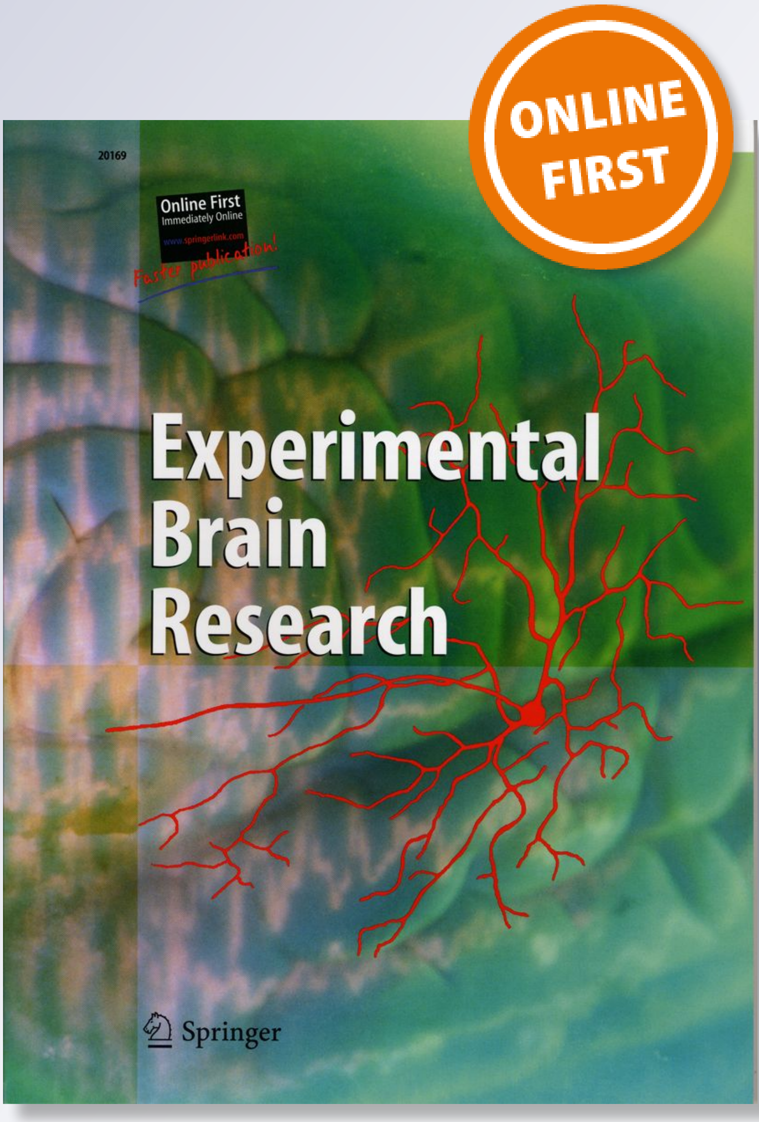
Role of vision in sighted and blind soccer players in adapting to an unstable balance task

María Campayo-Piernas, Carla Caballero, David Barbado & Raúl Reina

Experimental Brain Research

ISSN 0014-4819

Exp Brain Res
DOI 10.1007/s00221-017-4885-8



Exp Brain Res
DOI 10.1007/s00221-017-4885-8

RESEARCH ARTICLE

Role of vision in sighted and blind soccer players in adapting to an unstable balance task

María Campayo-Piernas[1] · Carla Caballero[1] · David Barbado[1] · Raúl Reina[1]

Received: 5 August 2016 / Accepted: 16 January 2017

Abstract This study tested whether a compensatory hypothesis exists on postural control during standing unstable balance tasks comparing blind soccer players ($n = 7$) to sighted soccer players ($n = 15$) and sighted sedentary individuals ($n = 6$). All subjects performed a pre-test, a training of ten practice trials on a single day, and a post-test balance test. All tests were performed on an unstable surface placed on a force platform and under closed-eyes conditions, and a final test was performed with open eyes. Balance performance was assessed by resultant distance (RD) and the magnitude of mean velocity (MV) of the centre of pressure (CoP) displacement, and EMG signals from the gastrocnemius lateralis, tibialis anterior, rectus femoris, and peroneus longus were measured with surface electromyography. Principal component analysis (PCA) on EMG muscular activation was used to assess EMG pattern differences during the balance tasks. All groups improved their performance, obtaining low scores for the closed-eyes condition balance task after the training period in RD, VM, and aids received to keep balance in the novel task, and no differences were found between groups or in interaction effects. Sighted individuals and the control group showed significantly lower RD and VM scores under open-eyes conditions than blind participants. As regards neuromuscular behaviour, three principal patterns explained 84.15% of the variability in the measured data. The theoretical improvement of the other senses caused by visual deprivation does not allow blind individuals to obtain better balance than sighted individuals under closed-eyes conditions, thereby reinforcing the prominent role of vision in integrating and processing the other sensory inputs. In addition, blind individuals seem to increase their muscular co-activation as a safety strategy, but this behaviour is not different to that shown by sighted people under closed-eyes conditions.

Keywords Compensatory hypothesis · Balance · Brain plasticity · Electromyography · Principal component analysis

Introduction

Vision plays a paramount role in postural control (Choy et al. 2003, Hsu et al. 2007; Piao et al. 2006; Schwesig et al. 2010). In fact, some authors have suggested that the visual system may be more suitable for obtaining information about the body relative to the physical surroundings than the haptic and vestibular systems, allowing a more effective regulation of the postural control during upright stance (Riley et al. 1997). This idea is supported by several studies conducted by non-visually impaired people, showing that stability is reduced during single-leg or double-leg quiet stance in the absence of vision (Choy et al. 2003; Giagazoglou et al. 2009, Hsu et al. 2007; Schieppati et al. 1999; Schmid et al. 2007). Specifically, balance in upright stance appeared to be worse in participants with visual impairment, because their loss of vision affects the vestibular-labyrinthine system via feedback from the visual system (Ray and Wolf 2008; Tomomitsu et al. 2013). In addition, a visual impairment

Electronic supplementary material The online version of this article (doi:10.1007/s00221-017-4885-8) contains supplementary material, which is available to authorized users.

✉ Raúl Reina
rreina@goumh.es

[1] Sports Research Centre, Miguel Hernández University, Av. de la Universidad s/n, 03202 Elche, Alicante, Spain

Published online: 14 February 2017

can have a major impact on motor development and skill acquisition (Giagazoglou et al. 2009; Hallemans et al. 2010, 2011). For instance, Reimer et al. (2011) agreed that the motor development of children with low vision is lower than that of children with normal vision.

The role of visual information in postural control seems to become more and more important with advancing age in normally sighted people and their balance is based mostly on vision (Ivers et al. 2000; Lord and Menz 2000). In contrast, people with visual impairments depend more on somatosensory and vestibular inputs than sighted people (Anand et al. 2003). The compensatory hypothesis suggests that blind people compared with sighted people can improve the use of their remaining senses (Goldreich and Kanics 2003; Gougoux et al. 2004; Pascual-Leone et al. 2005; Schwesig et al. 2010; van Boven et al. 2000; Voss et al. 2004) by replacing the lack of visual information with other sensory inputs. It has been observed that visual information brain areas in blind people are recruited in a compensatory cross-modal manner (Bavelier and Neville 2002; Cohen et al. 1997; Théoret et al. 2004). Some authors have found that blind subjects exhibit superior auditory, tactile and kinaesthetic acuity in various manual tasks than sighted individuals wearing blindfolds (Goldreich and Kanics 2003; Röder et al. 1999; Yoshimura et al. 2010), thereby supporting the idea that a prolonged visual deprivation can contribute to brain reorganization and behavioural compensations (Théoret et al. 2004). Although blind people have shown similar proprioception and vestibular reactions to sighted ones (Juodžbalienė and Muckus 2006), it is not clear whether long-term plasticity can replace vision in blind individuals allowing them to achieve as good postural control as sighted individuals during balance (Juodžbalienė and Muckus 2006; Schmid et al. 2007).

One possible reason for the controversy about the evidence regarding cross-modal plasticity in relation to postural control in balance tasks could be lifestyle. Blind children and adolescents have been reported to adopt a more sedentary lifestyle and to have lower physical fitness than their sighted counterparts (Houwen et al. 2008; Kozub and Oh 2004; Lieberman and McHugh 2001; Lieberman et al. 2006; Longrnuir and Bar-Or 2000). In blind adults, visual field loss is also a risk factor for low physical activity levels because of the fear of falling. Fear of falling is an important predictor of future falls (Black et al. 2008; Shabana et al. 2005; Wood et al. 2011), and therefore, it usually leads to a reduction in self-confidence and activities and, consequently, a deterioration of physical abilities and quality of life, especially in older individuals (Papadopoulos et al. 2011; Soong et al. 2001; Wang et al. 2012). Thus, cross-modal plasticity evidence during balance tasks could be biased by the level of physical stimulation or impaired motor skills acquisition of visually impaired individuals (Chen and Lin 2011; Ponchillia et al. 2005, 2002).

Due to the unclear results shown in the literature, the aim of this study was to test whether a compensatory hypothesis exists on postural control during standing balance tasks comparing visually impaired but physically active individuals with their sighted and sedentary counterparts. Participants' postural control in a non-common (novel) unstable standing balance task was assessed before and after an intra-session training under unstable and non-vision conditions, using centre of pressure displacement and muscular activation of the lower limb muscles. We hypothesized that: (1) the absence of vision is compensated during balance maintenance by visually impaired athletes; and (2) visually impaired athletes adapt better than sighted athletes and a control group to an instability training using blindfolds. Finally, considering that a novel balance task was used, we performed within-session test–retest reliability analysis to increase the generalisability and interpretability of the result of this study.

Methods

Participants

Fifteen sighted soccer players (SSP) (age: 25.1 ± 6.2 years; height: 1.76 ± 0.05 m; mass: 73.6 ± 6.0 kg), six sighted sedentary individuals (control group, CG) (age: 28.0 ± 5.2 years; height: 1.72 ± 0.04 m; mass: 79.5 ± 15.0 kg), and seven blind soccer players (BSP) (age: 28.4 ± 6.4 years; height: 1.73 ± 0.07 m; mass: 72.8 ± 7.2 kg) took part in this study. The sighted soccer players had 14.1 years of practice with a workout frequency of two to three days per week. The BSP players had 8.6 years of practice with a workout frequency of two to three days per week. Although the soccer players with visual impairment had a shorter sport experience, five of them had played for their national team, and two of them had taken part in the London Paralympic Games, winning a bronze medal. All the participants from this group were blind, and were in class B1 according to IBSA classification rules, which define B1 players as those that have a visual acuity poorer than LongMAR 2.60 (De Salvia 2012). Ten sighted healthy participants (age: 32.7 ± 4.4 years; height: 1.71 ± 0.08 m; mass: 70.1 ± 5.3 kg), who were not involved in the main study, were recruited to participate in a reliability study. None of the participants reported a recent history of lower limb or back injuries, abdominal surgery, or inguinal hernia, and all the participants were free of neurological or musculoskeletal disorders.

Written informed consent was obtained from each participant prior to testing. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the University Office for Research Ethics.

Instrumentation and data collection

Centre of pressure (CoP) recording

To assess postural stability, this study used a force platform (Kistler, Switzerland, Model 9287BA). Ground reaction forces were recorded at 1000 samples and calibrated at the beginning of each participant's collection. CoP displacement was calculated in millimetres (mm).

EMG recording

Surface electromyography was bilaterally recorded (Fig. 1) from the gastrocnemius lateralis (GL) (electrodes placed at 1/3 of the line between the head of the fibula and the heel), tibialis anterior (TA) (electrodes placed at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus), rectus femoris (RF) (electrodes placed at 50% on the line from the anterior spina iliaca superior to the superior part of the patella), and peroneus longus (PL) (electrodes placed at 25% on the line between the tip of the head of the fibula to the tip of the lateral malleolus). The SENIAM guidelines (Hermens et al. 2000) for surface EMG electrode placement were used to direct the collocation of the sensors. The area where the sensors were placed was shaved with a disposable razor, and vigorously abraded with an alcohol swab to remove dead skin cells and oils from the surface of the skin. The EMG sensor was attached with double-sided sticky tape (BSN Medical Strappal). The precise electrode positions were drawn on the skin using a surface marker. Pre-gelled disposable bipolar Ag–AgCl disc surface electrodes (Blue Sensor, Ambu A/S, Denmark) were positioned parallel to the muscle fibers at an inter-electrode distance of 2.5 cm. The reference electrodes were placed on bony landmarks.

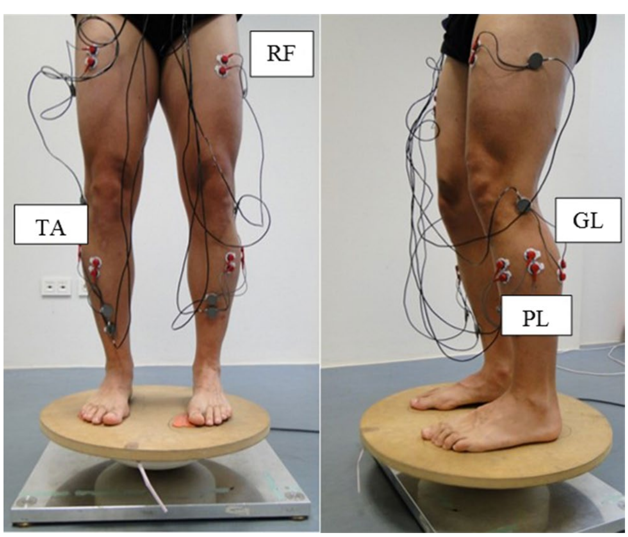


Fig. 1 Surface electromyography collocation (*RF* rectus femoris, *TA* tibialis anterior, *GL* gastrocnemius lateralis, *PL* peroneus longus)

A portable telemetry electromyography eight-channel Muscle Tester Mega ME6000 (Mega Electronics LTD, Finland) was used for collecting the EMG data, with the dedicated software Megawin 2.5 on a personal computer. The myoelectric signals were amplified (gain: ×1000; bandpass filter: 20–450 Hz; common mode rejection ratio: 95 dB), using an A/D converter (16-bit resolution) at 1000 Hz. EMG activity was recorded using bipolar surface electrodes (Arbo 24 mm). A digital trigger was used to synchronise EMG measurements and force plate. When the software of both signals was ready, the trigger was activated by pushing the 'enter' key of the laptop keyboard, sending a digital signal (1 = activated/0 = non-activated) through the A/D converter for the EMG, and to the trigger input for the force platform.

Procedure

Participants performed a pre-test consist of a double-limb stance on an unstable wooden platform affixed to the flat surface of a polyester resin hemisphere for 1 min (radius = 25 cm, free to move on the antero-posterior (AP) and mediolateral (ML) axes simultaneously and able to turn around 360° on the horizontal plane) (Fig. 1). This task was used to challenge the three groups of participants, allowing us to maximise participants' learning processes and compare their ability to adapt to this situation. The sighted participants were allowed to see the test room, and those with visual impairment were also allowed to explore the protocol set by sequential haptic information to know the distribution of the equipment before starting the data collection (Ruggiero and Iachini 2010).

Participants were asked to "stand as still as possible" (Cavanaugh et al. 2007; Duarte and Sternad 2008) using a blindfold and with their hands resting on their hips. Each data collection began when participants were relatively stable with the help of one of the researchers. After that, to analyse the effect of training, participants performed ten practice trials on a single day. Each practice trial lasted 30 s, with a 1-min rest period between trials. Then, they performed two post-tests (1 min), the first one immediately after the end of the training period and the second one after a 1-min rest, both in the same conditions as the pre-test. Finally, participants performed the same test without the blindfold and with open eyes (1 min). Participants from the reliability study only performed pre- and post-tests with closed eyes using a blindfold. All trials were performed barefoot and the feet were positioned such that the line between their heels coincided with the mediolateral axis of the platform. One of the researchers was placed in front of the participant for safety. From the fourth trial of the training period, all participants were able to maintain a standing posture without external aids. Participants were allowed to take the blindfold off between trials.

To normalize the EMG signal, the participants performed three maximal voluntary isometric contractions (MVCs) from the eight recorded muscles based on the previous study methodologies (Chen et al. 2015; Hsu et al. 2006; Rouffet and Hautier 2008). The maximal exertions were performed by reaching maximal force and maintaining it for 3–4 s. For the TA, participants were placed in a sitting position and performed a unilateral dorsiflexion at 90° of ankle position against manual resistance. For the RF, a single-knee extension in a 90° knee flexion position was performed against manual resistance. For the PL, an eversion of the foot with plantarflexion at 90° of ankle position was performed against manual resistance. Finally, for GL, a unilateral plantarflexion at 90° of ankle position was performed. For this muscle, participants were placed on an examination table to keep the ankle position fixed during each isometric effort. The examination table was equipped with padded cuffs attached to chains to provide resistance. The length of the chains was adjusted for each participant. Participants were verbally encouraged during the execution and they rested for 2 min after each maximal contraction to avoid fatigue.

Data analysis and reduction

Measures of stability

A custom software program in Labview (version 12.0f3, National Instruments, Texas, USA) was used for data analysis. Because there is a little physiological significance to COP signal frequencies above 10 Hz (Borg and Laxåback 2010), COP was first filtered using a low-pass filter (4th order, zero-phase lag, Butterworth, 5-Hz cut-off frequency) according to Lin et al. (2008), and second, COP time series were subsampled at 20 Hz. The first 5 s of each trial were discarded to avoid nonstationarity related to the start of the measurement (van Dieën et al. 2010). Since the orientation of the participant was only approximately aligned with the axes of the force platform, the resultant distance (RD, Eq. 1) was used as a global measure to quantify the performance during balance trials (Prieto et al. 1996):

$$\mathrm{RD} = \frac{\sum_{i=1}^{n}\sqrt{\left(\left(\mathrm{AP}_i - \overline{\mathrm{AP}}\right)^2 + \left(\mathrm{ML}_i - \overline{\mathrm{ML}}\right)^2\right)}}{N}. \tag{1}$$

In addition, the magnitude of mean velocity (MV) of the centre of pressure was calculated according to the following equation:

$$\mathrm{MVM} = \frac{1}{T}\sum_{i=1}^{N-1}\sqrt{\left(\left(\left(X_{i+1} - X_i\right)\right)^2 + \left(\left(Y_{i+1} - Y_i\right)\right)^2\right)}. \tag{2}$$

The RD and MV, in the pre-test, the averaged RD and MV of trials five and six (training equator), and the averaged RD and MV of the two post-tests were used for subsequent statistical analyses. The averaged RD of trials five and six was introduced in our statistical analysis, because participants were only able to maintain the standing posture without external aids from the fourth trial of the training period.

Finally, to obtain a full and comprehensive knowledge of learning effect, aids were also accounted.

Measures of EMG 3

As a pre-processing step, a 30-ms moving window root-mean-square (RMS) envelope was applied on the normalized EMG signal. (Barbado et al. 2012; Hatton et al. 2011). We selected a 30-ms time frame, because short time windows have been recommended for fast movements (Sinkjær and Arendt-Nielsen 1991), and here, the upright stance posture was controlled through intermittent stabilization bursts (fast adjustments) to produce ballistic torque impulses (Loram et al. 2005; Morasso and Sanguineti 2002). The mean of the normalized EMG amplitude was calculated across participants for each muscle and balance trial.

The amount of information from EMG data was reduced using a principal component analysis (PCA) aimed at achieving a global behaviour, reducing the time for pattern recognition (Chu et al. 2006). This analysis enables the identification of important underlying features and the relations between muscles, and also simplification of the statistical procedures (Butler et al. 2009). PCA was applied to the normalized activation mean amplitudes from eight leg muscle sites extracting the total generalized data variation for each group and for each principal pattern to provide an estimate of the relative importance of each principal component (PC) to the measured variables (Butler et al. 2009). A data matrix X [n_p] with p-variables ($p =$ eight leg muscle sites) and n-observations was constructed, and the order of the leg muscle sites was fixed and created a unique pattern: TAR, TAL, PLR, PLL, GLR, GLL, RFR, and RFL. To aid in the interpretation of each principal pattern, an example of activation amplitude patterns (see Fig. 2) corresponding to high and low scores for each PC factor was presented (Butler et al. 2009). Finally, PC scores from the pre-test, the averaged PC scores from trials five and six and

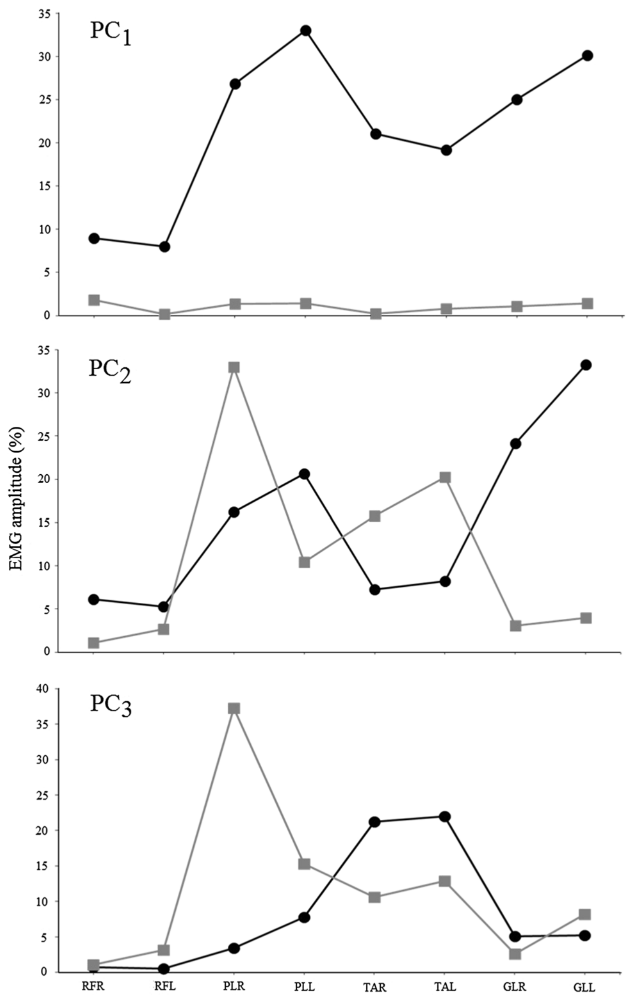


Fig. 2 Example of the EMG profile of different participants who showed higher and lower scores in principal component factors. *GL* gastrocnemius lateralis, *TA* tibialis anterior, *RF* rectus femoris, *PL* peroneus longus (PL), *R* right, *L* left

the averaged PC scores from the two post-tests were used for subsequent statistical analyses. The PCA is shown in the "Results" section.

Statistical analysis

Descriptive statistics were calculated for RD and PC scores. A mixed ANOVA was carried out for all variables with training as a within-subject factor (pre-test, averaged five and six—training equator—, averaged from both post-tests) and with group as an inter-subject factor (sighted soccer players, blind soccer players, and sedentary sighted individuals). To test differences according to visual availability, a second mixed ANOVA was performed with visual condition as a within-subject factor (with and without blindfold) and group as an inter-subject factor (SSP, BSP, and CG). A Scheffé post-hoc analysis was used for multiple comparisons. Two effect size indexes were used to assess the practical signification within and between group differences. On one hand, Partial eta-square (η_p^2) values were calculated as a measure of effect size for mean differences with the following interpretation: above 0.26, between 0.26 and 0.02, and lower than 0.02 were considered as large, medium, and small, respectively (Pierce et al. 2004). On the other hand, to calculate the effect size of post-hoc within-groups differences, Hedges' *g* index was used (Hedges and Olkin 1985). This index is based on Cohen's *d* index (Cohen 1988), but it provides an effect size estimation reducing the bias caused by small samples ($n < 20$). Interpretation of Hedge's *g* was: above 0.8, between 0.5 and 0.8, between 0.2 and 0.5, and lower than 0.2 were considered large, moderate, small, and trivial, respectively.

The intra-class correlation coefficient ($ICC_{2,1}$) and the typical error (TE) were also calculated to assess test–retest relative and absolute reliability, respectively (Hopkins 2000; Weir 2005). The ICC values were categorised as follows: excellent (0.90–1.00), high (0.70–0.89), moderate (0.50–0.69), and low (<0.50) (Fleiss 1986). TE was calculated as the standard deviation of the difference between two scores divided by $\sqrt{2}$. Thus, TE was also expressed as a percentage (%) dividing its score by the mean. Confidence interval limits for ICC and TE were calculated at 90%.

All analyses were performed using the SPSS package (version 20, SPSS Inc., Chicago, IL, USA) with a significance level chosen at $p < 0.05$.

Results

Reliability analysis of centre of pressure parameters

As shown in Table 1, RD and MV parameters of the centre of pressure showed a high-to-excellent absolute and relative reliability. MV reliability results were higher than RD ones. In addition, no differences were found between pre-test and post-test in RD and MV.

Balance performance

As can be seen in Fig. 3, overall, all groups improved their performance, obtaining low scores for the closed-eyes condition balance task after the training period in RD, VM, and Aids (RD: $F_{4,50} = 9.286$; $p < 0.001$; $\eta_p^2 = 0.271$, large; VM: $F_{4,50} = 4.006$; $p = 0.024$; $\eta_p^2 = 0.138$, medium; Aids: $F_{4,50} = 16.35$; $p < 0.001$; $\eta_p^2 = 0.397$, large). In RD, post-hoc comparisons between pre- and post-test showed medium-to-high practical effects (d_g) (SSP = 0.88, large; BSP = 0.61, medium; CG = 0.63, medium). Similar results were obtained for the aids received by the three groups

Table 1 Descriptive statistics and relative and absolute reliability of mean radial error showed during the different tasks of the sitting protocol

	Trial 1 χ± SD	Trial 2 χ± SD	*F*	*p*	*d*		
RD (mm)	46.01 ± 13.16	42.00 ± 15.14	3.040	0.115	0.29		
VM (mm/s)	133.23 ± 53.37	124.23 ± 59.09	2.291	0.123	0.16		
	TE	TE (%)	LL	UL	ICC	LL	UL
RD (mm)	5.14	11.17	3.75	8.46	0.90	0.71	0.97
VM (mm/s)	11.83	8.88	8.63	19.47	0.97	0.89	0.99

Repeated-measures ANOVA

LL lower limit of the confidence limits (80%), *UL* upper limit of the confidence limits (80%), *TE* typical error, *ICC* intra-class correlation coefficient, *d* effect size

across the training trials (SSP = 0.56, medium; BSP = 0.86, large; CG = 0.77, medium-to-large). However, the practical effects in the VM were small-to-medium (SSP = 0.42; BSP = 0.45; CG = 0.47). The ANOVA did not show differences between groups or in interaction effects. In addition, sighted individuals and the control group showed lower RD and VM scores in the balance task with open-eyes than under closed-eyes conditions (d_g = 1.75–3.54, large), but no differences were observed in blind individuals (d_g = 0.12–0.54, small-to-medium) (see Online Appendix III). Sighted individuals and the control group showed significantly lower RD and VM scores under open-eyes conditions than blind participants (RD: $F_{2,25} = 16.278$; $p < 0.001$; $\eta_p^2 = 0.566$, large; VM: $F_{2,25} = 46.398$; $p < 0.001$; $\eta_p^2 = 0.788$, large). The differences between open-eyes and closed-eyes conditions regarding the aids were not calculated because of the lack of assistance during the open-eyes condition for sighted individuals.

EMG analysis

Three principal patterns explained 84.15% of the variability in the measured data. As shown in Table 2, the first PC explained 53.96% of the total variance and represented the magnitude and shapes of the activation amplitude patterns. The second PC explained 17.41%, representing the relationship between flexor and extensor ankle muscles. The third PC explained 12.77% of the total variance and represented the relationship between supine and prone ankle muscles.

Regarding PC_1, overall all groups reduced their magnitude of the activation amplitude in the closed-eyes condition balance task after the training period ($F_{2,50} = 15.566$; $p < 0.001$; $\eta_p^2 = 0.384$, large), but post-hoc comparisons showed that only sighted soccer players (d_g = 0.72, medium-to-large) and the control group (d_g = 0.49, medium) reduced their EMG activation significantly from pre-test to post-test (Fig. 4) (see Online Appendix II). Although, the ANOVA did not show differences between groups in PC_1 values ($F_{2,50} = 2.785$; $p = 0.081$; $\eta_p^2 = 0.182$, small), and overall, SSP group had lower values of EMG activation. Both SSP and CG groups showed lower PC_1 than BSP group under open-eyes conditions ($F_{2,25} = 3.756$; $p = 0.037$; $\eta_p^2 = 0.231$, small). In addition, sighted soccer players (d_g = 1.54, large) and the control group (d_g = 1.04, large) showed lower PC_1 values in the balance task with open-eyes than under closed-eyes conditions, but no differences were observed in blind individuals (see Online Appendix IV). No significant differences for PC_2 and PC_3 were found due to the training or between groups (Fig. 4). However, SSP and CG groups showed lower PC_3 values than the BSP group under the open-eyes conditions ($F_{2,25} = 3.572$; $p = 0.043$; $\eta_p^2 = 0.221$, medium).

Discussion

This study compared the postural control during unstable standing balance tasks of high-level soccer players with severe visual impairment to sighted counterparts and sedentary individuals. All subjects performed the pre-test, training, and post-test trials under closed-eyes conditions, but finally, all participants performed one trial with open eyes. Considering that a novel protocol was chosen to maximise learning processes and facilitating the comparisons of the adaptation ability, a reliability assessment was also conducted. Our reliability results were better than those found in the previous studies (Barbado et al. 2016; Caballero et al. 2015) in both scattering and velocity variables, showing high-to-excellent scores of the absolute (TE < 11%) and relative (ICC > 0.90) reliability. These results facilitated the comparability and interpretability of the between groups differences analysis.

An important question planned in the literature is whether the compensatory adaptations made by blind individuals allow them to fully replace vision during standing balance tasks. Our main outcome showed that visually impaired individuals in the task with open eyes had worse

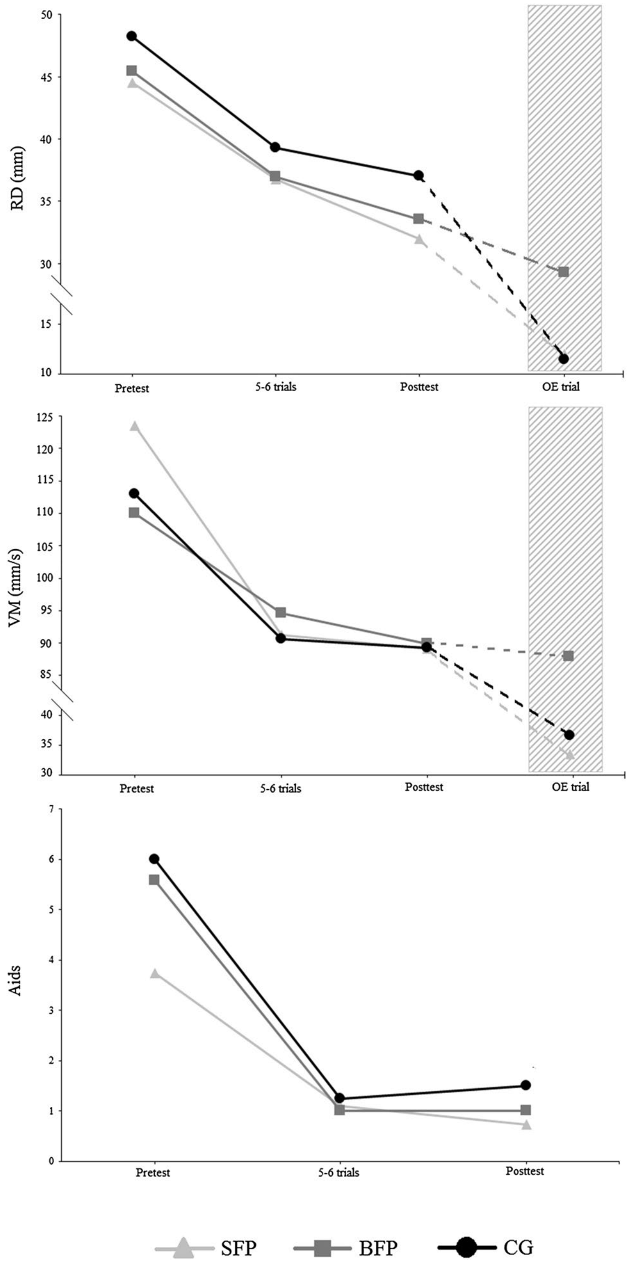


Fig. 3 Mean values of the resultant distance (RD), mean velocity (MV), and number of aids of the three groups (*SSP* sighted soccer players, *BSP* blind soccer players, *CG* control group) in each assessment (pre-test; 5–6 trials, the average score of trials five and six; post-test, the average score from two post-tests; EO trial, trial with open eyes)

balance performance than sighted individuals. Although, in a previous study, it was found that blind individuals had better balance control than their sighted counterparts, especially when postural control was hampered by surface perturbation (i.e., a foam rubber covered surface) (Pyykkö et al. 1991), our results support those previous findings showing no evidence of compensatory brain adaptations

Table 2 Principal component factors (PC) obtained from the Principal Component Analysis of EMG signal during the pre-test

Components	PC_1	PC_2	PC_3
TAR	0.663	−0.518	0.330
TAL	0.720	−0.449	0.459
PRR	0.722	−0.324	−0.600
PRL	0.751	−0.001	−0.098
GSR	0.811	0.490	0.050
GSL	0.809	0.521	0.058
RFR	0.537	0.272	0.123
RFL	0.517	0.158	0.187
% of Variance	53.96	17.42	12.77

GL gastrocnemius lateralis, *TA* tibialis anterior, *RF* rectus femoris, *PL* peroneus longus, *R* right, *L* left

in blind individuals that allow them to replace the role of vision in postural control during balance (Juodžbalienė and Muckus 2006; Schmid et al. 2007). Differences between studies could be related to the protocol used. While Pyykkö et al. (1991) assessed postural sway during bipedal stance introducing a postural perturbation using vibrators placed on calf muscles, other studies applied perturbation modifying the tilt of the support surface (Ozdemir et al. 2013), performing reaching voluntary movements (Juodžbalienė and Muckus 2006) or moving a platform continuously in the antero-posterior direction (Schmid et al. 2007). It has been found that blind individuals exhibit better ankle proprioception than sighted ones (Ozdemir et al. 2013) which would help to overcome the calf perturbations applied on the Pyykkö et al.'s study (1991). However, this better ankle proprioception would not be able to compensate visual deprivation on more challenging balance tasks which require a proper coordination of multiple joints. These findings reinforce the belief that vision plays a mandatory role in balance, allowing a proper integration and processing of other sensory inputs, and thus cannot be compensated for by the other senses (Schmid et al. 2007). The contribution of this study lies in the fact that the compensatory hypothesis has been checked by analysing high-level blind athletes who play soccer, a sport with high balance demands (Bressel et al. 2007; Gerbino et al. 2007; Paillard et al. 2006; Stølen et al. 2005). Therefore, vision does not seem to be replaced due to brain cross-modal plasticity even in an environment of high physical stimulation.

The second question was related to balance performance under closed-eyes conditions. Based on blind individuals hypothetically developing their other senses to a greater extent than sighted individuals (Goldreich and Kanics 2003; Röder et al. 1999; Yoshimura et al. 2010), it could be expected that they would show better balance performance or faster training adaptation under

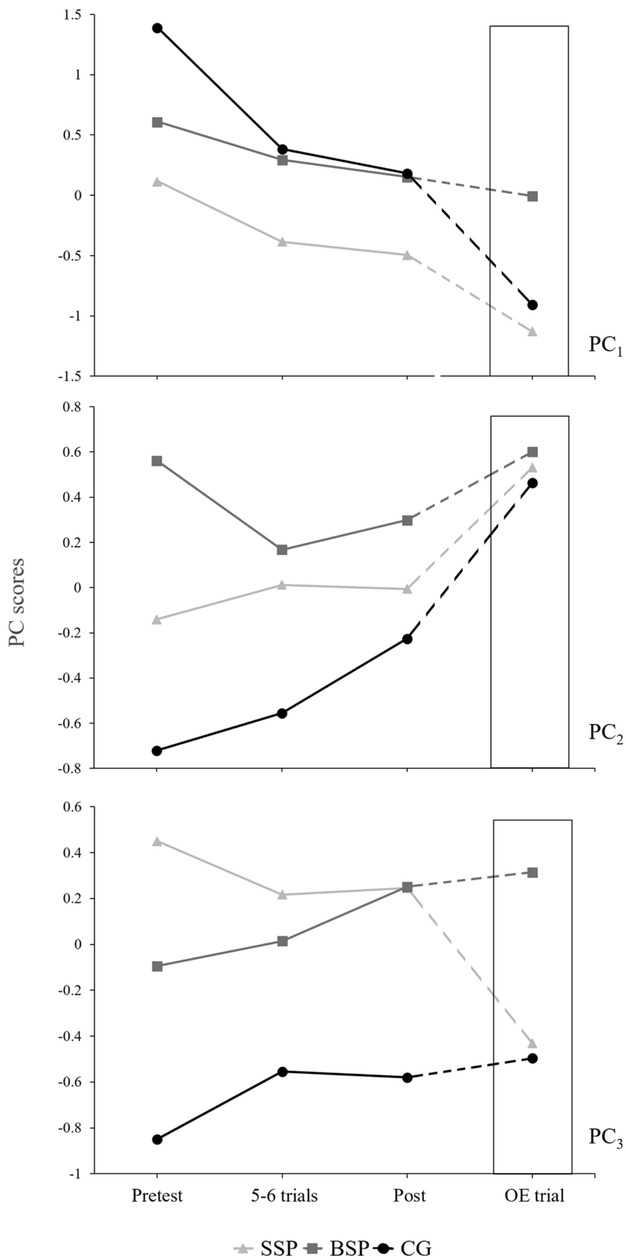


Fig. 4 Principal component scores, PC_1, PC_2, and PC_3, across assessments (pre-test; trials 5 and 6, the averaged RD from trials 5 and 6; post-test, the averaged RD from two post-tests; EO trial, trial with open eyes; SSP sighted soccer players; *CG*, sighted sedentary individuals, *BSP* blind soccer players)

closed-eyes conditions. This might also be supported by the fact that 87.5% of BSP participants are blind from birth. However, some authors have stated that vision is fundamental for the calibration of the other senses even if vision is not available during a task performance (Pascual-Leone et al. 2005; Rauschecker 1995). The general-loss hypothesis suggests that prolonged deprivation of vision is harmful to integration of the other sensory inputs (Pascual-Leone et al. 2005), and it could also be expected that blind individuals would show worse balance performance than sighted individuals. However, no differences between groups were found in balance performance either before or after training, and the results of this study cannot support either the compensatory or the general-loss hypothesis. In spite of our interpretations, it must be pointed out as a limitation that no differences in balance performance were found between sighted soccer players and sedentary individuals either, but soccer expertise does not seem to improve balance performance on an non-common balance task on an unstable surface. Considering that our unstable balance task was quite different from the participants' daily workout, our results suggest that specific balance adaptation caused by sport practice cannot easily be revealed by a non-specific balance test. Future studies should evaluate a compensatory hypothesis in postural control using a balance test more closely related to participants' physical activity or daily life activities.

In this study, we assessed EMG patterns using PCA (Butler et al. 2009) to evaluate whether blind individuals develop different neuromuscular strategies to accomplish the required balance task. PCA showed three neuromuscular patterns reflecting the prominent features of the EMG. Only PC_1 showed significant differences within and between groups. PC_1 meant the general magnitude and shapes of the activation amplitude patterns with higher participation of ankle muscles than knee muscles. Therefore, within-group changes mean a reduction of muscle co-activation. These results confirmed the previous findings that showed a reduction of muscle co-contraction after training (Freyler et al. 2014). Regarding between groups differences, blind individuals showed higher muscular activation than sighted individuals under open-eyes conditions. These results support the previous finding on gait showing that blind individuals have higher muscular co-activation than sighted ones, which has been related to safety strategy to avoid falls (Carpenter et al. 1999). However, under the closed-eyes conditions, sedentary individuals had higher EMG amplitude than the other groups in the pre-test. Higher EMG amplitude would be related to higher energy expenditure and, therefore, less efficiency in accomplishing the given task. Sighted and blind soccer players showed an earlier adaptation to a new balance task, but our experimental design did not allow us to discriminate as to whether this was caused by the prolonged deprivation of visual input or by the sport (i.e., soccer) practice. In addition, it is important to point out that after the intra-session instability, the sedentary group achieved similar muscular activation. This quick adaptation after training in sighted but sedentary individuals seems to support the view that vision is so important for balance that even if vision is not available during a task performance, it will enable individuals to make faster improvement (Pascual-Leone et al. 2005; Rauschecker 1995).

In addition, we did not find differences between groups in the flexor and extensor ankle muscles relationship (PC_2) and the supine and prone ankle muscles relationship (PC_3) either under closed- or open-eyes conditions. These results suggest that ankle extensor/flexor or supinator/pronator muscle predominance could be more closely related to individual strategies to accomplish the task according to the body position (higher weight over heels or over toes or left or right) rather than balance performance (Carpenter et al. 2001). However, under open-eyes conditions, sighted individuals (SSG and CG) reduced their PC_3 scores compared to closed-eyes conditions. That is, tibialis anterior reduced their activation when visual feedback was available. Although it not clear that pronated or supinated foot postures have an effect on balance control, a study by Cote et al. (2005) demonstrated that individuals with supinated foot posture have better static balance than those with pronated foot posture. Under this perspective, supinator foot behaviour under more challenging conditions as those used in our study would relate to a more efficient foot behaviour to keep the balance. These results would be in line with those observed from walking, where an increased tibialis anterior activation during one leg stance phase in individuals with ankle instability was found (Louwerens et al. 1995), which has been interpreted as a safety behaviour to increase balance.

In conclusion, our findings may suggest that brain plasticity is not able to fully compensate for balance deterioration caused by prolonged visual deprivation even in highly experienced blind athletes who practice a sport with high demands on balance control. In addition, the theoretical improvement of the other senses caused by visual deprivation does not enable blind individuals to obtain better balance than sighted individuals under closed-eyes conditions, reinforcing the prominent role of vision in integrating and processing the other sensory inputs. Finally, blind individuals seem to increase their muscular co-activation as a safety strategy, but this behaviour is not different to that shown by sighted people under closed-eyes conditions.

References

Anand V, Buckley JG, Scally A, Elliott DB (2003) Postural stability changes in the elderly with cataract simulation and refractive blur. Invest Ophthalmol Vis Sci 44(11):4670–4675

Barbado D, Sabido R, Vera-Garcia FJ, Gusi N, Moreno FJ (2012) Effect of increasing difficulty in standing balance tasks with visual feedback on postural sway and EMG: complexity and performance. Hum Mov Sci 31:1224–1237

Barbado D, Moreside J, Vera-Garcia FJ (2016) Reliability and repetition effect of the center of pressure and kinematics parameters that characterize trunk postural control during unstable sitting test. PM&R. doi:10.1016/j.pmrj.2016.08.029

Bavelier D, Neville HJ (2002) Cross-modal plasticity: where and how? Nat Rev Neurosci 3:443–452

Black AA, Wood JM, Lovie-Kitchin JE, Newman BM (2008) Visual impairment and postural sway among older adults with glaucoma. Optom Vis Science 85:489–497

Borg FG, Laxåback G (2010) Entropy of balance – some recent results. J Neuroeng Rehabil 7(1):38–49

Bressel E, Yonker JC, Kras J, Heath EM (2007) Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. J Athl Train 42(1):42–46

Butler HL, Hubley-Kozey CL, Kozey JW (2009) Electromyographic assessment of trunk muscle activation amplitudes during a simulated lifting task using pattern recognition techniques. J Electromyogr Kinesiol 19:505–512

Caballero C, Barbado D, Moreno FJ (2015) What COP and kinematic parameters better characterize postural control in standing balance tasks? J Mot Behav 47(6):550–562

Carpenter MG, Frank JS, Silcher CP (1999) Surface height effects on postural control: a hypothesis for a stiffness strategy for stance. J Vestib Res 9:277–286

Carpenter MG, Frank JS, Silcher CP, Peysar GW (2001) The influence of postural threat on the control of upright stance. Exp Brain Res 138:210–218

Cavanaugh JT, Mercer VS, Stergiou N (2007) Approximate entropy detects the effect of a secondary cognitive task on postural control in healthy young adults: a methodological report. J Neuroeng Rehabil 4(1):42–49

Chen C-C, Lin S-Y (2011) The impact of rope jumping exercise on physical fitness of visually impaired students. Res Dev Disabil 32:25–29

Chen J, Jack R, Appelle J, Bushuk M, Smith C (2015) Surface electromyographic study of peroneus longus activation during ankle eversion and heel lift. Open J Ther Rehabil 3(03):101–108

Choy NL, Brauer S, Nitz J (2003) Changes in postural stability in women aged 20 to 80 years. J Gerontol Ser A Biol Sci Med Sci 58(6):525–530

Chu J-U, Moon I, Mun M-S (2006) A real-time EMG pattern recognition system based on linear-nonlinear feature projection for a multifunction myoelectric hand. IEEE Trans Biomed Eng 53:2232–2239

Cohen J (1988) Statistical power analysis for the behavioral sciences. Lawrence Erlbaum Associates, Hillsdale

Cohen LG et al (1997) Functional relevance of cross-modal plasticity in blind humans. Nature 389:180–183

Cote KP, Brunet ME II, Gansneder BM, Shultz SJ (2005) Effects of pronated and supinated foot postures on static and dynamic postural stability. J Athl Train 40(1):41–46

De Salvia L (2012) IBSA Classification rules and procedures. http://www.ibsasport.org/documents/files/68-1-IBSA-Classification-Rules-and-Procedures.pdf. Accessed 20 Apr 2016

Duarte M, Sternad D (2008) Complexity of human postural control in young and older adults during prolonged standing. Exp Brain Res 191:265–276

Fleiss JL (1986) Analysis of data from multiclinic trials. Control Clin Trials 7(4):267–275

Freyler K, Weltin E, Gollhofer A, Ritzmann R (2014) Improved postural control in response to a 4-week balance training with partially unloaded bodyweight. Gait Posture 40(2):291–296

Gerbino PG, Griffin ED, Zurakowski D (2007) Comparison of standing balance between female collegiate dancers and soccer players. Gait Posture 26:501–507

Giagazoglou P, Amiridis IG, Zafeiridis A, Thimara M, Kouvelioti V, Kellis E (2009) Static balance control and lower limb strength in blind and sighted women. Eur J Appl Physiol 107:571–579

Goldreich D, Kanics IM (2003) Tactile acuity is enhanced in blindness. J Neurosci 23:3439–3445

Gougoux F, Lepore F, Lassonde M, Voss P, Zatorre RJ, Belin P (2004) Neuropsychology: pitch discrimination in the early blind. Nature 430:309–309

Hallemans A, Ortibus E, Meire F, Aerts P (2010) Low vision affects dynamic stability of gait. Gait Posture 32:547–551

Hallemans A, Ortibus E, Truijen S, Meire F (2011) Development of independent locomotion in children with a severe visual impairment. Res Dev Disabil 32:2069–2074

Hatton AL, Dixon J, Rome K, Martin D (2011) Standing on textured surfaces: effects on standing balance in healthy older adults. Age Ageing 40(3):363–368

Hedges LV, Olkin I (1985) Statistical methods for meta-analysis. Academic, San Diego

Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G (2000) Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 10:361–374

Hopkins WG (2000) Measures of reliability in sports medicine and science. Sports Med 30(1):1–15

Houwen S, Visscher C, Lemmink K, Hartman E (2008) Motor skill performance of school-age children with visual impairments. Dev Med Child Neurol 50:139–145

Hsu WL, Krishnamoorthy V, Scholz JP (2006) An alternative test of electromyographic normalization in patients. Muscle Nerve 33(2):232–241

Hsu WL, Scholz JP, Schöner G, Jeka JJ, Kiemel T (2007) Control and estimation of posture during quiet stance depends on multijoint coordination. J Neurophysiol 97:3024–3035

Ivers RQ, Norton R, Cumming RG, Butler M, Campbell AJ (2000) Visual impairment and hip fracture. Am J Epidemiol 152:633–639

Juodžbalienė V, Muckus K (2006) The influence of the degree of visual impairment on psychomotor reaction and equilibrium maintenance of adolescents. Medicina (Kaunas) 42:49–56

Kozub FM, Oh H-K (2004) An exploratory study of physical activity levels in children and adolescents with visual impairments. Clin Kinesiol J Am Kinesiother Assoc 58:1–8

Lieberman L, McHugh E (2001) Health-related fitness of children who are visually impaired. J Vis Impair Blind 95(05):272–287

Lieberman LJ, Robinson BL, Rollheiser H (2006) Youth with visual impairments: Experiences in general physical education. RE View 38(1):35

Lin D, Seol H, Nussbaum MA, Madigan ML (2008) Reliability of COP-based postural sway measures and age-related differences. Gait Posture 28:337–342

Longrnuir PE, Bar-Or O (2000) Factors influencing the physical activity levels of youths with physical and sensory disabilities. Adapt Phys Activ Q 17:40–53

Loram ID, Maganaris CN, Lakie M (2005) Human postural sway results from frequent, ballistic bias impulses by soleus and gastrocnemius. J Physiol 564:295–311

Lord SR, Menz HB (2000) Visual contributions to postural stability in older adults. Gerontology 46:306–310

Louwerens JWK, Linge BV, de Klerk LW, Mulder PG, Snijders CJ (1995) Peroneus longus and tibialis anterior muscle activity in the stance phase: a quantified electromyographic study of 10 controls and 25 patients with chronic ankle instability. Acta Orthop Scand 66(6):517–523

Morasso PG, Sanguineti V (2002) Ankle muscle stiffness alone cannot stabilize balance during quiet standing. J Neurophysiol 88:2157–2162

Ozdemir RA, Pourmoghaddam A, Paloski WH (2013) Sensorimotor posture control in the blind: Superior ankle proprioceptive acuity does not compensate for vision loss. Gait Posture 38(4):603–608

Paillard T, Noe F, Riviere T, Marion V, Montoya R, Dupui P (2006) Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. J Athl Train 41:172–176

Papadopoulos K, Metsiou K, Agaliotis I (2011) Adaptive behavior of children and adolescents with visual impairments. Res Dev Disabil 32:1086–1096

Pascual-Leone A, Amedi A, Fregni F, Merabet LB (2005) The plastic human brain cortex. Annu Rev Neurosci 28:377–401

Piao YJ, Yu M, Kim YY, Kwon TK, Hong C-U, Kim NG (2006) Experimental studies on the training of postural control using an unstable platform. In: 2005 IEEE Engineering in Medicine and Biology Society. 27th Annual Conference, pp 2551–2554

Pierce CA, Block RA, Aguinis H (2004) Cautionary note on reporting eta-squared values from multifactor ANOVA designs. Educ Psychol Measur 64:916–924

Ponchillia P, Ponchillia S, Strause B (2002) Athletes with visual impairments: attributes and sports participation. J Vis Impair Blind 96(4):267–272

Ponchillia P, Armbruster J, Wiebold J (2005) The national sports education camps project: introducing sports skills to students with visual impairments through short-term specialized instruction. J Vis Impair Blind 99(11):587–598

Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM (1996) Measures of postural steadiness: differences between healthy young and elderly adults. IEEE Trans Biomed Eng 43:956–966

Pyykkö I, Vesikivi M, Ishizaki H, Magnusson M, Juhola M (1991) Postural control in blinds and in usher's syndrome. Acta Otolaryngol 111:603–606

Rauschecker JP (1995) Compensatory plasticity and sensory substitution in the cerebral cortex. Trends Neurosci 18:36–43

Ray CT, Wolf SL (2008) Review of intrinsic factors related to fall risk in individuals with visual impairments. J Rehabil Res Dev 45:1117–1124

Reimer A, Cox R, Nijhuis-Van der Sanden M, Boonstra F (2011) Improvement of fine motor skills in children with visual impairment: an explorative study. Res Dev Disabil 32:1924–1933

Riley M, Wong S, Mitra S, Turvey M (1997) Common effects of touch and vision on postural parameters. Exp Brain Res 117:165–170

Röder B, Rösler F, Neville HJ (1999) Effects of interstimulus interval on auditory event-related potentials in congenitally blind and normally sighted humans. Neurosci Lett 264:53–56

Rouffet DM, Hautier CA (2008) EMG normalization to study muscle activation in cycling. J Electromyogr Kinesiol 18(5):866–878

Ruggiero G, Iachini T (2010) The role of vision in the Corsi Block-Tapping task: Evidence from blind and sighted people. Neuropsychology 24(5):674–679

Schieppati M, Tacchini E, Nardone A, Tarantola J, Corna S (1999) Subjective perception of body sway. J Neurol Neurosurg Psychiatry 66:313–322

Schmid M, Nardone A, De Nunzio AM, Schmid M, Schieppati M (2007) Equilibrium during static and dynamic tasks in blind subjects: no evidence of cross-modal plasticity. Brain 130:2097–2107

Schwesig R, Goldich Y, Hahn A, Müller A, Kohen-Raz R, Kluttig A, Morad Y (2010) Postural control in subjects with visual impairment. Eur J Ophthalmol 21:303–309

Shabana N, Cornilleau-Pérès V, Droulez J, Goh JC, Lee GS, Chew PT (2005) Postural stability in primary open angle glaucoma. Clin Exp Ophthalmol 33:264–273

Sinkjær T, Arendt-Nielsen L (1991) Knee stability and muscle coordination in patients with anterior cruciate ligament injuries: an electromyographic approach. J Electromyogr Kinesiol 1:209–217

Soong GP, Lovie-Kitchin JE, Brown B (2001) Does mobility performance of visually impaired adults improve immediately after orientation and mobility training? Optometr Vis Sci 78:657–666

Stølen T, Chamari K, Castagna C, Wisløff U (2005) Physiology of soccer. Sports Med 35:501–536

Théoret H, Merabet L, Pascual-Leone A (2004) Behavioral and neuroplastic changes in the blind: evidence for functionally relevant cross-modal interactions. J Physiol Paris 98:221–233

Tomomitsu MS, Alonso AC, Morimoto E, Bobbio TG, Greve J (2013) Static and dynamic postural control in low-vision and normal-vision adults. Clinics 68:517–521

van Boven RW, Hamilton RH, Kauffman T, Keenan JP, Pascual-Leone A (2000) Tactile spatial resolution in blind Braille readers. Neurology 54:2230–2236

van Dieën JH, Koppes LLJ, Twisk JWR (2010) Postural sway parameters in seated balancing: their reliability and relationship with balancing performance. Gait Posture 31:42–46

Voss P, Lassonde M, Gougoux F, Fortin M, Guillemot JP, Lepore F (2004) Early-and late-onset blind individuals show supra-normal auditory abilities in far-space. Curr Biol 14:1734–1738

Wang MY et al (2012) Activity limitation due to a fear of falling in older adults with eye disease. Investig Ophthalmol Vis Sci 53:7967–7972

Weir JP (2005) Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. J Strength Cond Res 19(1):231–240

Wood JM, Lacherez P, Black AA, Cole MH, Boon MY, Kerr GK (2011) Risk of falls, injurious falls, and other injuries resulting from visual impairment among older adults with age-related macular degeneration. Investig Ophthalmol Vis Sci 52:5088–5092

Yoshimura A, Matsugi A, Esaki Y, Nakagaki K, Hiraoka K (2010) Blind humans rely on muscle sense more than normally sighted humans for guiding goal-directed movement. Neurosci Lett 471:171–174