effectively without conscious attention. Such functioning characteristics of postural control are critical and allow humans to perform simultaneous tasks such as standing upright and speaking, reading, or performing mathematical operations. Postural control associated with a secondary task (dual task), or even multiple tasks, seems to be a rule and not an exception within the ecological context. By contrast, attention seems to play an important role in postural control either when sensory interaction produces a cue conflict (Redfern et al., 2001; Shumway-Cook & Woollacott, 2000; Teasdale & Simoneau, 2001) or when disturbances elicit compensation in postural control orientation (Woollacott, 2000). Therefore, the postural control system seems to deal well with several easy concomitant tasks with minimum attentional demands, whereas with more challenging dual tasks, it requires attentional involvement to succeed.

The availability of sensory cues also impacts postural control. For example, if sensory cues are diminished and/or removed (i.e., eyes closed) while maintaining an upright stance, the body sway magnitude increases when compared to normal visual conditions (Paulus et al., 1984). Conversely, if sensory cues are enhanced and manipulated, for example, by providing a visible target closer to participants (Bonnet et al., 2010) and guiding eye movements to specific targets (Rodrigues et al., 2013; Stoffregen et al., 2007), sway magnitude is reduced. A reduction in body sway is also observed when one manipulates somatosensory cues by lightly touching a rigid surface (Jeka & Lackner, 1994) or by holding an anchor systems (AS) (Mauerberg-Decastro et al., 2014). In these previous studies, the participants swayed less when somatosensory cues were enhanced than they did with no additional sensory information.

Sensory cue manipulation not only leads to a reduction in the magnitude of body sway, but also to coherent sway. For instance, oscillating the visual scenario (the moving room paradigm) or a rigid touch surface (the moving touch paradigm) induces correspondent and coherent body oscillations (Jeka et al., 1997). Interestingly, under conditions of sensory cue manipulation with small amplitude and low velocity, participants coupled to visual (Barela et al., 2009; Barela et al., 2014) and light touch (LT) (Barela et al., 2003; Jeka et al., 1997) unconsciously. They were unaware that they were swaying in synchronization with the sensory manipulation.

The unconscious influence of visual cues on body sway was disrupted as young adults received verbal information either that the available visual cues were unreliable (Freitas Junior & Barela, 2004) or they were requested to resist (Aguiar et al., 2014). However, cognitive demands to perform an additional task (backward counting) prevented participants from resisting or diminishing the influence of visual manipulation (Aguiar et al., 2014). Vuillerme et al. (2005) observed that the use of a LT on a rigid bar to maintain an upright stance also demanded attention from young adults. The impact on decision-making was a longer reaction time. Thus, apparently the use of sensory cues by the postural control system leads to improved performance, but it is dependent on cognitive resources.

Body sway reduction has also been observed in adults using the AS, when they hold, usually with both hands, flexible cables attached to weights on the ground (Mauerberg-Decastro et al., 2010). Although AS and LT are similar in that subtle contact providing significant stabilization, they are two paradigms that differ in several aspects. LT implies a fixed and stationary surface, whereas AS implies cables that can be slightly moved around. LT usually requires continuous application of small pressure downwards and AS involves small upward pulling forces. In the LT paradigm, the touch surface is a small and rigid surface, whereas in the AS, the cables are flexible and must be kept tensioned with weights on the ground. Thus, the AS is characterized as a paradigm with more degrees of freedom than LT. While participants are required to maintain the fingertip contact with a fixed surface, in the LT paradigm (Jeka & Lackner, 1994), participants in the AS paradigm are required to maintain variable tension on a moveable system. Despite these differences, the magnitude of the body sway is reduced in both the LT and AS conditions compared to the no-contact condition, but with a larger reduction for LT compared to AS (Moraes et al., 2018). The difference in sway reduction suggests that the surface in LT might be more informative than the flexible cables in AS.

Despite providing an additional and important source of sensory cues, the flexible cables employed in AS provide a significant change in coupling of the upper arm with numerous joints and segments. This indicates that exploratory and supra-postural components may be involved (Moraes et al., 2018). Such differences in the degrees of freedom between LT and the AS provide different external frames of reference to the users, which might imply different cognitive involvement. Using sensory cues in postural control tasks demands attentional involvement (Aguiar et al., 2014) even reducing the effectiveness of decision-making during LT (Vuillerme et al., (2005). Therefore, it is also possible that using cues from lightly touching a surface and holding flexible cables require different cognitive involvement. If this is the case, the cognitive involvement in the AS would be even more demanding considering the exploratory behavior and larger degrees of freedom involved. No research has examined this issue during the use of haptic information furnished by the AS.

The aim of this study was to examine the characteristics of postural sway during LT and the AS while performing a cognitive task. We hypothesized that (1) the use of haptic cues, from both LT and an AS, would reduce sway magnitude; (2) the reduction in the magnitude of body sway would be greater with the use of LT than AS, following previous results (Moraes et al., 2018); and (3) performing a cognitive task (backward counting), as previously employed (Aguiar et al., 2014; Pellecchia, 2003), would modify the body sway reduction effects of LT and the AS, all while maintaining an upright tandem stance.

Methods

Participants

Nine adults (26.0 ± 7.4 years, 4 males/5 females, 169.3 ± 0.5 cm; 68.1 ± 6.6 kg) participated in this study. None of the participants presented any known musculoskeletal or cognitive impairment that could compromise the performance of the proposed tasks. Prior to the experimental procedures, all participants signed a written consent form containing the procedures approved by the Institutional Ethics Committee.

Procedures

In a single visit to the laboratory, after a brief period of adaptation, participants were asked to maintain an upright tandem stance while standing barefoot on a wooden platform placed on the floor. Seven IRED emitters of a three-dimensional motion analysis system (OPTOTRAK CERTUS, Northern Digital Inc.) were affixed to the following anatomical landmarks: 2^{nd} cervical vertebra, 6^{th} cervical vertebra, and 8^{th} thoracic vertebra; right and left acromion; and right and left wrists (joint centers).

Initially, for a control visual task (data not considered in this study), participants were asked to keep their eyes open and stand as still as possible with parallel feet, slightly separated (≈ 5 cm). Afterwards, they were asked to stand as still as possible in the tandem stance position, evenly distributing body weight on their legs, with eyes closed (maximizing possible use of touch/anchor system and avoiding any confounding vision effect) under three sensory conditions: no contact (NC), LT, and AS (Figure 1), and two cognitive conditions: backward counting and no counting. In all three sensory conditions, participants were asked to maintain both arms beside the trunk with elbows flexed at approximately 130°. In the LT condition, participants were asked to contact the tip of their right (dominant hand) index finger the rigid metallic surface of a multi-axis force/torque transducer (Nano 17 Titanium, ATI, Inc.). This contact surface was mounted on an adjustable tripod set to the appropriate height. In the AS condition, participants were asked to hold two flexible cables (nylon ropes), each attached to a load cell (Load Cell - Model S-5, Alfa Instruments, Ltda.) that was fixed to the wood platform on which the participants stood. Participants were centered behind the load cells, and the length of the cables was adjusted to accommodate approximately 130° of elbow flexion. The cables first contacted and were mostly held by the index and thumb fingers, as the as the palms were oriented up with wrist straight and aligned with the forearm.

In this position, the participants were instructed to maintain tension in the cables. In both LT and AS conditions, participants were asked to apply up to 2N of force on the touch surface or each cable, respectively. The force magnitude was visually inspected in real time, and if the limit of 2N was exceeded, the trial would be discarded and repeated. We did not encounter this issue as no participant exceeded this limit in any of the conditions.

[Insert Figure 1 here]

The cognitive condition consisted of counting backward silently, avoiding any sway disturbance due to verbalization (Dault, Yardley & Frank, 2003), from 100, in steps of 3. At the end of the trial, the last number reached in the backward counting task was reported to the researcher and the number of mental calculations was obtained. In the no-counting condition, participants were instructed to maintain a tandem stance throughout the trial.

Data from IREDs, transducers, and load cells were synchronously acquired under all experimental conditions using the analogic device (ODAU II) of the OPTOTRAK system at a frequency of 100 Hz. Each experimental condition was repeated twice, and each trial lasted for 30 s. The combination of these conditions was performed in a random order.

Data analysis

Data analyses were performed using MATLAB (MathWorks, Inc.). Position data from IRED markers for both anterior-posterior (AP) and medial-lateral (ML) directions, and vertical force from the touch bar transducer and AS load cells were digitally filtered using a 2nd order digital Butterworth filter with a 5 Hz cutoff frequency. The following variables were obtained for further analysis. The trunk mean sway amplitude, for both the AP and ML directions, was calculated as an estimate of the overall postural control performance for each direction (Jeka & Lackner, 1994; Barela, Jeka & Clark, 2003). It was calculated in subtracting a first-order polynomial of the trunk from each data point within a trial, and calculating the standard deviation of this signal. The ellipse area was obtained for the wrist and elbow using the area encompassing 95% of all joint positioning for each joint. It was used to estimate variability of each joint, taking into account displacement in both

AP and ML directions, as the joint was moved as a mean of participant's whole body sway and/or joint positioning. Finally, the mean vertical force acquired from LT and AS transducers was calculated. The average of the two trials under each condition was calculated for all the variables and used for further comparisons.

Statistical analysis

After accepting the assumptions of normality and homogeneity of variance, we used one multivariate analysis of variance (MANOVA) and two analyses of variance (ANOVA) with sensory and cognitive conditions as factors, both treated as repeated measures. The dependent variables for the MANOVA and the two ANOVAs were the trunk mean sway amplitude in both the AP and ML directions, and the area of variation of the right shoulder and wrist, respectively. Another ANOVA was also employed with force and cognitive conditions as factors, both treated as repeated measures. When necessary, univariate analyses and Tukey *post-hoc* tests were applied, followed by Bonferroni correction. All analyses were performed using SPSS software with a significance level of 0.05.

Results

Figure 2 depicts the trunk mean sway amplitude in the AP and ML directions under all experimental conditions. The MANOVA revealed a sensory effect (Wilks' Lambda = 0.059; $F_{4,32}$ = 23.34, p = 0.001; ηp2 = 0.757), but no cognitive effect (Wilks' Lambda = 0,909; $F_{2,7}$ = 0.35 *p* = 0.715; ηp2 = 0.091) and no sensory-cognitive interaction (Wilks' Lambda =0.812; $F_{4,32}$ = 0.82, p = 0.522; ηp2 = 0.099). Univariate analyses showed a sensory condition effect for both the AP ($F_{2,16}$ = 16.12, p = 0.001; ηp2 = 0.668) and ML ($F_{2,16}$ = 66.73, p = 0.001, ηp2 = 0.89) directions. Post-hoc tests revealed that the mean AP sway amplitude was smaller in the LT condition than in the NC and AS conditions ($p < 0.05$). Furthermore, the mean AP sway amplitude in the AS condition was smaller than that in the NC condition ($p < 0.05$). Post-hoc tests revealed that the mean ML sway amplitude was significantly smaller in the LT than in the NC and AS conditions ($p < 0.05$).

[Insert Figure 2 here]

Figure 3 depicts the wrist and shoulder areas under all experimental conditions. For the wrist, the ANOVA revealed a sensory effect ($F_{2,16}$ = 5.61, p = 0.014, ηp2 = 0.41) but no cognitive effect ($F_{1,8}$ = 2.45, p = 0.156; ηp2 = 0.23), and no sensory-cognitive interaction ($F_{2,16}$ = 1.78, p = 0.199; ηp2 = 0.18). Post-hoc tests revealed that the wrist area was smaller in the LT than in the NC and AS conditions ($p < 0.05$). For the shoulder, the ANOVA revealed a sensory condition effect ($F_{2,16}$ = 10.74, p = 0.001, ηp2 = 0.57) but no cognitive effect ($F_{1,8}$ = 1.25, p = 0.295; ηp2 = 0.136), and no sensory-cognitive interaction ($F_{2,16}$ = 0.88, p = 0.432, ηp2 = 0.100). Post-hoc tests indicated that the shoulder area was smaller in the LT condition than in the NC and AS conditions, and that the area was smaller in the AS than in the NC condition ($p < 0.05$).

[Insert Figure 3 here]

Table 1 depicts the mean applied force in the sensory and cognitive conditions. The ANOVA revealed no sensory ($F_{2,16}$ = 3.92, p = 0.063; ηp2 = 0.29) or cognitive ($F_{1,8}$

= 0.29, p = 0.601; ηp2 = 0.036) effects, nor any sensory-cognitive interaction ($F_{2,16}$ = 0.23, p = 0.792; ηp2 = 0.029). These results indicated that participants applied a similar mean vertical force throughout sensory and cognitive conditions.

[Insert Table 1 about here]

Finally, the mean number of mental calculations performed by the participants in the cognitive conditions were 11.2 ± 2.2 and 10.2 ± 3.1 for the LT and AS conditions, respectively. ANOVA revealed no sensory effect ($F_{1,8}$ = 2.25, p = 0.172; ηp2 = 0.220), indicating that the counting task was performed similarly in both the LT and AS conditions.

Discussion

Our results showed that haptic information from both LT and AS improved postural control, leading to reduced body sway, corroborating our first hypothesis. As expected, the haptic information diminished body sway more for LT than AS, also corroborating our second hypothesis. Finally, concomitant cognitive tasks did not influence postural control, not corroborating our third hypothesis. Taken together, haptic enhanced cues reduced body sway, although the magnitude of the decrease was dependent on the nature of the available cues. Despite this dependence on haptic type, cognitive tasks did not increase body sway, suggesting that the use of such haptic systems for postural control does not demand attention.

Postural control during the use of light touch and an anchor system

Our results confirmed our hypothesis that haptic cues lead to improvements in postural control. These results are not new, as several previous studies have shown body sway reduction in adults under various conditions in which researchers employed the use of LT (Bolton et al., 2011; Jeka & Lackner, 1994; Tremblay et al., 2004; Vuillerme et al., 2006) and a non-rigid AS (Mauerberg-De Castro et al., 2014; Mauerberg-Decastro et al., 2012; Moraes et al., 2018). Therefore, our results corroborate both haptic sources of enhanced cues relate to the reduction of body sway. The novelty of the present study is that these results could still be found even when a cognitive task was performed simultaneously.

The reduction in body sway was larger in the experimental condition using LT compared to that using AS, also confirming our hypothesis. The difference in reduction is due to the characteristics of haptic cues provided by each condition. In both cases, sway reduction occurred because of the improved sway-reference information. LT furnished cues arising from a stationary surface touched by the fingertip and the AS from non-stationary and moveable cables held by the hands. Our results showed that postural control improved more in the LT condition than in the AS condition (Figure 2). Indeed, when using LT, there was a clear and well-established spatial and temporal relationship between the applied force and sway changes (Jeka & Lackner, 1995). In the experimental condition with LT, information regarding changes in the applied force provided a reference for body sway that was used to activate postural muscles for sway attenuation. On the other hand, in the experimental conditions with the AS, the relationship between changes in the cable tension and changes in body sway was mild (Moraes et al., 2018). Therefore, overall, the efficiency of postural control is dependent on external object stability and there is a greater reduction in sway magnitude when the contact surface is stationary than when it is non-stationary.

The difference in the external reference provided by the LT and the AS can also be understood by considering the variability observed in the wrist and shoulder joints. Our results revealed that the requirement for maintaining fingertip contact on a stationary surface led to quite a low wrist variability, which was lower than that observed when holding moveable cables (Figure 3). Lower variability at the shoulder was also found in the LT conditions than in the AS conditions (Figure 3). Thus, the lack of a stationary reference in the AS leads to a less informative and efficient system to promote sway attenuation than the LT condition. If this were the case, these differences in sway reduction between LT and AS do not seem to be due to exploratory and supra-postural issues, as previously suggested (Moraes et al., 2018) but instead, it seems to be due to the nature of the reference that each condition furnishes to the user.

Undoubtedly, the experimental condition using the AS can be performed with a greater number of degrees of freedom (for example, upward traction movements, movements in the anteroposterior and ML directions, and several possibilities for hand rotation) that are characteristic of the AS (Mauerberg-De Castro et al., 2014). As such, it restricts the efficiency of the frame of reference available to the postural control system. Conversely, the reference provided by the stationary surface in LT is more informative, but also restrictive.

Our results can be used in everyday life situations. In fact, the AS allows greater possibility of movement and more degrees of freedom. Therefore, the AS can be implemented in a variety of situations, such as walking on stable and regular (Hedayat et al., 2017), dynamic (Mauerberg-Decastro et al., 2013) and challenging surfaces (Mauerberg-De Castro et al., 2014; Mauerberg-Decastro et al., 2010). In contrast, LT is applied when using a cane (Jeka & Lackner, 1995) and can be used in many other everyday situations, for example, when holding a card in a bank system to withdraw money or to make a payment, and when using a utensil to stir food in a pan.

Haptic information and attentional demands

Our results showed no deterioration of postural control performance in any of the conditions when participants had to count backward in steps of 3, concomitantly. These results refuted our third hypothesis that the addition of a cognitive task would modify postural control performance, but are consistent with those observed in previous studies (Andersson et al., 2002; Polskaia et al., 2015). However, our findings disagree with those of other studies, indicating that cognitive tasks while maintaining upright posture lead to an increase in body sway in young (Ceyte et al., 2014; Polskaia et al., 2015; Richer et al., 2017) and older (Casteran et al., 2016; Laufer et al., 2008; Manckoundia et al., 2006) adults. One possibility is that the enhanced sensory cues, due to contacting or holding an external object, providing body dynamics information might overcome the cognitive demand and not deteriorate postural control performance. If this is the case, the backward counting task was not hard enough to affect the use of sensory cues and impact sway dynamics. Future studies should further investigate the influence of cognitive tasks on postural control functioning and the impact on the regulation of sway magnitude.

More importantly, we observed that a concomitant counting task did not affect the variability of haptic cues from both LT and AS. Our results contradict the suggestion that LT demands attention to improve postural control, thus leading to longer reaction times (Vuillerme et al., 2005). Similarly, several studies have shown that changes in the coupling between visual information and body sway occur (Freitas Junior & Barela, 2004), but require cognitive effort (Aguiar et al., 2014). However, these studies employed different strategies and experimental conditions.

The lack of cognitive influence on the performance of participants using the AS also raises questions regarding possible supra-postural and more demanding implications related to the AS. If sway reduction favoring LT compared to the AS was due to heavier exploratory and supra-postural issues (Moraes et al., 2018), cognitive involvement should have had some impact on postural control performance. This does not seem to be the case and thus highlights an important function of our postural control system that allows us to perform concomitant and several tasks while maintaining stability and functionality.

Conclusion

We conclude that both LT and the AS were effective in reducing body sway in young adults, irrespective of the experimental cognitive load. The LT paradigm reduced body sway more than the AS, thus confirming our assumption that both systems present ways of obtaining haptic cues with more effective information available in the LT condition. Finally, the use of both LT and AS to attain a more stable control of postural orientation does not impact attentional resources and may be employed as an important functional solution.

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Declaration of interest statement

The authors declare no conflicts of interest.

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Table 1. Mean (± SD) of mean applied force (N) in the light touch (LT) and in the anchor system (AS) sensory conditions, and no counting and backward counting cognitive conditions.

Sensory/Cognitive	No counting	Backward counting
LT (right index finger)	0.50 ± 0.25	0.46 ± 0.25
AS (right hand)	0.49 ± 0.22	0.42 ± 0.19
AS (left hand)	0.67 ± 0.29	0.69 ± 0.49

Figure captions

Figure 1. Illustrative representation of participant in tandem upright stance performing all three sensory conditions (a) no contact; (b) light touch; and (c) anchor system.

Figure 2. Mean (± SD) of mean sway amplitude, in the anteroposterior – AP and medial-lateral – ML directions, in all sensory and cognitive conditions, Notes: NC=non-contact, LT=light touch, AS=anchor system, *denotes significant difference between conditions.

Figure 3. Mean (± SD) of the wrist and shoulder ellipse area in all sensory and cognitive conditions. Notes: NC=non-contact, LT=light touch, AS=anchor system, *denotes significant difference between conditions.

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Figure 1.

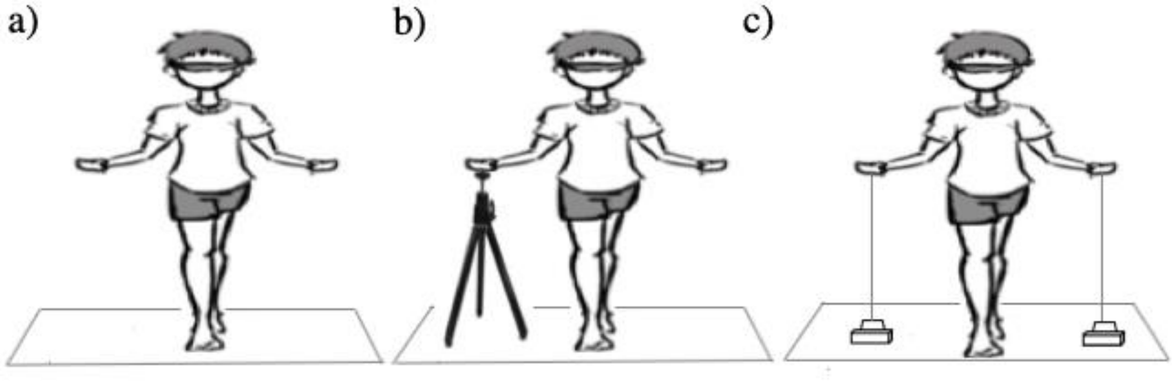


Figure 2.

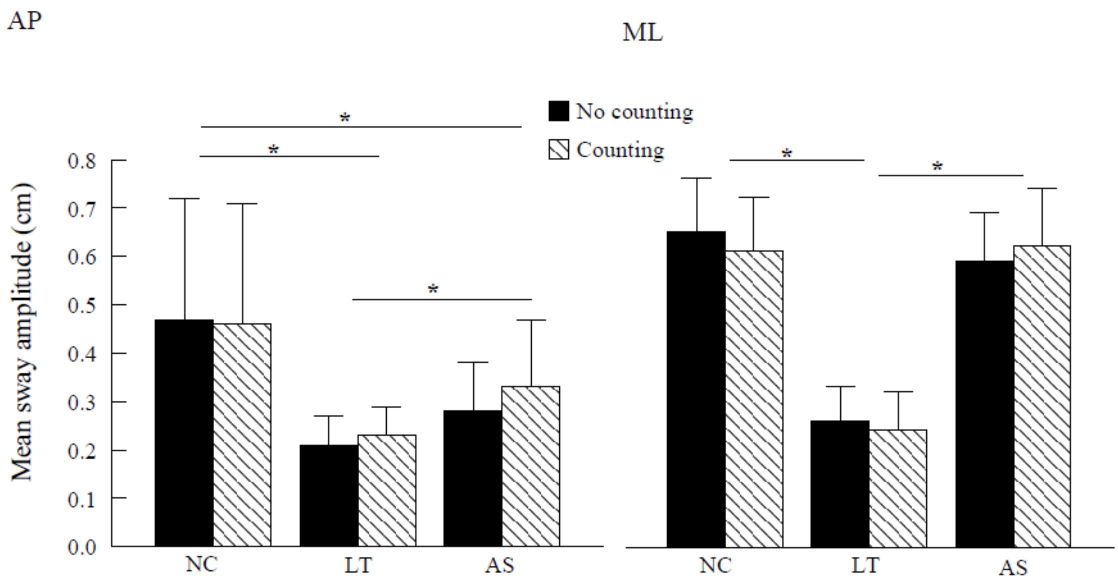
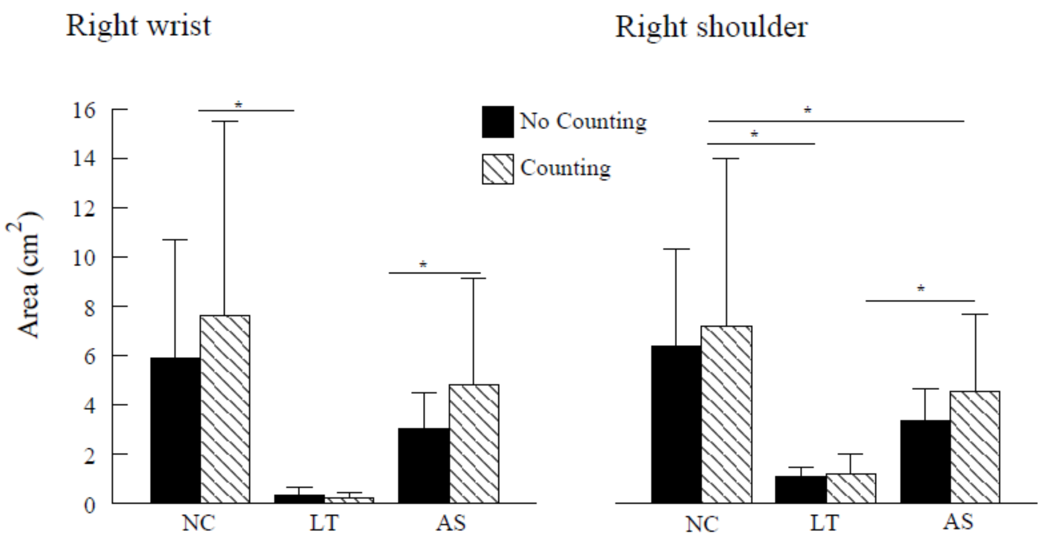

AP
ML
No counting
Counting
Mean sway amplitude (cm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
*
*
*
*
*
NC
LT
AS
NC
LT
AS

Figure 3.


Right wrist
Right shoulder
No Counting
Counting
Area (cm2)
16
14
12
10
8
6
4
2
0
*
*
*
*
*
NC
LT
AS
NC
LT
AS