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1 **Effect of manipulation of the feet and ankles on postural control in elderly adults**

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1 Abstract

2 The purpose of the present experiment was to investigate the effect of a therapeutic
3 manipulation of the feet and ankles on postural control during quiet standing in elderly
4 adults. Seventeen elderly adults stood barefoot on a force platform and were asked to sway
5 as little as possible. Within a trial, vision was suppressed by eyes closure. The task was
6 executed in two experimental sessions: before and after a therapeutic manipulation of the
7 foot and ankle. Centre of foot pressure (COP) displacements along the mediolateral (ML)
8 and anteroposterior (AP) axes were recorded. For the two experimental sessions, subjects
9 exhibited comparable COP displacements when vision was available and were similarly
10 affected by the suppression of vision. However, when subjects had to adapt to the absence
11 of vision within a 10 s temporal frame, postural behavior became different in the two
12 experimental sessions: The sum of the ML and AP COP displacements increased within the
13 10 s temporal frame before the therapeutic manipulation of the feet and ankles, whereas it
14 remained unchanged after it. These results suggested that the therapeutic manipulation of
15 the foot and ankle allows the elderly adults to partially compensate for the destabilising
16 effect induced by the suppression of vision.

17

18 **Key words:** Manipulation; Foot; Ankle; Balance; Elderly.

1 **Introduction**

2 Postural control is a particularly complex system involving various sensory and
3 motor components. Among the sensory inputs relevant to the regulation of postural sway,
4 the importance of somatosensory information from the feet and ankles is now well
5 established (Dietz, 1992; Fitzpatrick et al., 1994; Meyer et al., 2004a, 2004b). Data
6 supporting this view were obtained through experimental and clinical approaches.
7 Experimental manipulations of somatosensory information from cutaneous, muscles,
8 tendons and joints receptors were shown to have an effect on postural control, as evidenced
9 either by cooling (Magnusson et al., 1990), anaesthetising (Thoumie & Do, 1996; Meyer et
10 al., 2004a, 2004b) or stimulating (Kavounoudias et al., 1998, 2001; Maurer et al., 2001) the
11 plantar soles, by vibrating ankle muscles (Kavounoudias et al., 1998; Hay et al., 1996), by
12 applying an ischemic block above the ankles (Fitzpatrick et al., 1994; Dierner et al., 1984),
13 or by changing the characteristics of the supporting surface on which individuals are
14 standing (Redfern et al., 1997; Robbins et al., 1998). Clinically, alteration or loss of
15 somatosensory information from the lower limbs resulting from disease (diabetic peripheral
16 neuropathy) is known to impair postural control (Simmons et al., 1997). Progressive
17 degeneration of sensory inputs from the lower extremities also represents a common
18 clinical finding associated with aging (Kenshalo, 1986; Skinner et al., 1984) and has even
19 been identified as an important contributing factor to the occurrence of falls in elderly
20 (Lord et al., 1991; Tinetti & Speechley, 1989). Therefore, it is legitimate to propose that a
21 therapeutic intervention designed to increase somatosensory function of the feet and ankles
22 could be of great interest for controlling balance and preventing falls in the elderly. While
23 the benefits of proprioceptive exercises are documented (Gauchard et al., 1999; Sinaki &

1 Lynn, 2002), it is surprising that there is an absence of data investigating whether and how
2 a therapeutic manipulation of the feet and ankles can modify postural control in elderly
3 adults.

4 The purpose of the present experiment was to improve the understanding of the
5 contribution of distal lower limb inputs to the control of balance during functional
6 activities. More precisely, it was to investigate the effects of a therapeutic manipulation of
7 the feet and ankles on postural control during quiet standing in elderly adults. Since visual
8 information is known to play an important role in postural control, particularly in elderly
9 (Lord & Menz, 2000; Sundermier et al., 1996), subjects' ability to regulate their postural
10 sway was evaluated while being exposed to an abrupt suppression of visual information, as
11 previously done by others (Hay et al., 1996; Teasdale et al., 1991). It was hypothesised that
12 an "over-activation" of somatosensory information induced by a therapeutic manipulation
13 of the feet and ankles allows the elderly persons to compensate for the destabilising effect
14 of visual suppression. Since the somatosensory system includes various receptors that
15 provide information about pressure distribution (cutaneous), muscle tension (Golgi tendon
16 organs), joint angle changes (joint receptors) and muscle length changes (spindles), the
17 intervention involved manual massage of the feet and mobilisation of both the feet and
18 ankles joints.

19 **Methods**

20 17 male elderly adults (mean age = $74.5 \pm 9,6$ years; mean body weight = $73.2 \pm$
21 12.3 kg; mean height = $165.6 \pm 9,3$ cm) participated in the experiment. Subjects were
22 volunteers and gave written informed consent to the experimental procedure as required by
23 the Helsinki declaration (1964) and the local Ethics Committee. None of the subjects

1 presented any musculoskeletal problems, defects in the peripheral sensory system of the
2 lower extremities, vascular pathology, neurological disorders or vestibular impairment.
3 Finally, all subjects had normal or corrected-to-normal vision.

4 Subjects stood barefoot on a force platform, feet joined, and were asked to sway as
5 little as possible, with their eyes open. Fifteen seconds into a trial, an auditory stimulus
6 directed the subjects to close their eyes. A trial finished with 10 s of no-vision. When vision
7 was available, subjects were asked to fixate the intersection of a black cross placed onto the
8 white wall distant 1 m in front of them, at the eyes level. When vision was not available,
9 they were asked to keep their gaze in a straight-ahead direction. This task was executed in
10 two experimental sessions (Pre- and Post test). Six 25 s trials were executed for each
11 experimental session, for a total of 12 trials. The duration of an experimental session lasted
12 6 min, approximately. The Pre-test served as a control session. In the Post-test session, the
13 measurements were performed immediately after a therapeutic manipulation of the feet and
14 ankles. This intervention, widely used by manual therapists (Dufour, 1996), was designed
15 to target the somatosensory system of the feet and ankles, using manual massage of the feet
16 and mobilisation of both the feet and ankles joints.

17 The aim of the massage was to enhance local blood circulation and to stimulate
18 cutaneous receptors. Massage technique application involved frictions and glide force
19 pressure of the plantar sole. Mobilisations elicited dorsiflexion and plantar flexion of the
20 mortise joints, eversion and inversion of the subtalar joints, anteroposterior glide, torsion,
21 flexion and extension of the midtarsal joints, anteroposterior glide and rotation of
22 tarsometatarsal joints, anteroposterior glide of intermetatarsal joints, plantar flexion and
23 extension of metatarsophalangeal and interphalangeal joints. Manual massage and

1 articulation techniques were applied to both the feet and ankles for 20 min. Six 25 s trials
2 were executed for each experimental session, for a total of 12 trials. The duration of an
3 experimental session lasted 6 min, approximately.

4 A force platform (AMTI model OR6-5-1) was used to measure displacements of the
5 centre of foot pressure (COP). Signals from the force platform were sampled at 200 Hz (12
6 bit A/D conversion) and filtered with a second-order low-pass Butterworth filter (10 Hz
7 cut-off frequency).

8 CoP displacements (*in millimetres*) along the mediolateral (ML) and anteroposterior
9 (AP) axes were used to estimate a global postural performance before and after the
10 therapeutic manipulation. This measure corresponds to the sum of the displacement scalars
11 over the sampling period. For convenience purposes, these two dependent variables will be
12 referred to as ML and AP COP displacements, respectively. The first 10 sec of a trial were
13 used to allow subjects' stabilisation. COP displacements were analysed over three periods
14 of 4 s, immediately before the suppression of vision (T1), 1 s after the visual transition to
15 prevent from the presumed effect of the visual transition from vision to no-vision (T2) and
16 at the end of the trial (T3). Comparison of these three temporal frames yielded information
17 on (1) the immediate effect of the suppression of vision on COP displacements (T1 vs. T2)
18 and (2) the postural adaptation over time to the absence of vision (T2 vs. T3).

19 Analyses of variance (ANOVAs) were used for statistical comparison of the
20 different conditions. Level of significance was set at 0.05. Post-hoc analyses (Newman-
21 Keuls) were used whenever necessary.

1 **Results**

2 Figure 1 illustrates representative COP displacements across a trial from a typical
3 subject for each of the two Pre (*left panel*) and Post-test (*left panel*) experimental sessions.

4 -----
5 Insert Figure 1 about here
6 -----

7 **Postural control following the suppression of vision**

8 A preliminary analysis consisted in controlling whether the immediate effect of the
9 suppression of vision on COP displacements was similar across the trials performed in the
10 Pre-test session for the temporal frames T1 versus T2. The first three and the last three
11 trials of the Pre-test session were compared using 2 Series (First 3 vs. Last 3 trials) \times 2
12 Temporal frames (T1 vs. T2) ANOVAs. For both the ML and AP COP displacements,
13 results showed no effect of Series and no interaction of Series \times Temporal frame ($P_s >$
14 0.05). This suggested that the immediate effect of the suppression of vision on COP
15 displacements was constant across the Pre-test trials. Thus, data obtained in the Post-test
16 session were not likely to be confounded with a possible effect of training or fatigue.

17 The purpose of the following analysis was to investigate whether subjects' ability to
18 immediately adapt to the transition from vision to no vision was modified by the
19 therapeutic manipulation of the feet and ankles. 2 Sessions (Pre vs. Post-test) \times 2 Temporal
20 frames (T1 vs. T2) ANOVAs with repeated measures on both factors were applied to the
21 data.

1 Analysis of the ML COP displacements showed a main effect of Temporal frame,
2 with smaller ML COP displacements before than immediately after the suppression of
3 vision ($F(1,16) = 27.58, P < 0.001$). The absence of an interaction of Session \times Temporal
4 frame ($P > 0.05$) showed that the therapeutic intervention did not affect ML COP
5 displacements immediately after the visual transition (Figure 2A).

6 -----
7 Insert Figure 2 about here
8 -----

9 Analysis of the AP COP displacements confirmed a main effect of Temporal frame
10 ($F(1,16) = 31.26, P < 0.001$) and showed a main effect of Session, yielding smaller AP
11 COP displacements in the Post- than in the Pre-test session ($F(1,16) = 8.01, P < 0.05$). The
12 absence of an interaction of Session \times Temporal frame ($P > 0.05$) also showed that the
13 therapeutic intervention did not affect AP COP displacements immediately after the
14 suppression of vision (Figure 2B).

15 To further investigate the persistence of the effect of the manipulation of the feet
16 and ankles, the first three and the last three trials of the Post-test session were compared
17 using 2 Series (First 3 vs. Last 3 trials) \times 2 Temporal frames (T1 vs. T2) ANOVAs. For
18 both the ML and AP COP displacements, results showed no effect of Series and no
19 interaction of Series \times Temporal frame ($P_s > 0.05$). This suggested that the therapeutic
20 intervention on COP displacements was constant across the Post-test trials, for 6 min at
21 least.

22 **Adaptation of postural control to the absence of vision**

1 A preliminary analysis controlled whether the postural adaptation to the suppression
2 of vision within a 10 s temporal frame was similar in the trials performed in the Pre-test
3 session for the temporal frames T2 versus T3. The first three and the last three trials of the
4 Pre-test session were compared using 2 Series (First 3 vs. Last 3 trials) \times 2 Temporal
5 frames (T2 vs. T3) ANOVAs. For both the ML and AP COP displacements, results showed
6 no effect of Series ($P_s > 0.05$), and no interaction of Series \times Temporal frame ($P_s > 0.05$).
7 This suggested that postural adaptation to the suppression of vision within a 10 s temporal
8 frame was constant across the Pre-test trials. This further confirmed that data obtained
9 following the therapeutic manipulation were not likely to be confounded with a possible
10 effect of training or fatigue.

11 The purpose of the following analysis was to investigate whether subjects'
12 adaptation to the effect of the visual transition within a 10 s temporal frame was modified
13 by the therapeutic intervention. Two Sessions (Pre vs. Post-test) \times 2 Temporal frames (T2
14 vs. T3) ANOVAs with repeated measures on both factors were applied to the data.

15 Analysis of the ML COP displacements showed a significant interaction of Session
16 \times Temporal frame ($F(1,16) = 6.53, P < 0.05$). The decomposition of the interaction into its
17 simple main effects showed that ML COP displacements increased over time in the Pre-test
18 session, with smaller values immediately after the suppression of vision than after 6 s of
19 adaptation in No-vision ($P < 0.05$), whereas they remained unchanged in the Post-test
20 session ($P > 0.05$) (Figure 2A).

21 Analysis of the AP COP displacements showed a significant interaction of Session \times
22 Temporal frame ($F(1,16) = 5.48, P < 0.05$). The ANOVA also confirmed main effects of

1 Temporal frame ($F(1,16) = 4.53, P < 0.05$) and Session ($F(1,16) = 11.07, P < 0.01$). The
2 decomposition of the interaction into its simple main effects showed that AP COP
3 displacements increased over time in the Pre-test session, with smaller values immediately
4 after the suppression of vision than after 6 s of adaptation in No-vision ($P < 0.01$), whereas
5 they remained unchanged in the Post-test session ($P > 0.05$) (Figure 2B).

6 To further investigate the persistence of the effect of the therapeutic manipulation of
7 the feet and ankles, the first three and the last three trials of the Post-test session were
8 compared using 2 Series (First 3 vs. Last 3) \times 2 Temporal frames (T2 vs. T3) ANOVAs.
9 For both ML and AP COP displacements, results showed no effect of Series ($P_s > 0.05$),
10 and no interaction of Series \times Temporal frame ($P_s > 0.05$). This suggested that the benefits
11 of the therapeutic intervention on COP displacements was constant across the Post-test
12 trials, for 6 min at least.

13 **Discussion**

14 The purpose of the present experiment was to investigate the effects of a therapeutic
15 manipulation of the feet and ankles on postural control during quiet standing in elderly
16 adults. Subjects' ability to maintain a stable upright posture was evaluated while facing
17 changes in the availability of visual information before and after the therapeutic
18 intervention. Withdrawing visual information forced the subjects to reorganise the
19 hierarchy of sensory information since vestibular and proprioceptive inputs became the
20 only remaining sources of sensory information available for regulating posture.

21 Before and after the therapeutic manipulation, subjects exhibited comparable COP
22 displacements when vision was available (temporal frame T1), suggesting that the massage

1 and mobilisation of the feet and ankles had no immediate effect on postural stability and/or
2 that vision largely compensated for the presumed benefits of a therapeutic manipulation.
3 Previous studies showed similar compensations following fatigue of the lower limbs
4 (Vuillerme et al., 2001). Similarly, the therapeutic manipulation did not affect COP
5 displacements immediately following the visual transition from vision to no-vision
6 (temporal frame T2). This absence of effect may be due to the limited impact of the
7 therapeutic manipulation with respect to the amplitude of normal body oscillations in the
8 absence of vision.

9 Interestingly, it is when adapting to this absence of vision within a 10 s temporal
10 frame that the postural behaviour in the two experimental sessions became different
11 (temporal frame T3). After 10 s of adaptation, postural instability still increased in the
12 control session whereas following the therapeutic manipulation subjects seemed able to
13 provide a rapid recalibration and reorganisation of postural control to take into account the
14 new sensory conditions by switching from visual to proprioceptive control. This adaptive
15 mechanism would ensure a stabilisation of subjects' postural behaviour following the
16 withdrawal of vision.

17 With regard to the hypothesis of a global “over-activation” of somatosensory
18 information induced by the therapeutic manipulation of the feet and ankles, the present
19 results are in line with those of Nougier et al. (1997) when altering somatosensory inputs
20 by means of a foam support surface. In their experiment, postural control in young adults
21 was analysed in different conditions of vision and two conditions of ankle proprioceptive
22 information (normal and altered support surface with a 5 cm thick foam support). When
23 somatosensory information was not altered, as in the Post-test session, young subjects

1 adapted to the absence of vision. Conversely, when the proprioceptive inputs were altered
2 by the use of the foam support surface, as in the Pre-test session, subjects showed no
3 adaptation. Altogether, these results and the present ones demonstrate that the quality of
4 somatosensory information plays a major role in compensating for the absence of vision. In
5 the present case, the therapeutic manipulation seemed to partially compensate for the
6 observed alteration of somatosensory information with age (Kenshalo, 1986; Skinner et al.,
7 1984), by temporarily increasing subjects' sensitivity to these inputs.

8 In conclusion, the present findings showed that elderly adults can benefit from a
9 therapeutic manipulation of the feet and ankles, even though estimated for a short time, for
10 regulating their postural sway during quiet standing. This suggested that such
11 manipulations may allow people to overcome or compensate for functional difficulties due
12 to age and more generally to disease-related sensory loss. It remains, however, to further
13 investigate the underlying neurophysiological mechanisms and to better locate the sites of
14 these effects . It remains also to further investigate the overall duration of the observed
15 benefits in order to validate the utility of these various manipulations and to better specify
16 the most efficient characteristics of a training/rehabilitation program that would include this
17 kind of manipulation.

18

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1 **Figures captions**

2 Figure 1. Representative displacements of COP along the mediolateral (A) and
3 anteroposterior (B) axis for the two Pre- and Post-test sessions. The dotted lines indicate the
4 suppression of vision.

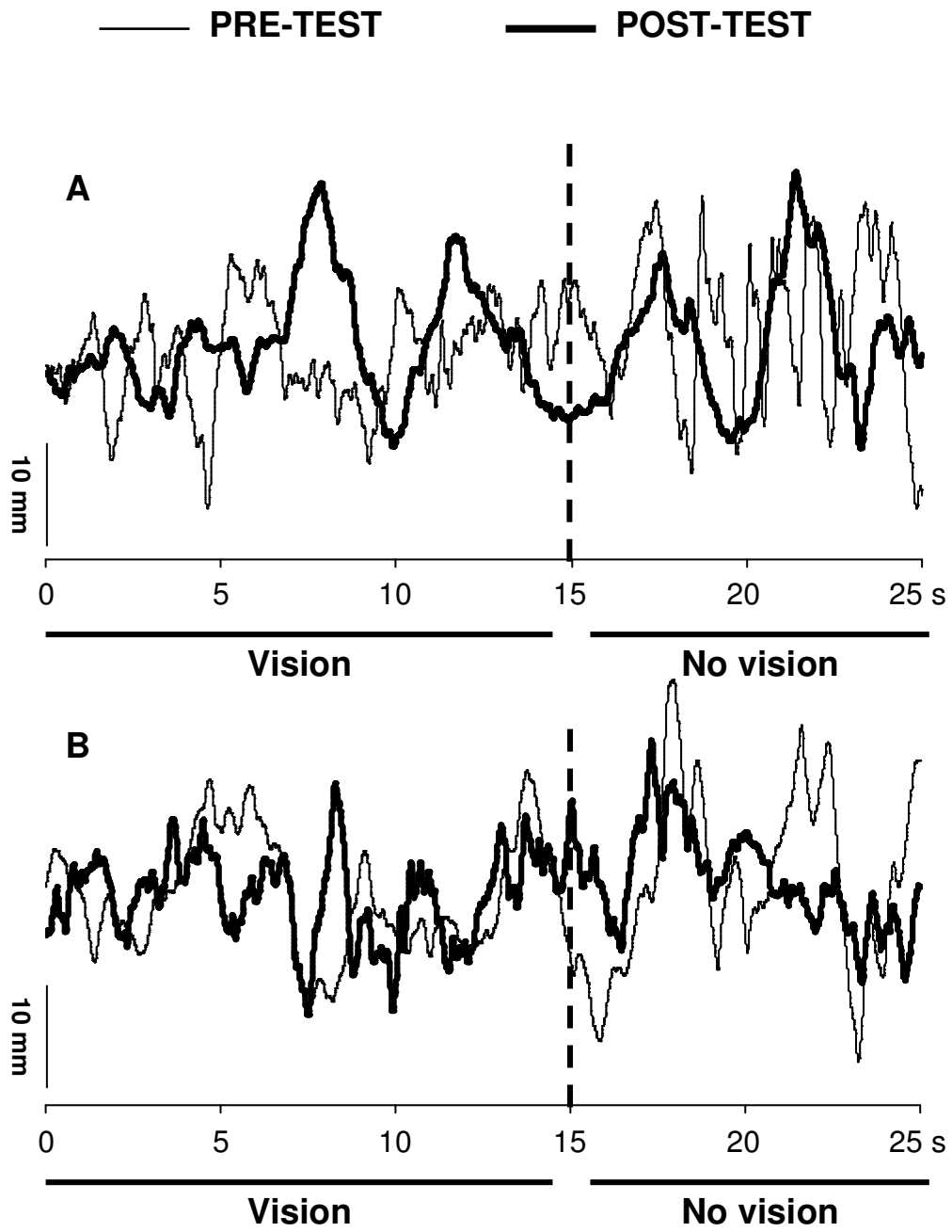
5 .

6

7 **Figure 2.** Mean COP displacements and standard deviation along the two mediolateral (A)
8 and anteroposterior (B) axes and for the two Pre and Post-test sessions. The two
9 experimental sessions are presented with different symbols: Pre-test (*white diamonds*) and
10 Post-test (*black squares*).

1 **Figure 1**

2



1 **Figure 2**

2

