Attentional demands associated with augmented visual feedback during quiet standing

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To investigate how additional visual feedback (VFB) affects postural stability we compared 20-sec center-of-pressure (COP) recordings in two conditions: without and with the VFB. Seven healthy adult subjects performed 10 trials lasting 20 seconds in each condition. Simultaneously, during all trials the simple auditory reaction time (RT) was measured. Based on the COP data, the following sway parameters were computed: standard deviation (SD), mean speed (MV), sample entropy (SE), and mean power frequency (MPF). The RT was higher in the VFB condition (p<0.001) indicating that this condition was attention demanding. The VFB resulted in decreased SD and increased SE in both the medial-lateral (ML) and anterior-posterior (AP) planes (p<.001). These results account for the efficacy of the VFB in stabilizing posture and in producing more irregular COP signals which may be interpreted as higher automaticity and/or larger level of noise in postural control. The MPF was higher during VFB in both planes as was the MV in the AP plane only (p<0.001). The latter data demonstrate higher activity of postural control system that was caused by the availability of the set-point on the screen and the resulting control error which facilitate and speed up postural control.

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14   **Abstract**

15   To investigate how additional visual feedback (VFB) affects postural stability we compared 20-

16   sec center-of-pressure (COP) recordings in two conditions: without and with the VFB. Seven

17   healthy adult subjects performed 10 trials lasting 20 seconds in each condition. Simultaneously,

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19   the following sway parameters were computed: standard deviation (SD), mean speed (MV),

20   sample entropy (SE), and mean power frequency (MPF). The RT was higher in the VFB

21   condition ($p<0.001$) indicating that this condition was attention demanding. The VFB resulted in

22   decreased SD and increased SE in both the medial-lateral (ML) and anterior-posterior (AP)

23   planes ($p<.001$). These results account for the efficacy of the VFB in stabilizing posture and in

24   producing more irregular COP signals which may be interpreted as higher automaticity and/or

25   larger level of noise in postural control. The MPF was higher during VFB in both planes as was

26   the MV in the AP plane only ($p<0.001$). The latter data demonstrate higher activity of postural

27   control system that was caused by the availability of the set-point on the screen and the resulting

28   control error which facilitate and speed up postural control.

29   **Introduction**

30

31   The contribution of visual control of balance while standing increases significantly with

32   additional visual feedback (VFB) implemented through the conscious control of the center of

33   pressure displacements under the feet (COP) (Litvinenkova & Hlavacka, 1973).

34   A positive effect of VFB has been shown in many studies (Litvinenkova & Hlavacka, 1973;

35   Takeya, 1976; Rougier, 2003) indicating a reduction of the centre of gravity motions with

36   associated increase in muscular activity. However, there are also the investigations that do not

37   confirm such influence. Results of Danna-Dos-Santos et al., (2008) indeed demonstrated that

38   participants were unable to decrease sway amplitude when presented with visual feedback,

39   whereas in Boudrahem & Rougier, (2009) it has been shown that only 69% of subjects were able

40   to use additional visual feedback to reduce COP displacements. Ambiguous findings are also

41   reports of attempts to apply VFB technique for rehabilitation. In some studies, the effects appear

42   quite positive (Shumway-Cook, Anson & Haller, 1988; Sihvonen, Sipilä & Era, 2004; Cheng et

43   al., 2004; Ledebt et al., 2005; Sayenko et al., 2010), whereas others should be considered as

44   scarce (C et al., 1984; Walker, Brouwer & Culham, 2000; Geiger et al., 2001). The sources of

45   these discrepancies may be inherent in the way of presenting feedback (insufficient scale display

46   of COP on the screen (Vuillerme, Bertrand & Pinsault, 2008) and/or delay of the signal on the

47   screen (Rougier, 2004; van den Heuvel et al., 2009)), but also a high cognitive demands

48   associated with learning a new task (Wulf & Shea, 2002; van Vliet & Wulf, 2006). Also, many

49   studies have provided evidence that there are significant attentional requirements for postural

50   control (Woollacott & Shumway-Cook, 2002). Further, the attentional demand associated with

51   postural control can be modified by the sensory context (Vuillerme, Isableu & Nougier, 2006).

52   A fuller understanding of postural control mechanisms through the conscious control of the

53   center of pressure displacements under the feet allows for a more in-depth diagnosis of certain

54   pathological conditions, and can also be important in training the balance of both patients and

55   athletes (Szczepańska-Gieracha et al., 2016).

56   Taken together, there is still no consensus as to how vertical posture is controlled when the

57   participants are presented with visual feedback from the actual position of their COP. The

58   predominant view is that attentional resources must be involved due to the larger complexity of

59   the VFB as compared to quiet stance (Lakhani & Mansfield, 2015), however little is known in

60   what way these resources are used and whether their shifts facilitate or interfere with maintaining

61   balance. To better elucidate the underlying mechanisms, it seems crucial to compare the COP

62   measures during VFB and quiet stance with simultaneously recorded reaction time task. While

63   the traditional sway measures account for postural performance, of special interest is sway

64   entropy which quantifies the attentional investment in postural control (Roerdink, Hlavackova &

65   Vuillerme, 2011).

66   Therefore, this study aims to answer the question whether and how the postural task with

67   additional visual feedback requires more attentional demands in young adults. Therefore, we

68   examined reaction times during VFB and change of the amount and structure of COP time series.

69

70   **Methods**

71

72   Seven young students participated in the study (mean age (SD): 22.9 (1.1) years; range: 22-25

73   years, 3 females, 4 males). All subjects were healthy and did not undergo any disease that might

74   affect the balance system. They gave their written informed consent to the procedure and were

75   naive as to the purpose of the experiment. The study was approved by the Senate Ethics

76   Committee for Research at the University School of Physical Education in Wroclaw. Written

77   informed consent was obtained from all participants.

78   Data were collected as previously described in (Simoneau, Bégin & Teasdale, 2006; Vuillerme,

79   Isableu & Nougier, 2006). Specifically, postural stability was assessed on a force plate

80   (AccuSway, AMTI, Watertown, MA) in front of a computer monitor positioned at eye level at a

81   distance of 1 m. Participants were asked to perform two different dual tasks. In the reference

82   condition (REF), they were asked to sway as little as possible fixating a white sign on the screen

83   and simultaneously perform a probe-reaction time (RT) task. The RT task consisted of

84   responding as rapidly as possible to an unpredictable auditory stimulus by pressing a handheld

85   button. Eight reaction time stimuli were presented within each 20 s trial. During second

86   condition (VFB), the COP position was displayed as a spot (diameter of about 4 mm) on the

87   monitor and the subjects were instructed to keep the spot inside the circle (diameter of about 5

88   mm) on the monitor and simultaneously perform RT task. The ratio between the real

89   displacements of the COP and their display on the 19-inch screen was twofold for both the

90   anterior-posterior (AP) and medial-lateral (ML) planes. The AP and ML displacements of the

91   COP were represented on the screen from top to bottom and from left to right, respectively.

92   Postural tasks were the primary tasks, and the subjects were asked to treat it as a priority.

93   Subjects stood in the position as follows: 17 cm between heel centers, with an angle of 14°

94   between the long axes of the feet (McIlroy & Maki, 1997). Ten trials for each condition (lasting

95   20-second each) were presented in pseudo-random (balanced) order.

96

97   Data were recorded at sampling frequency 50 Hz. The instantaneous center of foot pressure was

98   calculated from the recorded ground reaction forces in the medial-lateral and anterior-posterior

99   plane separately. The raw COP data were not digitally filtered. Postural balance was evaluated

100   by following parameters based on the COP time-series: standard deviation (SD), mean speed

101   (MV), mean power frequency (MPF) (Prieto et al., 1996; Duarte & Freitas, 2010) and sample

102   entropy (SE) (Richman & Randall Moorman, 2000). The SD, MV measures postural

103   performance, with lower values of these parameters indicating better performance and MPF

104   reveals postural strategy. SD, MV and MPF were computed using MATLAB codes available at

105   (Duarte & Freitas, 2010). SD is the dispersion of COP displacement from the mean position

106   during a trial duration, MV was calculated as the total COP displacement divided by trial

107   duration and MPF is the mean spectral power frequency of the signal estimated up to 25 Hz

108   range. The power spectral density of the detrended COP data was estimated by the Welch

109   periodogram method. SE indexes the regularity or predictability of a time-series. Increased

110   values of sample entropy, which indicate larger irregularity of the COP, has been attributed to a

111   reduced amount of attention invested in posture (Roerdink, Hlavackova & Vuillerme, 2011).

112   Input parameters for estimating the sample entropy were based on the median value of the

113   relative error (Lake et al., 2002) resulting in the selection of pattern length m=2 and error

114   tolerance r=0.08 and 0.05 as optimal parameters for ML and AP time series (normalized to unit

115   variance) respectively of all subjects and trials. SE was computed using MATLAB script

116   available at www.physionet.org. RT (in milliseconds) helped for determining the attentional

117   demand associated with postural control and was defined as the time interval between the

118   presentation of the auditory stimulus and the subjects' pressing the handheld button (Abernethy,

119   1988).

120

121   A linear mixed-effects model was used to test the effect of VFB on RT and COP indices. Trial,

122   feedback (no feedback vs. additional visual feedback) and their interaction were subjected as

123   fixed factors. The effect of trial was chosen as fixed factor to account for any potential fatigue

124   and/or learning effects. Participants were included as a random intercept to take dependency

125   (correlation structure) in the data into the account (Kuznetsov et al., 2015; Boisgontier et al.,

126   2017). Due to skewed distributions, we used log10-transformed data. The level of significance

127   was set at P<0.05. Random intercept models take into account the dependence of repeated trials

128   and have substantial advantages over repeated measures ANOVA. All analyses were performed

129   using free and open software JAMOVI 0.8.2.2 with GAMLj module (retrieved from

130   https://www.jamovi.org).

131

132   **Results**

133   RT was higher in the VFB condition (fixed effects ANOVA, $F_{(1,1094)}=96.89$, $p<0.001$). No

134   trial main effect ($F_{(9,1094)}=1.32$, $p=0.219$) or feedback x trial interaction ($F_{(9,1094)}=1.16$,

135   $p=0.317$) showed statistical significance. The distributions of the RT are shown in Figure 1.

136

137   Figure 1 about here

138

139   For SD there were no interaction feedback x trial effects for both ML ($F_{(9,114)}=0.92$, $p=0.507$)

140   and AP planes ($F_{(9,114)}=1.82$, $p=0.072$). SD was lower in the VFB condition for both ML

141   ($F_{(1,114)}=68.24$, $p<0.001$) and AP planes ($F_{(1,114)}=62.47$, $p<0.001$); there was no significant

142   main effect of trial (ML: $F_{(9,114)}=1.13$, $p=0.347$; AP: $F_{(9,114)}=0.95$, $p=0.483$).

143   For MV there were no interaction feedback x trial effects for both ML ($F_{(9,114)}=0.96$, $p=0.479$)

144   and AP planes ($F_{(9,114)}=1.40$, $p=0.198$). MV was higher in the VFB condition for AP plane

145   ($F_{(1,114)}=15.08$, $p<0.001$) and showed no change in the ML plane ($F_{(1,114)}=0.71$, $p=0.402$);

146   there was no significant main effect of trial (ML: $F_{(9,114)}=0.85$, $p=0.570$; AP: $F_{(9,114)}=0.74$,

147   $p=0.675$).

148   For SE there were no interaction feedback x trial effects for both ML ($F_{(9,114)}=0.94$, $p=0.490$)

149   and AP planes ($F_{(9,114)}=1.07$, $p=0.393$). SE was higher in the VFB condition for both ML

150   ($F_{(1,114)}=78.61$, $p<0.001$) and AP planes ($F_{(1,114)}=74.83$, $p<0.001$); there was no significant

151   main effect of trial (ML: $F_{(9,114)}=1.61$, $p=0.120$; AP: $F_{(9,114)}=1.60$, $p=0.123$).

152 For MPF there were no interaction feedback x trial effects for both ML (F(9,114)=0.98, p=0.463)

153 and AP planes (F(9,114)=0.846, p=0.575). MPF was higher in the VFB condition for both ML

154 (F(1,114)=68.49, p<0.001) and AP planes (F(1,114)=99.99, p<0.001); there was no significant

155 main effect of trial (ML: F(9,114)=0.813, p=0.605; AP: F(9,114)=0.50, p=0.827).

156

157 The distributions of the COP parameters are shown in the Figure 2.

158

159 Figure 2 about here

160

161 All analyses are available for download using the Open Science Framework: https://osf.io/mptkr/

162

163 **Discussion**

164 The purpose of this study was to determine whether and how the postural task with additional

165 visual feedback requires additional attentional demands in young adults. The results show that:

166 1) VFB condition requires additional attentional demands because reaction times were longer, 2)

167 concurrent visual feedback about postural sway shifts focus of attention not directly to postural

168 control because of increase of SE, 3) the implementation of the VFB task has triggered the need

169 for a change in the postural strategy through a reduction in the amount of sway and increase of

170 MV and MPF.

171 In agreement with our work, the increased COP entropy during visual feedback tasks was

172 reported by (Donker et al., 2008) and (Lakhani & Mansfield, 2015). They attributed these results

173 to the effect of using the external reference system which is thought to facilitate more automatic

174 control of posture (Wulf, McNevin & Shea, 2001). Similarly, the increased reaction times in our

175 experiments account for shifting the attention of participants to the task of keeping their COP

176 inside the target on the screen. Focusing significant attentional resources on the latter task took

177 from the attention which is normally used to maintaining postural control which also implies

178 more automaticity in maintaining balance.

179 All participants were able to effectively use the VFB in reducing their sway amplitude, yet this

180 activity was accompanied by the increase in sway frequency. Higher frequency of postural sway

181 has been often reported during dual tasks that led to reduced amount of attention which is

182   normally involved in postural control. It is argued that increased sway frequency results from

183   increased joint stiffness (Vuillerme & Vincent, 2006; Bieć et al., 2014). Such an interpretation

184   seems justified based on the relationship between the effective postural stiffness and the

185   frequency of the COP signal that was established by (Winter et al., 1998). In contrast, (Stins,

186   Roerdink & Beek, 2011) did not find a direct association between postural stiffness and the level

187   of automaticity in controlling posture. However, it is possible that postural tasks with visual

188   feedback have different effects on the distribution of attentional resources than other

189   supplementary cognitive tasks that are apparently not related to posture.

190   The difference lies in the final application of the attention diverted from posture and invested

191   into the supplementary task. In the latter tasks a necessary portion of attentional resources is

192   being withdrawn from the normal postural control and this loss requires compensation or some

193   other form of reinforcement. According to several authors, this is usually accomplished by

194   promoting the more automatic control process (Kuczyński, Szymańska & Bieć, 2011; Lakhani &

195   Mansfield, 2015).

196   However, in the former task, attention transferred to the VFB was indirectly reverted and

197   actually supported the process of postural control. Larger reaction times in the VFB indicate that

198   this task is attention demanding and one can speculate that the diverted attention is necessary for

199   the integration of the ancillary visual input with the remaining sensory information. Again,

200   elevated sway frequency seems to irrevocably contribute to this purpose. In fact, the stiffening of

201   postural strategy was suggested as the means to perform the postural exploratory and/or

202   monitoring function which significantly increases with the difficulty of postural tasks (Latash et

203   al., 2003). This exploratory function of sway is ceaselessly active, even during conscious control

204   of posture, and is thought to have random bearing. A certain level of randomness of spontaneous

205   sway is inherent because of its unconscious origin. However, an additional and quite substantial

206   uncertainty in this signal may develop from the conscious action of participants using the visual

207   error to correct their position inside the target on the screen. Although the purpose of action is

208   conscious, its timing and magnitude are not, and the two latter factors depend heavily on the

209   sensorimotor abilities and performance of the subjects. In other words, increased sway entropy

210   observed during VFB may be not only the consequence of a more automatic control of posture

211   but also the reflection of increased uncertainty in performance. This would be in agreement with

212 (Morrison, Hong & Newell, 2007) who found that subjects who voluntarily produced random
213 sway motions exhibited higher COP entropy as compared to standing still. In a similar vein
214 (Borg & Laxaback, 2010) postulated that higher entropy may be interpreted as an inability in
215 some circumstances to exert effective attentive control.

216 **Conclusions**
217 In conclusion, the VFB is effective in enhancing and improving postural performance. This
218 benefit is associated with increased sensorimotor activity which effect on humans, depending on
219 circumstances, may be different. VFB has higher attentional demands as compared to normal
220 stance. VFB increases irregularity and entropy of sway, still presented results seem insufficient
221 to disentangle the role of elevated automaticity or noisiness in these changes.
222

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Figure 1

Violin plots of the RT for the REF and the VFB conditions collapsed over trials with mean and standard deviations superimposed.

These plots show full distribution of the data obtained by kernel density estimation. The dot symbol denotes mean, whisker denotes standard deviation.
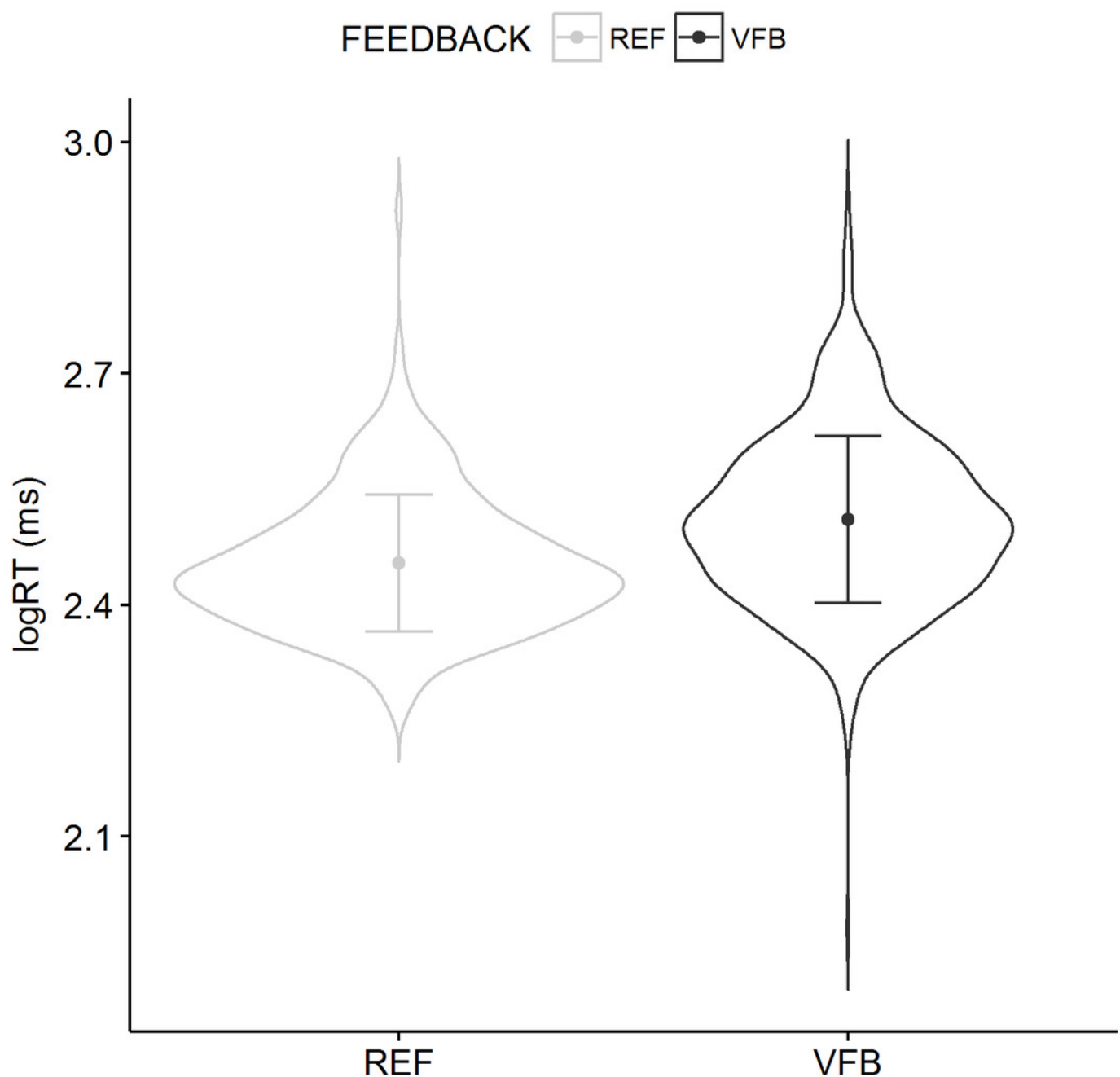
Figure 2

Violin plots of the COP parameters for the REF and the VFB conditions collapsed over trials with and mean ± standard deviations superimposed: SD – variability, MV – mean speed, SE – sample entropy, MPF - mean power frequency

These plots show full distribution of the data obtained by kernel density estimation. The dot symbol denotes mean, whisker denotes standard deviation.