Exp Brain Res (2008) 188:353–361
DOI 10.1007/s00221-008-1370-4

RESEARCH ARTICLE

Influence of enhanced visual feedback on postural control and spinal reflex modulation during stance

Wolfgang Taube · Christian Leukel · Albert Gollhofer

Received: 31 July 2007 / Accepted: 1 April 2008 / Published online: 18 April 2008

Abstract The present study assessed the influence of visual feedback on stance stability and soleus H-reflex excitability. The centre of pressure (COP) displacement was measured in upright stance on a rigid surface (stable surface) and on a spinning top (unstable surface) while subjects either received "normal" visual feedback (without laser pointer = WLP) or pointed with a laser pointer on a target on the wall (LP). In order to verify that laser pointing influenced visual feedback, two additional experiments were conducted: (1) Subjects performed a finger reaction task which was thought to increase attention and cognitive demands without alteration of the visual feedback. (2) The effect of laser pointing on the wall was compared with pointing at a board, which was attached to the subjects themselves. In this case, the laser point could not serve as a reference for sway because the board moved in synchrony with the body. On stable and unstable surface, COP displacement was reduced in the LP compared to the WLP task (-17 cm $\pm$ 6, $P < 0.05$; -14 cm $\pm$ 6, $P < 0.05$). Conversely, H-reflexes were greater in the LP condition (stable: +20 μV $\pm$ 30, not significant; unstable +115 μV $\pm$ 40, $P < 0.05$). Stance stability and H-reflex modulation were negatively correlated ($R^2 = -0.5$; $P < 0.001$). The finger reaction task did neither influence COP displacement nor H-reflexes. Pointing at the body-fixed target did not alter COP displacement. These findings suggest that postural sway can be reduced by a handheld laser pointer targeting on an external reference point. It is argued that altered visual input was responsible for modulating the H-reflex.

W. Taube (✉) · C. Leukel · A. Gollhofer
Department of Sport Science, University of Freiburg,
Schwarzwaldstr. 175, 79117 Freiburg i.Br., Germany
e-mail: wolfgang.taube@sport.uni-freiburg.de

Introduction

The role of vision in modulating spinal reflexes has received little attention. This is surprising as the interaction between the visual system and the spinal reflex behaviour may have great relevance for postural control. It is well established that the control of upright posture depends not only on sensory information from proprioceptive (Fitzpatrick and McCloskey 1994), vestibular (Nashner et al. 1989) and cutaneous (Kavounoudias et al. 2001; Meyer et al. 2004) sources but also on the visual feedback (Buchanan and Horak 1999; Duarte and Zatsiorsky 2002). For example it was shown that sway increased when the visual field was restricted or visual motion feedback was deprived (Hafstrom et al. 2002). Similarly, motion of the visual scene evokes postural responses (Guerraz et al. 2001; Mergner et al. 2005). It is known that visual, somatosensory and vestibular information is passed on to the cerebellum which in turn may use this input to adapt postural control (Brodal 1981). The close interaction of the afferent inputs makes it difficult to determine the relative contribution of each system. Potentially, all the abovementioned sources could affect motor output by gating the spinal reflex circuit.

Regarding upright stance, previous studies showed that the soleus H-reflex is functionally modulated dependent on the standing condition: Whenever stance support was diminished and thus, task complexity increased, the H-reflex amplitude decreased (Trimble and Koceja 2001; Chalmers and Knutzen 2002). Conversely, additional mechanical stance support decreased task complexity and enhanced spinal excitability (Katz et al. 1988; Trimble 1998). Concerning the visual system, it was demonstrated that H-reflexes in the soleus muscle were reduced when subjects closed their eyes (Hoffman and Koceja 1995;

Earles et al. 2000). In both studies, the influence of vision on the spinal reflex system was evaluated while subjects stood in bipedal stance on (i) a stable surface and (ii) an unstable surface (foam surface and mini-trampoline, respectively). As a common finding, occluded vision increased postural sway and reduced the gain of the soleus H-reflex (Hoffman and Koceja 1995; Earles et al. 2000). The interaction of the H-reflex modulation and the change of visual input fit well with the common finding of reduced spinal excitability when postural demands are enhanced. The aim of the present study was to clarify, whether the opposite is also true. Based on the abovementioned studies it was hypothesized that enhanced visual feedback would provide an opportunity to reduce postural sway and probably interact with the spinal reflex system in terms of a facilitated Ia-afferent transmission. To test this assumption, the centre of pressure (COP) displacement and the soleus H-reflex were recorded during stance with normal vision and while subjects received "enhanced" visual feedback by means of a handheld laser pointer which was directed on a wall in front of them. The effect of this "enhanced visual feedback" was assessed while subjects stood on two different surfaces (a) on solid ground and (b) on a spinning top. In two amendatory experiments, it was ensured that the effect of laser pointing was in fact due to an altered visual feedback and not caused by changes in the level of concentration and/or arousal.

Materials and methods

Twenty-two subjects (mean 25.05 ± 2.56 years) volunteered to participate in this study. None of the subjects had neurological or orthopaedic disorders. Before testing, all subjects were informed and gave written consent to the experimental procedure. The experiments were run in accordance with the Declaration of Helsinki and approved by the local ethics committee.

EMG and force recordings

EMG was recorded from the right soleus (SOL) and tibialis anterior (TA) muscle. After preparation, bipolar surface electrodes (Hellige®, diameter 10 mm, centre to centre distance 25 mm) were attached to the skin. The reference electrode was placed on the patella pole. The EMG signals were amplified (1000×), bandpass-filtered (10 – 1,000 Hz) and sampled at 4 kHz. All measurements took place on a force plate (GKS 1000®, IMM Holding GmbH) with a sampling frequency of 40 Hz in order to assess the centre of pressure (COP) displacement.

Peripheral nerve stimulation

H-reflexes were elicited with an electrical stimulator (Digitimer®, DS 7) in the right SOL muscle by stimulating the posterior tibial nerve with square-wave pulses of 1 ms duration. The anode, a 10×5 cm dispersal pad, was fixed on the anterior aspect of the knee just underneath the patella. The cathode (2 cm in diameter) was placed in the popliteal fossa and moved stepwise until the best position for eliciting an H-reflex was found. Care was taken that the stimulation did not activate the TA muscle. H/M recruitment curves were recorded during upright stance. As the sensitivity of the H-reflex to facilitation and inhibition varies with respect to the size of the control H-reflex, the stimulation intensity was adjusted to elicit H-reflexes with the size of 20% of M_{max} (Crone et al. 1990). This ensured that the same portion of the motor pool was activated in each subject. In all cases, this resulted in an H-reflex being on the ascending slope of the H-reflex recruitment curve. When present, the M-wave that accompanied the H-reflex was used to ensure that the posterior tibial nerve was stimulated with the same stimulation intensity throughout the experiment.

Experimental procedure

Three different protocols were carried out in this study. In the main protocol (Protocol 1), the influence of altered visual feedback on spinal reflex modulation was tested in two different support conditions: (a) on a stable rigid surface (stable surface) and (b) on a spinning top (unstable surface). The commercially available spinning top was 40 cm in diameter and had a height of 9 cm. Protocol 2 and 3 were conducted as "test protocols" to ensure that the observed modulations in Protocol 1 were due to an altered visual feedback. Protocol 2 was accomplished to exclude the possibility that simply the execution of a second motor task (i.e. the performance of laser pointing) would alter the standing behaviour. Therefore, laser pointing was replaced by finger tapping, which did not alter visual feedback, but was assumed to require also an enhanced level of alertness and motor action compared to standing without any additional task. Protocol 3 compared the influence of laser pointing on a rigid wall (external reference system) with laser pointing on a movable blackboard which was attached to the subject's body (body-fixed reference system; Fig. 1). This experiment aimed to ensure that visual feedback and not the level of concentration or task complexity accounted for alterations in Protocol 1. All trials lasted 60 seconds while subjects stood in a defined position (upright stance, head straight, knees extended and heel centres 15 cm apart). Subjects rested for 2 min after each trial in order to avoid fatigue. Prior to the actual experiment, each subject

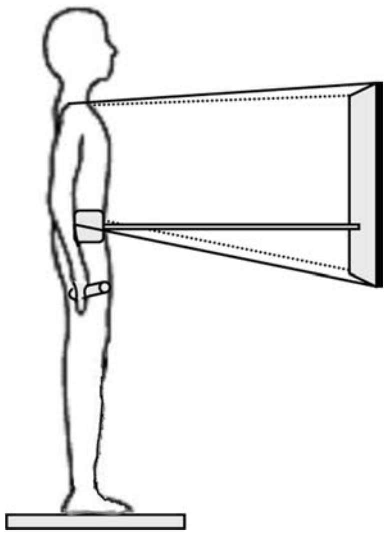

Fig. 1 In Protocol 3, subjects carried a movable blackboard. The influence of laser pointing was evaluated while subjects either pointed at the body-fixed board, at a target fixed to a rigid wall or did not point at all. It was hypothesised that pointing at the body-fixed board would not provide "enhanced visual feedback" as the board moved in parallel with the body

performed three trials on the spinning top to get accustomed to the unstable support surface.

Protocol 1—laser pointing

This protocol was tested on 12 subjects (9 males/3 females). In the laser pointer condition (LP), subjects stood barefoot with their left hand fixed at their hip while holding a laser pointer in their right hand. The right hand was positioned close to the iliac crest. The laser pointer was aimed at a target, which was fixed at a wall 2.5 m in front of them. Subjects had to trace a circled line as accurately as possible with the laser pointer by moving their wrists. During pointing, H-reflexes were randomly elicited with interstimulus intervals ranging from 5 to 7 s. In the "without laser pointer" condition (WLP) subjects stood in the same way as in the LP condition, i.e. facing the circled line but did not point. Both conditions (LP and WLP) were tested twice on a rigid surface (force plate) and on an unstable spinning top placed on top of the force plate. The order of the conditions was randomly altered. Each condition lasted 120 s (two times 60 s with a two minutes break in between) in which 20 H-reflexes were recorded.

Protocol 2—finger tapping

Protocol 2 was carried out on the same subjects and the same experimental setup like in Protocol 1. Instead of aiming with a laser pointer, subjects had to perform a reaction finger tapping task. The fingertips of their right hands were marked with different colours (blue, red, yellow and green). Dependent on the colour which was displayed on a computer screen, subjects had to use the finger labelled in the same colour to press a button. The button was held in the left hand to ensure that subjects would not receive additional support by touching a stable object. Subjects were not allowed to look down at their fingers to avoid changes in their visual perception. H-reflex amplitudes and the COP were recorded while subjects stood on the spinning top either performing the finger tapping task or standing there without executing an additional task.

Protocol 3—body-fixed target

Protocol 3 was tested on 10 people (7 males/3 females). A board (450 g; 30 × 40 cm) was fixed to the subjects' bodies (see Fig. 1). All subjects carried the movable board during the entire experiment. Like in Protocol 1, a line was presented on the board, which had to be followed with the laser pointer. In contrast to Protocol 1, the body-fixed board shifted in synchrony with the subject's body movements. The COP was recorded while people stood on the unstable spinning top and either (i) aimed with the laser pointer at the body-fixed target, (ii) aimed at the rigid target on the wall (iii) or stood there without pointing.

Data analysis

For each subject, the COP displacement was determined in every standing condition. COP was calculated every 25 ms and the overall COP displacement in medial–lateral and anterior–posterior direction was assessed. To quantify changes in the excitability of the SOL H-reflex across conditions, peak to peak amplitudes of the 20 H-reflexes were measured and the mean was calculated for each condition. The background EMG of the TA and the SOL muscle was expressed as a root-mean square (RMS) value in a 200 ms time interval prior to the stimulation. RMS values were also calculated 20 ms around the peak of the M-wave.

Statistics

Differences in the COP displacement in the four conditions of Protocol 1 were analysed with a repeated measures ANOVA [2 (stance condition: stable vs. unstable) × 2 (visual feedback: laser pointer vs. WLP)]. Changes in the H-reflex behaviour were analysed in the same way [2 (stance condition) × 2 (visual feedback)]. Where significant interactions were found, a Bonferroni corrected paired Student's *t*-test was performed for pair-wise comparisons. Correlation between H-reflex modulation and changes in the COP displacement was determined using the Pearson correlation coefficient. The effect of finger tapping on stance stability and reflex behaviour (Protocol 2) was assessed by Bonferroni corrected paired Student's *t*-tests. COP displacements during laser pointing at the rigid target, at the body-fixed target and without the use of the laser pointer (Protocol 3) were compared in the same way. SPSS 15.0 software was used for statistical analysis. Data are presented as group mean values ± SE of the mean (SEM), if not indicated differently.

Results

Protocol 1—laser pointing

Protocol 1 revealed that the COP displacement was influenced by changes in the support surface (stable vs. unstable; $F_{1,11} = 29.011$; $P < 0.001$; Fig. 2) as well as by alterations in the visual feedback (LP vs. WLP; $F_{1,11} = 14.317$; $P < 0.01$). The effective sway velocity was consequently reduced in the same way, as less sway occurred during the same period of time ($v = s/t$; v = sway velocity; s = COP displacement; t = time).

The excitability of the H-reflex was also dependent on the stance condition ($F_{1,11} = 5.366$; $P < 0.05$) and the amount of visual feedback ($F_{1,11} = 5.071$; $P < 0.05$) with an interaction of these two factors (ANOVA "standing condition" × "visual feedback" $F_{1,11} = 9.121$; $P = 0.01$). The effect of the laser pointer upon the COP displacement was similarly pronounced in the stable surface condition (LP vs. WLP, $P < 0.05$) and in the unstable surface condition (LP vs. WLP, $P < 0.05$; Fig. 2). The H-reflex on the other hand was most strongly modulated in the unstable surface condition (LP vs. WLP, $P < 0.05$; changes on the stable surface were not significant, $P = 0.51$). In general, there was a moderate negative correlation of the COP displacement and changes in the H-reflex amplitude ($R^2 = -0.5$; $P < 0.001$).

Protocol 2—finger tapping

The COP displacement was the same if subjects stood on the spinning top and performed the finger tapping task or if they did not execute a secondary task (186 cm ± 16 vs. 185 cm ± 13, $P = 0.94$). Likewise, the H-reflex was not

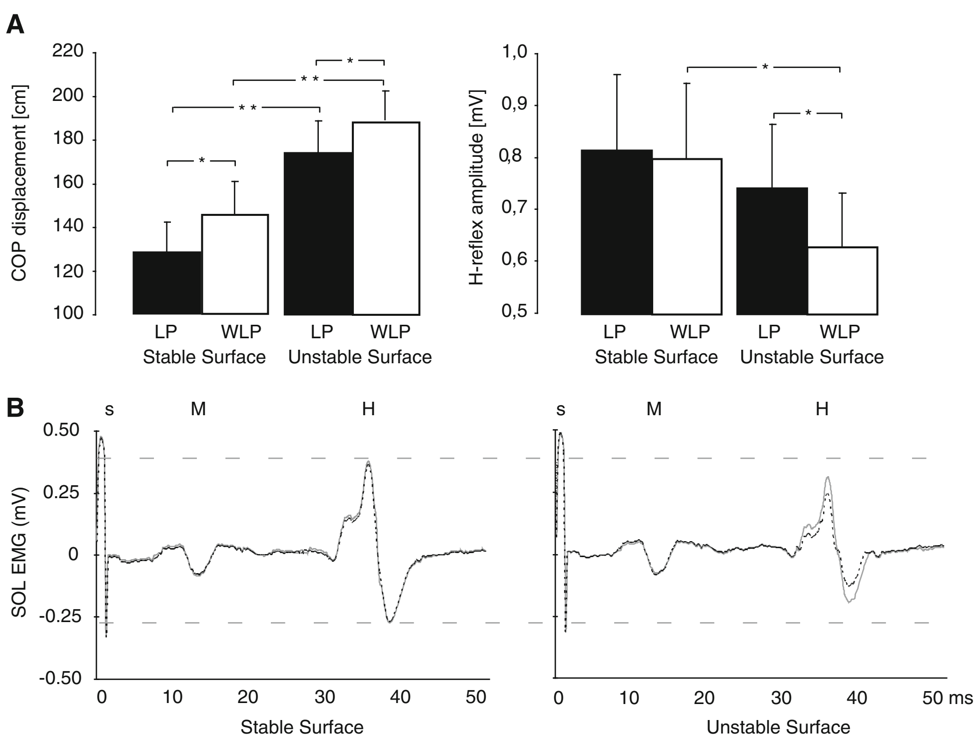

Fig. 2 The centre of pressure (COP) displacement and the H-reflex amplitude are displayed during different standing conditions (**a**). Laser pointing (LP) significantly reduced the sway path on both, stable and unstable surface ($P < 0.05$*; $P < 0.01$**). Conversely, the H-reflex was enhanced in the unstable surface condition when subjects were allowed to point with the laser. On the unstable surface, sway path was generally greater and accompanied by significantly reduced H-reflex amplitudes in the task without laser pointer (WLP). There was a significant negative correlation between modulation of the COP displacement and the H-reflex, i.e. the greater the sway path the smaller was the H-reflex ($R^2 = -0.5$; $P < 0.001$). In **b**, the influence of laser pointing on the H-reflex (average of 20 H-reflexes) is illustrated on the stable and unstable surface in a single subject. The *grey solid line* represents data with the usage of the laser pointer, the *black dotted line* without it. Laser pointing enhanced the H-reflex (H) amplitude solely in the unstable surface condition. The M-wave (M) did not change in any condition, indicating comparable stimulation intensities. *s* stimulus artefact

influenced by the finger tapping task as indicated by similar H-reflex amplitudes in the two tasks (finger tapping 0.74 mV ± 0.1; normal stance 0.71 mV ± 0.1, $P = 0.49$).

Protocol 3—body-fixed target

Compared to stance without laser pointing, the COP displacement was solely reduced when subjects pointed with the laser pointer on the target fixed to the wall ($P < 0.05$) whereas there was no significant effect when they pointed at the body-fixed target ($P = 0.09$; Fig. 3).

M-wave and background EMG activity

In six subjects, M-waves were present in the SOL muscle when the H-reflex was adjusted to 20% of M_{max}. The M-wave remained constant for all conditions (Fig. 4). This indicated comparable stimulation intensity in all tested tasks. The background EMG for the SOL muscle was similar in all conditions. The TA activity remained unchanged, too as did the ratio of SOL and TA EMG activity (Fig. 5).

Discussion

The effect of laser pointing on postural sway

The first main finding of this study was the strong influence of a hand-held laser pointer on postural sway. On the stable surface as well as on the unstable surface, laser pointing considerably reduced the amount of COP displacement and consequently the velocity of sway, too. As subjects with pathological postural control deficits often demonstrate increased postural sway (Shumway-Cook et al. 1988; Dickstein and Abulaffio 2000; Maurer et al. 2004), the reduction in sway path may be interpreted in terms of an improved postural stability. In favour of this speak own unpublished observations that were obtained in elderly people. When stance complexity was high (standing on the spinning top) some subjects could only maintain their balance with the help of the laser pointer. However, the reduced postural sway observed in the present study may not necessarily indicate improved postural control. For instance, patients with Parkinson's disease demonstrated similar or even reduced sway of COP in comparison to healthy control subjects when tested in upright stance on

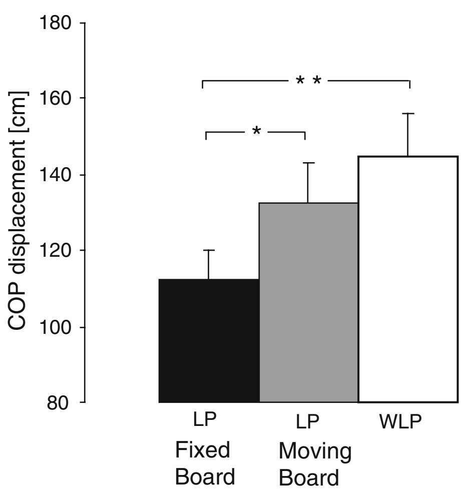

Fig. 3 Illustration of the COP displacement in three different feedback conditions on the unstable surface. Compared to stance without laser pointing, sway path decreased when subjects pointed at a target fixed to the wall (fixed board; $P < 0.01$**). In contrast, no significant effects could be seen when the target was attached to the subjects' bodies (moving board; $P = 0.09$). Subjects swayed significantly less when the target was fixed to the wall and not to their bodies ($P < 0.05$*)

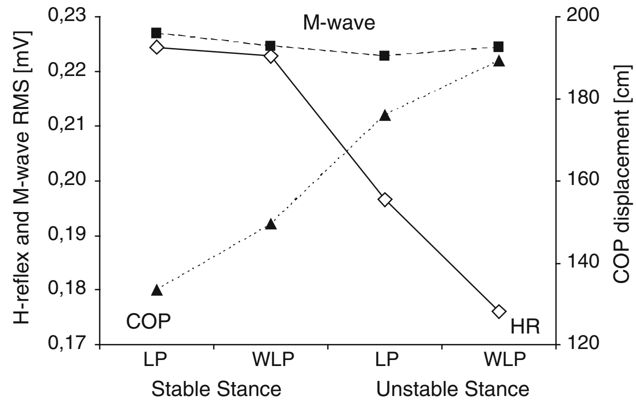

Fig. 4 In six subjects, M-waves were present in the SOL muscle when the H-reflex was adjusted to 20% of M_{max}. The modulations of the COP displacement (*filled triangle*), the H-reflex (*open diamond*) and the M-wave (*filled square*) are displayed for these subjects in the four conditions

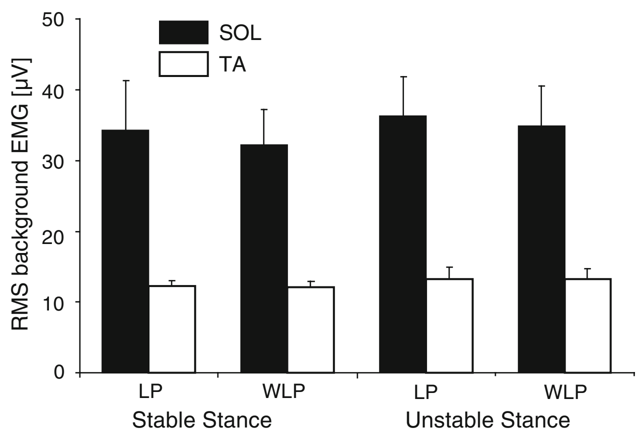

Fig. 5 Background EMG activity of the tibialis anterior (TA) and soleus (SOL) muscle on the stable and unstable surface with (LP) and without laser pointing (WLP). There was no significant difference between any of the conditions. The ratio between SOL and TA was constant

stable support surfaces (Horak et al. 1992; Schieppati et al. 1994; Smithson et al. 1998). However, when the postural demands were increased (one-legged stance or compensation of stance perturbations) the patients showed significant deficits in their balance control. In healthy subjects, reduced COP amplitudes were shown when the COP was displayed on a computer screen but at the same time sway frequency increased (Dault et al. 2003; Anker et al. 2008). Such a change in the postural control strategy was argued to reflect a "tighter" but not essentially better control of body sway. Interestingly, "tighter" postural control during quiet stance has also been reported for cognitive dual tasks (Dault et al. 2001) and for tasks involving postural threats (Carpenter et al. 1999, 2001). Thus, the secondary task of laser pointing may not (only) alter the visual feedback but lead to changes in the subjects' level of attention or arousal, which in turn may influence the postural control strategy. With respect to the execution of a secondary cognitive task, conflicting results have been presented in the literature: some studies reported reduced COP displacement (Weeks et al. 2003; Swan et al. 2004, 2006) whereas others showed greater postural sway (Maylor and Wing 1996; Maylor et al. 2001; Woollacott and Shumway-Cook 2002). Secondary motor tasks on the other hand seem to consistently enhance the COP excursion in both, healthy and impaired subjects (Weeks et al. 2003; Marchese et al. 2003). The latter studies support the view that an additional *motor* task would rather impair postural stability than improve this ability. Nevertheless, we wanted to exclude the possibility of an altered stance performance due to an intensified level of concentration and/or arousal induced by the execution of a second task. Therefore, subjects were asked to perform a "finger-tapping task" during stance (Protocol 2). As neither stance stability nor H-reflex amplitudes were modified by this additional motor task, it is unlikely that the reduced COP displacement during laser pointing was mainly caused by an altered level of alertness. To strengthen the hypothesis that the laser pointer provided additional visual cues about body sway a third protocol was accomplished. In Protocol 3, laser pointing was performed in the same way as in Protocol 1. However, the centre of reference was not a target fixed to the wall (Protocol 1) but a board attached to the subjects' bodies (Fig. 1). It was assumed that if body sway and reference system moved in parallel, the laser point would not provide additional information about body sway. The present results support this hypothesis. Compared to normal stance, the COP displacement was solely reduced when pointing at the target fixed to the wall (external reference system). In summary, all three protocols support the assumption that subjects received augmented visual feedback from a hand-held laser pointer which then in turn considerably reduced postural sway.

The effect of altered visual feedback and changes in stance support on the H-reflex

The second main finding of this study was that both changes in visual feedback and alterations in the support surface influenced the amplitude of the H-reflex. Subjects standing on the spinning top demonstrated augmented H-reflexes when they used the laser pointer compared to the task without laser pointing. The H-reflexes were greater during normal stance than in the unstable stance condition. As a general finding, the H-reflex modulation was directly opposed to the changes in COP displacement. This was expressed in a negative correlation of the H-reflex amplitude and the COP displacement ($R^2 = -0.5$; $P < 0.01$). In other words, the less subjects swayed, the greater were their H-reflexes. These results are well in line with the observation of an increased H-reflex excitability in supported standing compared to natural stance (Trimble 1998). Reciprocally it was shown that the H-reflex amplitude was smaller in the tandem stance position than during natural bipedal stance (Chalmers and Knutzen 2002). Reduced H-reflex excitability going along with increased sway was also observed when subjects closed their eyes during standing (Hoffman and Koceja 1995; Earles et al. 2000). Thus, the spinal reflex system seems to adapt to changes in stance stability in a very specific way: If stability is reduced and postural sway increases, H-reflexes are reduced (e.g. reduced base of support; eyes closed). On the contrary, reduced postural sway goes along with augmented spinal excitability (e.g. enhanced visual feedback; mechanical support). However, when anxiety is involved, the H-reflex modulation does not follow this pattern. Sibley et al. (2007) investigated H-reflexes while subjects were either standing 40 cm above ground (low height) or were lifted up to 160 cm (high height). When subjects stood directly at the edge of the platform, the H-reflex was solely reduced in the high height condition. The postural sway was not measured in this particular study but previous observations indicated that postural threat leads to reduction in sway amplitude and increases in sway frequency (Carpenter et al. 1999, 2001). Thus, anxiety induces a "tighter" postural control and at the same time reduces the H-reflex amplitude. This is in contrast to the modulation seen in all the abovementioned H-reflex studies enclosing the present one, in which reduction of the H-reflex was accompanied by enhanced postural sway. It may be speculated that in response to the perception of postural instability the central nervous system minimizes spinal reflex contributions. However, this change in the postural control strategy may in general not entirely compensate the instability, i.e. although the spinal reflexes are reduced, the postural sway is increased compared to the more stable condition. If, on the other hand, anxiety is the only driving force to alter the postural control strategy, this might result in reduced H-reflexes and reduced sway.

From a functional point of view, a high Ia-afferent transmission may be advantageous to easily activate the motoneuron pool whereas decreased spinal reflexes may improve movement control by preventing reflex-mediated joint oscillations (Llewellyn et al. 1990; Koceja and Mynark 2000; Aagaard et al. 2002). With respect to the latter point, Tokuda et al. (1991) showed that subjects with cerebellar ataxia who could not downwardly modulate their H-reflex stood more unstable than healthy subjects. Similarly, unbalanced stance in patients with Parkinson's disease was accompanied by the inability to alter the H-reflex amplitude task specifically (Hayashi et al. 1997). Reduced H-reflex amplitudes in balance trained subjects may further point towards the functional benefit of low spinal reflex excitability in postural tasks (Nielsen et al. 1993; Trimble and Koceja 1994, 2001; Gruber et al. 2007; Taube et al. 2007a, b).

Possible mechanisms responsible for the reflex modulation

Changes in the excitability of the H-reflex can be caused by pre- or postsynaptic mechanisms. As the background EMG activity and thus the excitability of the motoneuronal pool was comparable in all tested conditions, it is unlikely that the observed changes in H-reflex size were mainly due to changes on the postsynaptic side of the H-reflex pathway. With respect to the comparison of the stable and unstable stance condition, the unaltered EMG activity between these two tasks may surprise. Previous studies showed that performance of a new motor task involves an increased level of co-contraction probably in order to stabilize the joint (Smith 1981; Llewellyn et al. 1990). The co-contraction of ankle muscles is accompanied by enhanced presynaptic inhibition of Ia-afferents (Nielsen and Kagamihara 1993) and by increased recurrent inhibition (Nielsen and Pierrot-Deseilligny 1996). These mechanisms would cause a reduction in the H-reflex excitability. In the present study, the H-reflex modulation has to be explained differently as the level of co-contraction did not change between tasks. The absence of changes in the background EMG may be due to the mechanics of the spinning top. Despite a more unstable stance, subjects only required very little force to tilt the spinning top into the desired direction. Additionally, the trials prior to the actual experiment might have been sufficient to accustom the subjects to the new stance situation. The similar background EMG levels in all tested conditions point towards a presynaptic mechanism responsible for modulating the H-reflex. Short-term alterations in presynaptic inhibition of Ia-afferents have been demonstrated during gait, changes in postural orientation (supine vs. stance) and at the onset and execution of voluntary movements (Hultborn et al. 1987; Meunier and Pierrot-Deseilligny1989; Faist et al. 1996; Koceja and Mynark 2000). Furthermore, it was shown that the level of presynaptic inhibition increased as the postural stability decreased and it was assumed that descending influences might be responsible for this modulation (Katz et al. 1988). There are different supraspinal sites like the motor cortex (Meunier and Pierrot-Deseilligny 1998), the cerebellum (Dontsova and Shkvirskaia 1980) and the basal ganglia (Filloux 1996) which potentially influence the spinal reflex excitability. They are all dependent on feedback from visual, vestibular, cutaneous and proprioceptive sources. In the present study, it is unlikely that the vestibular system was the driving force for the reflex modulation. Head accelerations during quiet standing are not sufficiently high to activate the vestibular afferents (Nashner et al. 1989). Cutaneous afferent input was certainly different in stable and unstable stance and could therefore influence reflexive behaviour in these conditions (Iles 1996). However, it can hardly account for the reflex modulation observed with increased visual feedback. Similarly, proprioceptive inputs in the lower leg muscles are unlikely to change by the use of the laser pointer. If so, then similar effects would have been expected during the finger tapping task. The increase in the H-reflex when subjects used the laser pointer may therefore most likely be explained by changes in the visual feedback. Alike the somatosensory (Miyoshi et al. 2003) and the vestibular system (Aiello et al. 1983; Bacsi and Colebatch 2005) the visual system may be capable of influencing the spinal reflex excitability as was proposed by Hoffman and Koceja (1995). In contrast to this earlier study, we observed a significant interaction between the visual and the support surface conditions indicating that the H-reflex was more strongly affected by changes in visual feedback on the unstable surface. This is in line with the observation that vision is of greater relevance when the demands of the postural task are increased (Mergner et al. 1997; Buchanan and Horak 1999). These findings may be of importance for the conception and evaluation of visual feedback therapy interventions. In general, patients receive visual feedback about their COP displacement on a computer screen while bilateral standing on two force plates. Such visual feedback training was not superior to conventional therapy with respect to symmetry of weight distribution, postural sway in bilateral standing, gait and gait-related activities (for systematic review see Van Peppen et al. 2006). The authors argued that visual feedback training on stable support surfaces may not provide high enough challenges to improve postural control more efficiently than conventional therapy. To provide visual feedback in demanding and functional balance tasks, the use of a laser pointer may allow more effective training exercises than training systems consisting of two stable force plates.

In conclusion, the results of this study demonstrate that additional feedback by means of a hand-held laser pointer reduced the amount of COP displacement and the sway velocity. At the same time, laser pointing facilitated the H-reflex excitability. These results support the view that vision exerts a strong influence on postural control. Moreover, alterations in the visual feedback were most likely responsible for changes in the spinal Ia-afferent transmission.

References

Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P (2002) Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. J Appl Physiol 92:2309–2318

Aiello I, Rosati G, Serra G, Tugnoli V, Manca M (1983) Static vestibulospinal influences in relation to different body tilts in man. Exp Neurol 79:18–26

Anker LC, Weerdesteyn V, van Nes IJ, Nienhuis B, Straatman H, Geurts AC (2008) The relation between postural stability and weight distribution in healthy subjects. Gait Posture 27:471–477

Bacsi AM, Colebatch JG (2005) Evidence for reflex and perceptual vestibular contributions to postural control. Exp Brain Res 160:22–28

Brodal A (1981) Neurological anatomy in relation to clinical medicine. Oxford University Press, New York

Buchanan JJ, Horak FB (1999) Emergence of postural patterns as a function of vision and translation frequency. J Neurophysiol 81:2325–2339

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

Chalmers GR, Knutzen KM (2002) Soleus H-reflex gain in healthy elderly and young adults when lying, standing, and balancing. J Gerontol A Biol Sci Med Sci 57:B321–B329

Crone C, Hultborn H, Mazieres L, Morin C, Nielsen J, Pierrot-Deseilligny E (1990) Sensitivity of monosynaptic test reflexes to facilitation and inhibition as a function of the test reflex size: a study in man and the cat. Exp Brain Res 81:35–45

Dault MC, Geurts AC, Mulder TW, Duysens J (2001) Postural control and cognitive task performance in healthy participants while balancing on different support-surface configurations. Gait Posture 14:248–255

Dault MC, de Haart M, Geurts AC, Arts IM, Nienhuis B (2003) Effects of visual center of pressure feedback on postural control in young and elderly healthy adults and in stroke patients. Hum Mov Sci 22:221–236

Dickstein R, Abulaffio N (2000) Postural sway of the affected and nonaffected pelvis and leg in stance of hemiparetic patients. Arch Phys Med Rehabil 81:364–367

Dontsova ZS, Shkvirskaia LA (1980) Characteristics of presynaptic inhibition of monosynaptic spinal cord reflexes after removal of the anterior lobe of the cerebellum. Neirofiziologiia 12:429–431

Duarte M, Zatsiorsky VM (2002) Effects of body lean and visual information on the equilibrium maintenance during stance. Exp Brain Res 146:60–69

Earles DR, Koceja DM, Shively CW (2000) Environmental changes in soleus H-reflex excitability in young and elderly subjects. Int J Neurosci 105:1–13

Faist M, Dietz V, Pierrot-Deseilligny E (1996) Modulation, probably presynaptic in origin, of monosynaptic Ia excitation during human gait. Exp Brain Res 109:441–449

Filloux FM (1996) Neuropathophysiology of movement disorders in cerebral palsy. J Child Neurol 11(Suppl 1):S5–S12

Fitzpatrick R, McCloskey DI (1994) Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. J Physiol 478(1):173–186

Gruber M, Taube W, Gollhofer A, Beck S, Amtage F, Schubert M (2007) Training-specific adaptations of H- and stretch reflexes in human soleus muscle. J Mot Behav 39:68–78

Guerraz M, Thilo KV, Bronstein AM, Gresty MA (2001) Influence of action and expectation on visual control of posture. Brain Res Cogn Brain Res 11:259–266

Hafstrom A, Fransson PA, Karlberg M, Ledin T, Magnusson M (2002) Visual influence on postural control, with and without visual motion feedback. Acta Otolaryngol 122:392–397

Hayashi R, Tokuda T, Tako K, Yanagisawa N (1997) Impaired modulation of tonic muscle activities and H-reflexes in the soleus muscle during standing in patients with Parkinson's disease. J Neurol Sci 153:61–67

Hoffman MA, Koceja DM (1995) The effects of vision and task complexity on Hoffmann reflex gain. Brain Res 700:303–307

Horak FB, Nutt JG, Nashner LM (1992) Postural inflexibility in parkinsonian subjects. J Neurol Sci 111:46–58

Hultborn H, Meunier S, Pierrot-Deseilligny E, Shindo M (1987) Changes in presynaptic inhibition of Ia fibres at the onset of voluntary contraction in man. J Physiol 389:757–772

Iles JF (1996) Evidence for cutaneous and corticospinal modulation of presynaptic inhibition of Ia afferents from the human lower limb. J Physiol 491:197–207

Katz R, Meunier S, Pierrot-Deseilligny E (1988) Changes in presynaptic inhibition of Ia fibres in man while standing. Brain 111:417–437

Kavounoudias A, Roll R, Roll JP (2001) Foot sole and ankle muscle inputs contribute jointly to human erect posture regulation. J Physiol 532:869–878

Koceja DM, Mynark RG (2000) Comparison of heteronymous monosynaptic Ia facilitation in young and elderly subjects in supine and standing positions. Int J Neurosci 103:1–17

Llewellyn M, Yang JF, Prochazka A (1990) Human H-reflexes are smaller in difficult beam walking than in normal treadmill walking. Exp Brain Res 83:22–28

Marchese R, Bove M, Abbruzzese G (2003) Effect of cognitive and motor tasks on postural stability in Parkinson's disease: a posturographic study. Mov Disord 18:652–658

Maurer C, Mergner T, Peterka RJ (2004) Abnormal resonance behavior of the postural control loop in Parkinson's disease. Exp Brain Res 157:369–376

Maylor EA, Wing AM (1996) Age differences in postural stability are increased by additional cognitive demands. J Gerontol B Psychol Sci Soc Sci 51:143–154

Maylor EA, Allison S, Wing AM (2001) Effects of spatial and nonspatial cognitive activity on postural stability. Br J Psychol 92:319–338

Mergner T, Huber W, Becker W (1997) Vestibular-neck interaction and transformation of sensory coordinates. J Vestib Res 7:347–367

Mergner T, Schweigart G, Maurer C, Blumle A (2005) Human postural responses to motion of real and virtual visual environments under different support base conditions. Exp Brain Res 167:535–556

Meunier S, Pierrot-Deseilligny E (1989) Gating of the afferent volley of the monosynaptic stretch reflex during movement in man. J Physiol 419:753–763

Meunier S, Pierrot-Deseilligny E (1998) Cortical control of presynaptic inhibition of Ia afferents in humans. Exp Brain Res 119:415–426

Meyer PF, Oddsson LI, De Luca CJ (2004) The role of plantar cutaneous sensation in unperturbed stance. Exp Brain Res 156:505–512
Miyoshi T, Nozaki D, Sekiguchi H, Kimura T, Sato T, Komeda T, Nakazawa K, Yano H (2003) Somatosensory graviception inhibits soleus H-reflex during erect posture in humans as revealed by parabolic flight experiment. Exp Brain Res 150:109–113
Nashner LM, Shupert CL, Horak FB, Black FO (1989) Organization of posture controls: an analysis of sensory and mechanical constraints. Prog Brain Res 80:411–418
Nielsen J, Kagamihara Y (1993) The regulation of presynaptic inhibition during co-contraction of antagonistic muscles in man. J Physiol 464:575–593
Nielsen J, Crone C, Hultborn H (1993) H-reflexes are smaller in dancers from The Royal Danish Ballet than in well-trained athletes. Eur J Appl Physiol Occup Physiol 66:116–121
Nielsen J, Pierrot-Deseilligny E (1996) Evidence of facilitation of soleus-coupled Renshaw cells during voluntary co-contraction of antagonistic ankle muscles in man. J Physiol 493(2):603–611
Schieppati M, Hugon M, Grasso M, Nardone A, Galante M (1994) The limits of equilibrium in young and elderly normal subjects and in parkinsonians. Electroencephalogr Clin Neurophysiol 93:286–298
Shumway-Cook A, Anson D, Haller S (1988) Postural sway biofeedback: its effect on reestablishing stance stability in hemiplegic patients. Arch Phys Med Rehabil 69:395–400
Sibley KM, Carpenter MG, Perry JC, Frank JS (2007) Effects of postural anxiety on the soleus H-reflex. Hum Mov Sci 26:103–112
Smith AM (1981) The coactivation of antagonist muscles. Can J Physiol Pharmacol 59:733–747
Smithson F, Morris ME, Iansek R (1998) Performance on clinical tests of balance in Parkinson's disease. Phys Ther 78:577–592
Swan L, Otani H, Loubert PV (2006) Reducing postural sway by manipulating the difficulty levels of a cognitive task and a balance task. Gait Posture 26(3):470–474
Swan L, Otani H, Loubert PV, Sheffert SM, Dunbar GL (2004) Improving balance by performing a secondary cognitive task. Br J Psychol 95:31–40
Taube W, Gruber M, Beck S, Faist M, Gollhofer A, Schubert M (2007a) Cortical and spinal adaptations induced by balance training: correlation between stance stability and corticospinal activation. Acta Physiol (Oxf) 189:347–358
Taube W, Kullmann N, Kurz O, Leukel C, Amtage F, Gollhofer A (2007b) Differential reflex adaptations following sensorimotor and strength training in young elite athletes. Int J Sports Med 28(12):999–1005
Tokuda T, Tako K, Hayashi R, Yanagisawa N (1991) Disturbed modulation of the stretch reflex gain during standing in cerebellar ataxia. Electroencephalogr Clin Neurophysiol 81:421–426
Trimble MH (1998) Postural modulation of the segmental reflex: effect of body tilt and postural sway. Int J Neurosci 95:85–100
Trimble MH, Koceja DM (1994) Modulation of the triceps surae H-reflex with training. Int J Neurosci 76:293–303
Trimble MH, Koceja DM (2001) Effect of a reduced base of support in standing and balance training on the soleus H-reflex. Int J Neurosci 106:1–20
Van Peppen RP, Kortsmit M, Lindeman E, Kwakkel G (2006) Effects of visual feedback therapy on postural control in bilateral standing after stroke: a systematic review. J Rehabil Med 38:3–9
Weeks DL, Forget R, Mouchnino L, Gravel D, Bourbonnais D (2003) Interaction between attention demanding motor and cognitive tasks and static postural stability. Gerontology 49:225–232
Woollacott M, Shumway-Cook A (2002) Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 16:1–14