

# 1 Sequential Analysis of Postural Control Resource Allocation 2 During a Dual Task Test

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## 6 **Abstract**

7 To investigate postural control factors influencing automatic (reflex-controlled) and  
8 attentional (high cortical) factors on dual task.Method : We used a dual-task model to  
9 examine attentional factors affecting control of posture, subjecting test subjects to vibration  
10 stimulation, one-leg standing and verbal or nonverbal task trials. Twenty-three young, healthy  
11 participants were asked to stand on force plates and their centers of pressure (COP) were  
12 measured during dual task trials. We acquired 15 seconds of data for each volunteer during six  
13 dual task trials involving varying task combinations.Results : We observed significantly  
14 different sway patterns between early and late phases of the dual task trials that probably  
15 reflect attentional demands. Vibration stimulation perturbed sway more during the early than  
16 the late phases; with or without vibration stimulation, the addition of secondary tasks  
17 decreased sway in all phases, and greater decreases in sway were observed in late phases when  
18 subjects were assigned nonverbal tasks. Less sway was observed during nonverbal task in a  
19 sequential study.

22 *Index terms*— task performance, analysis, postural balance, attention.

## 23 **1 Introduction**

24 sensory perturbations of visual, somatosensory, and vestibular systems disrupt postural stability. Postural control  
25 can be influenced by automatic (reflex-controlled) and attentional (high cortical) factors, and previous studies  
26 have suggested that postural control systems require varying degrees of attention depending on the postural  
27 tasks involved and the age of the subjects. [1][2][3][4][5] Attentional factors are thought to arise from the central  
28 nervous system (CNS), while automatic factors are reflex-controlled by somatosensory (muscle, skin and pressure  
29 receptors), visual and vestibular inputs. 6,7 Dual task paradigms are important tools for understanding balance  
30 control. The primary task is usually postural control, which involves standing on a force plate with different levels  
31 of difficulty, for example on an uneven surface or standing on one leg. Teasdale et al. 8 showed that adults of all  
32 ages exhibit delays in reaction time as postural task complexity increases. When vibrations are applied during  
33 primary postural tasks they typically cause directional shifts in subjects, due to increasing primary (Ia) afferents  
34 that are discharged during vibration and interpreted as lengthening of the vibrated muscles. 7 In previous  
35 studies, tendon vibration stimulation was shown to increase postural sway, and subjects frequently experience  
36 vibration-induced compensatory losses of balance, falling in the same direction as the applied vibration. 9,10  
37 However, in several studies directional shifts were either increased or decreased according to stimulation intensity  
38 and type. [11][12][13][14][15] The secondary task in dual task paradigms is usually attention demanding, and  
39 task intensity and difficulty influence postural control in various ways. 5,16,17 Both verbal and nonverbal tasks  
40 have been applied as secondary tasks in dual task paradigms. 18,19 Verbal tasks are considered relatively  
41 easy for participants to complete, while nonverbal tasks are more difficult due to their attention demanding  
42 characteristics. Verbal and non-verbal working memory are thought to be associated with different regions of  
43 the brain. [20][21][22] Several studies have explored the effects of tendon vibration on postural control and the

## 6 STATISTICAL ANALYSIS

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44 ability to complete tasks. However, the relationships between these parameters and postural sway have not been  
45 investigated in a dual task study design. Furthermore, the sequential relationship between automatic control and  
46 attention factors during in dual task contexts is still unclear.

47 We examined the sequential relationships of dual task on postural control. When subjects were subjected  
48 to dual task trials, we were able to sequentially observe the demands of attention factors, how they differed  
49 depending on the combinations of tasks that were presented, and the effects of attentional factors on balance  
50 control. The clinical implications of postural control can be understood through dual task performance and  
51 resource allocation analysis.

## 52 2 II.

## 53 3 Materials and Methods

## 54 4 Subjects

55 Twenty-three young, healthy participants participated in this study. No participants reported neurological or  
56 orthopedic disorders, and none were receiving medications known to affect postural control. All participants  
57 provided informed consent prior to testing.

## 58 5 Methods

59 A total of 23 subjects participated in the study. Detailed demographic data are shown in Table 1. All participants  
60 were randomly assigned to six trials (Table 2). Three participants were excluded due to poor compliance and  
61 the other 20 participants were included in experiments.

62 Each participant stood on his or her dominant leg on a force plate while watching a computer display monitor.  
63 While standing on the force plate, each participant was subjected six successive dual task trials in random order  
64 (Table 2). Secondary tasks were given to participants via the computer display and center of pressure (CoP)  
65 values were recorded during each experiment.

66 Subjects were asked to stand with arms folded and a button in one hand, and to press the button to indicate  
67 correct answers to task questions, in order to reduce any confounding effects of articulation. 23 All participants  
68 were allowed two practice trials, and each trial began with the 'ready' cue, followed three seconds later by the  
69 'set' cue. When the participants were told to be 'ready', they stood on one leg and held that position for 15  
70 seconds. Participants rested for one minute between trials.

71 A primary task involving proprioceptive vibration stimulation was given to subjects as they stood on one leg  
72 for 15 seconds. A vibratory motor (consisting of two vibratory plates: 10 gram, 10 mm) was applied to the skin  
73 overlying the Achilles tendon and tibialis anterior on the inferior third of the dominant leg. The vibratory motor  
74 (Jahwa Co., Seoul, Korea) produced a stimulus at 8000 rpm and 10 mm of motor diameter. The amplitude  
75 and intensity of vibration were controlled by NI LabVIEW 8.0 software. As soon as participants could feel the  
76 vibratory stimulation, we determined and set it at supra-threshold intensity.

77 Leg dominance was determined by ball kick tests. During the one-leg stand, the CoP was measured and  
78 recorded by a Bertec force plate ® (Bertec Inc., Columbus, USA) system that consists of four road cells and  
79 Acquire software version 5.1.

80 A cognitive task was presented to subjects either as a series of random characters (verbal) or shapes (nonverbal)  
81 displayed on a computer screen. If the presented character or shape was identical to the one that had been  
82 displayed two steps before (two back task), participants were asked to respond by pressing the button. 24,25  
83 Cognitive performance was calculated by the number of correct responses and the response time. Sway was  
84 measured by the force plates and amplified, and the summation of the sway distance during each trial was  
85 recorded as the distance from the center of pressure (DCP). Three trials of DCP data were acquired per each  
86 test (trial I-VI), and the mean values were calculated for use in analyses. The recorded force information was  
87 used to derive the position time function of the CoP for each trial.

## 88 6 Statistical analysis

89 Data were collected during three sessions performed on three different days no more than a week apart. Acquire  
90 software was used to receive signals from the force plate, and Matlab software (The MathWorks Inc., Natick,  
91 USA) was used to analyze the data after filtering with the Butterworth method. [26][27] Experimental parameters  
92 included vibration (on, off) and task context (no task, verbal task, nonverbal task). The total summations of  
93 sway distances of 15 seconds from six different trials each were compared using paired t-tests. Participant  
94 performance under different test conditions (no secondary task, verbal/nonverbal tasks without vibration and  
95 without secondary task, and nonverbal/verbal tasks with vibration) were compared using one-way ANOVA with a  
96 Bonferroni correction. The amount of sway in time sequence was analyzed using one-way repeated ANOVA. After  
97 first one second for one leg standing adjustment, the summation of sway distance in the first phase (2~8 seconds)  
98 and late phase (9~15) were compared using paired t test. To analyze the sway difference in time sequence, the  
99 sway differences in each second were acquired and compared with the first one second sway difference (2 ~3  
100 second) using a paired t test.

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101 **7 III.**

102 **8 Results**

103 The total summation of the DCPs is shown in Fig. 1. Participants exhibited more sway when subjected to  
104 vibration ( $434.99 \pm 86.73$  mm) than in trials with no vibration ( $416.54 \pm 70.97$  mm). The addition of verbal and  
105 nonverbal secondary tasks decreased sway compared to trials in which participants were not given secondary  
106 tasks. We did not observe any significant differences between trials when secondary tasks were provided with or  
107 without vibration stimulation.

108 However, during trials in which participants are asked to maintain one-leg stands, greater postural control is  
109 needed as time goes by to maintain balance and eventually the participants were forced to break posture. In our  
110 study, we observed that after 8~10 seconds, sway began to increase in such trials. In addition, when secondary  
111 tasks were given to standing participants, noticeable changes of sway were observed after 8~10 seconds (Fig. 2).  
112 Therefore, we split the trials into early and late phases with the distinction made when we observed noticeable  
113 sway differences (Fig. 3, 6). a) Vibration stimulation study One-leg standing tasks and/or vibration stimulations  
114 were given to participants as primary tasks. More sway was noted when supra-threshold intensity vibration  
115 stimulations were applied than in trials with one-leg standing alone (Fig. 2). Significant increases in sway were  
116 noted during early phases, but none were observed in the late phases. After an adjustment period with one  
117 leg standing (1~2 seconds), more sway was noted during vibration trials than in trials requiring participants to  
118 maintain one-leg standing alone, up to 9 seconds. However, after 9 seconds, we did not observe any significant  
119 differences in sway between trials. In one-leg stand trials, after a short adjustment period with one leg standing,  
120 more sway was noted during late phases compared to early phases. In trials combining vibration and one-leg  
121 standing, more sway was noted in early phases but then decreased in late phases. The greatest amounts of sway  
122 were noted at the end of both types of trials (14 ~15 seconds).

123 **9 b) Secondary tasks given to subjects standing on one leg**

124 Sway decreased when subjects standing on one leg were given each secondary task to complete (Fig. 3). We  
125 observed significant decreases in sway during the late phases of verbal task trials when compared to trials in which  
126 participants were not given secondary tasks. Compared to trials in which participants were given verbal tasks,  
127 decreased sway was noted for all phases during nonverbal task trials, but this difference was not significant.  
128 Significant decreases in sway were noted for all phases of nonverbal task trials compared to trials in which  
129 participants were not given secondary tasks. c) Vibration stimulation applied to subjects given secondary tasks

130 For trials in which subjects were given nonverbal tasks, the application of vibration stimulation increased sway  
131 in the late phases, though this increase was not significant (Fig. 4). In trials in which participants were given  
132 verbal tasks, the application of vibration stimulation increased sway in the late phases, but this increase also  
133 was not significant. In a general sense, vibration did not increase sway when secondary tasks were given in any  
134 phases (Fig. 5).

135 **10 d) Secondary tasks given to subjects standing on one leg  
136 standing and exposed to vibration stimulation**

137 The assignment of secondary tasks decreased sway in all phases in subjects standing on one leg and simultaneously  
138 exposed to vibration stimulation (Fig. ??). Trials in which subjects were given both verbal and nonverbal tasks  
139 resulted in significantly decreased sway in all phases compared to trials with no secondary tasks. Compared to  
140 trials in which participants were given verbal tasks, nonverbal task trials resulted in significantly decreased sway  
141 within an early phase.

142 IV.

143 **11 Discussion**

144 The present study implemented a difficult, attention-demanding two-step recall memory task. Postural changes  
145 were less apparent in subjects given attention-demanding tasks than in subjects given a primary task only.  
146 The effects of attention-demanding tasks are similar to those of external foci. Attention-demanding tasks  
147 divert attention away from postural control, perhaps allowing for more automatic processes and less conscious  
148 interference in the control of balance. 28 Previous studies have suggested that requesting participants to focus  
149 on body sway induced an increase in sway and hampered neuromuscular efficiency for controlling posture during  
150 standing. 29,30 This phenomenon has been explained by either high cortical arousal 5,16 or automatic reflex  
151 caused by the total consumption of attention factors. 4,5 Previous studies suggested that stimuli used to test  
152 verbal and nonverbal working memory are received and interpreted by different regions of the brain. Based on  
153 neural networks, it has been suggested that the verbal/non-verbal dichotomy reflects ventral/dorsal or left/right  
154 domain differences in the brain. [20][21][22] Prominent activation of the left hemisphere is associated with verbal  
155 coding while right prefrontal activation is associated with nonverbal coding. 20 Therefore, differences in the area  
156 of cortical stimulation targeted by different tasks may also be related to body sway. In our study, in non-verbal  
157 task trials, which are presumably related to right prefrontal activation, directional shifts were less apparent.

158 Perhaps right prefrontal activation allows for more automatic processes to activate and control balance without  
 159 conscious interference. On the other hand, in verbal task trials, which are presumably related to left hemisphere  
 160 activation, fewer automatic processes may take place.

161 We found that the application of vibration stimulation induced sway, especially in the early phases during which  
 162 more automatic factors are activated. This may reflect an increase in body awareness due to the application of  
 163 supra-threshold degrees of vibration stimulation. McIlroy et al. 17 hypothesized that the processing requirements  
 164 for postural control vary during the time course of stability recovery and that therefore the related attentional  
 165 demands also vary. The characteristics of the time courses predicted by stability recovery theory are very  
 166 intriguing, and it is not clear whether the results of McIlroy's study can be generalized to the control of human  
 167 posture. 5 Furthermore, no studies have evaluated each phase in sequence after several seconds of postural  
 168 control.

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### 170 13 Year

171 We observed postural control response during a total period of 15 seconds per trial. We hypothesized that the  
 172 action of attentional factors becomes more important as time goes on and that body awareness increases after an  
 173 initial adjustment phase. This is similar to the summation of McIlroy's three phases. We divided each trial into  
 174 early and late phases. After 8 seconds, the amount of sway in time sequence was significantly increased. From 0  
 175 to 8 ~10 seconds, the early phase includes the characteristic adjustment time for one leg standing and our results  
 176 implicate the involvement of more automatic reflexes during that phase, as stance does not seem to be disturbed  
 177 by attentional factors. The late phase starts after 10 seconds, during which attention factors become more  
 178 prominent. When participants were given difficult memory tasks to complete, sway greatly decreased compared  
 179 to the performance of participants who were not given such tasks (Fig. 2, 3, 6). From these results, it seems  
 180 possible that postural response can be divided into an early phase and a more attention-demanding late phase.

181 We attempted to induce changes in postural control resource allocation by implementing dual task paradigm  
 182 comprised of a postural task (one leg standing, vibration stimulation with supra-threshold intensity) and a high  
 183 demand cognitive working memory task (two-word recall). Cognitive resources play a key role in maintaining  
 184 postural stability in older adults, which may be due to an age-related decline in sensory and motor function.  
 185 8,[31][32][33] In previous studies, older adults are characterized as giving greater priority to the task that they  
 186 perceive to have greater importance. 34 Given a choice between postural control and a cognitive task, older  
 187 adults prioritized the former 35 due to the high prevalence of instability and risk of falling in the elderly. 34  
 188 In one study, young adults did not show a decrease in postural sway for either easy or difficult balance tasks.  
 189 36 However, Swan et al. 36 demonstrated a decrease in postural sway in older adults during difficult dual task  
 190 balance conditions, but no sway reduction for relatively easy balance tasks. Since demanding tasks impose greater  
 191 cognitive loads for older adults than younger adults, older adults may be better subjects in which to evaluate  
 192 changes in postural control resource allocation.

193 We observed the sequential influence of automatic and attention factors in dual task paradigms in young  
 194 participants. Our results suggest that optimal training strategies for patients at high risk of injury from falls,  
 195 such as older adults, should prioritize automatic factors and the maintenance of external focus over postural  
 196 control.

197 The shortcomings of our study include a relatively small sample size and broad vibration stimulation levels that  
 198 were not sensitive enough to assess the differing effects of varying, sub-threshold vibration stimulation intensities.  
 199 Future studies that include more subjects and more standardized levels of difficulty may demonstrate clearer  
 200 results. Future research should focus not only on a better understanding of dual task on postural control in time  
 201 sequence, but also on their detailed applications in various rehabilitation settings.

202 In conclusion, both the automatic and attentional factors are required for postural control. We observed  
 203 that the attentional factors were prioritized for postural control and more dominant in the later phase during  
 204 a sequential study. By controlling the postural control factors, optimal parameters and training methods for  
 205 postural control can be designed for use in practical applications.

206 V.

### 207 14 Conflict of Interest

208 No potential conflict of interest relevant to this article was reported. ? \*Denotes significant differences between  
 209 different secondary tasks (none and verbal, none and nonverbal). ? ?Denotes significant differences between none  
 210 and Vibration. ? viS stands for vibration and one-leg standing as the dual task.

## 211 15 VI.

212 ? S stands for one-leg standing only as the primary task.

213 ? COP stands for the center of pressure distance.

214 ? Denotes significant differences between viS and S. ? S stands for one-leg standing as the primary task.

215 ? Sv stands for one-leg standing as the primary task and a verbal task as the secondary task.

216 ? Snv stands for one-leg standing as the primary task and a nonverbal task as the secondary task. ? Denotes  
217 significant differences between Sv and Snv.  
218 ? Denotes significant differences between viS and viSv. ? viS, stands for vibration and one-leg standing as  
219 the primary task.  
220 ? viSv, stands for vibration and one-leg standing as the primary task and a verbal task as the secondary task.  
221 ? viSnv, stands for vibration and one-leg standing as the primary task and a nonverbal task as the secondary  
222 task. ? \*Denotes significant differences between viS and viSnv.  
223 ? Denotes significant differences between viS and viSv.  
224 ? Denotes significant differences between viSv and viSnv. ? viSnv, stands for vibration and one-leg standing  
225 as the primary task and a nonverbal task as the secondary task. ? Snv, stands for one-leg standing as the primary  
task and a nonverbal task as the secondary task. <sup>1 2 3 4 5 6 7 8</sup>



Figure 1: Figure 1 :

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<sup>2</sup>( ) B Sequential Analysis of Postural Control Resource Allocation During a Dual Task Test

<sup>3</sup>( ) B Sequential Analysis of Postural Control Resource Allocation During a Dual Task Test

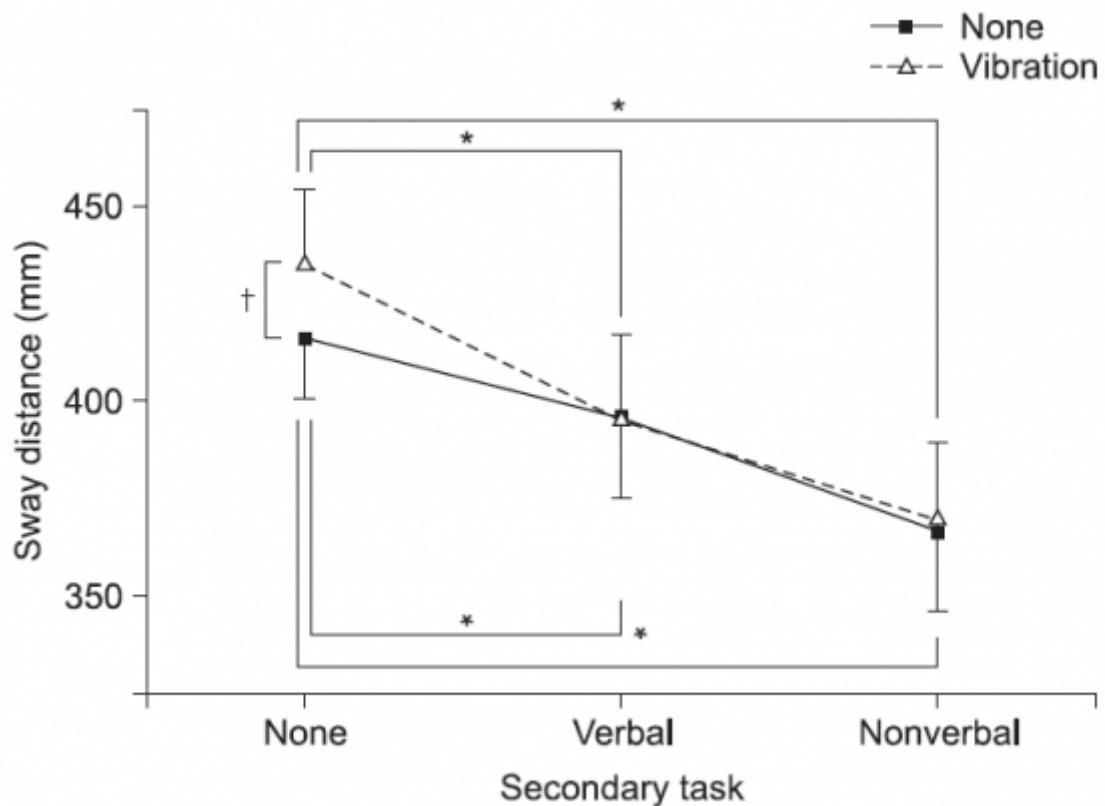
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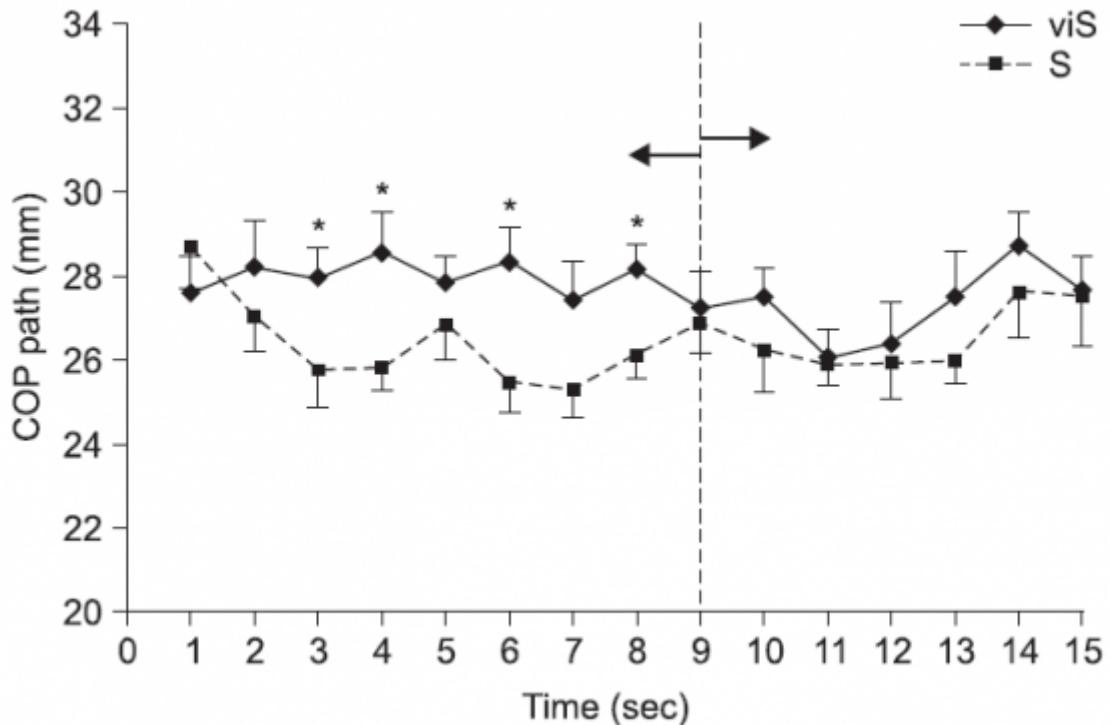
<sup>7</sup>( ) B Sequential Analysis of Postural Control Resource Allocation During a Dual Task Test

<sup>8</sup>( ) B Sequential Analysis of Postural Control Resource Allocation During a Dual Task Test



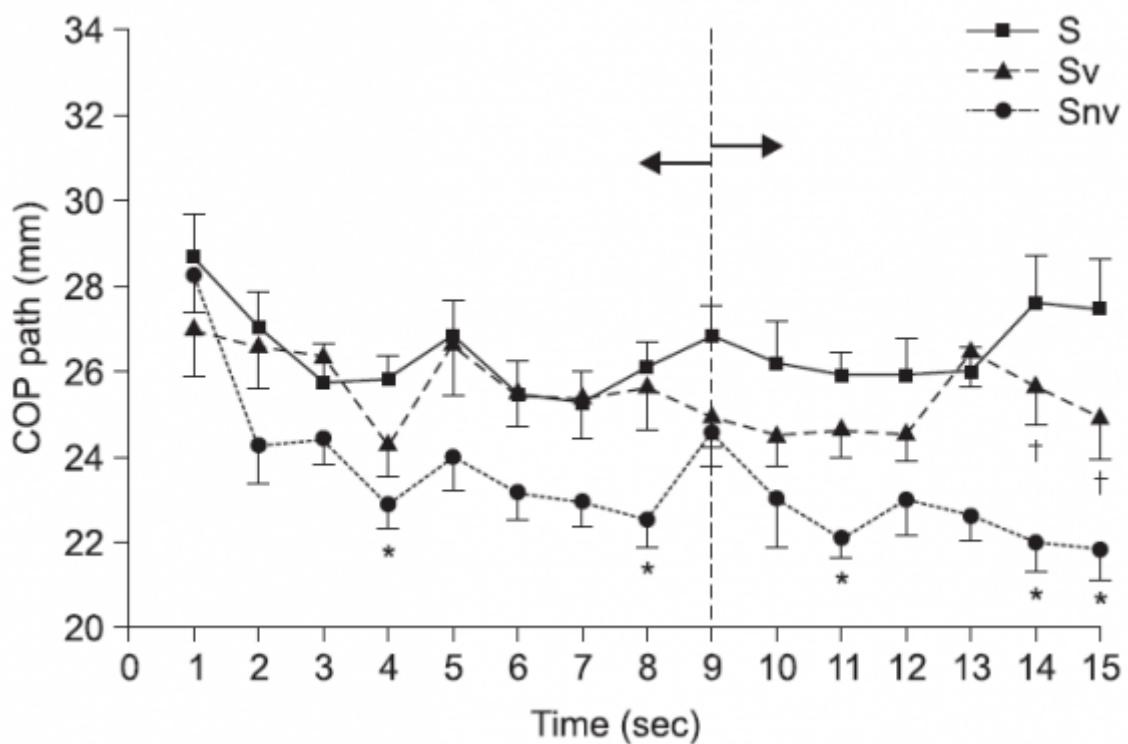
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Figure 2: Figure 2 :



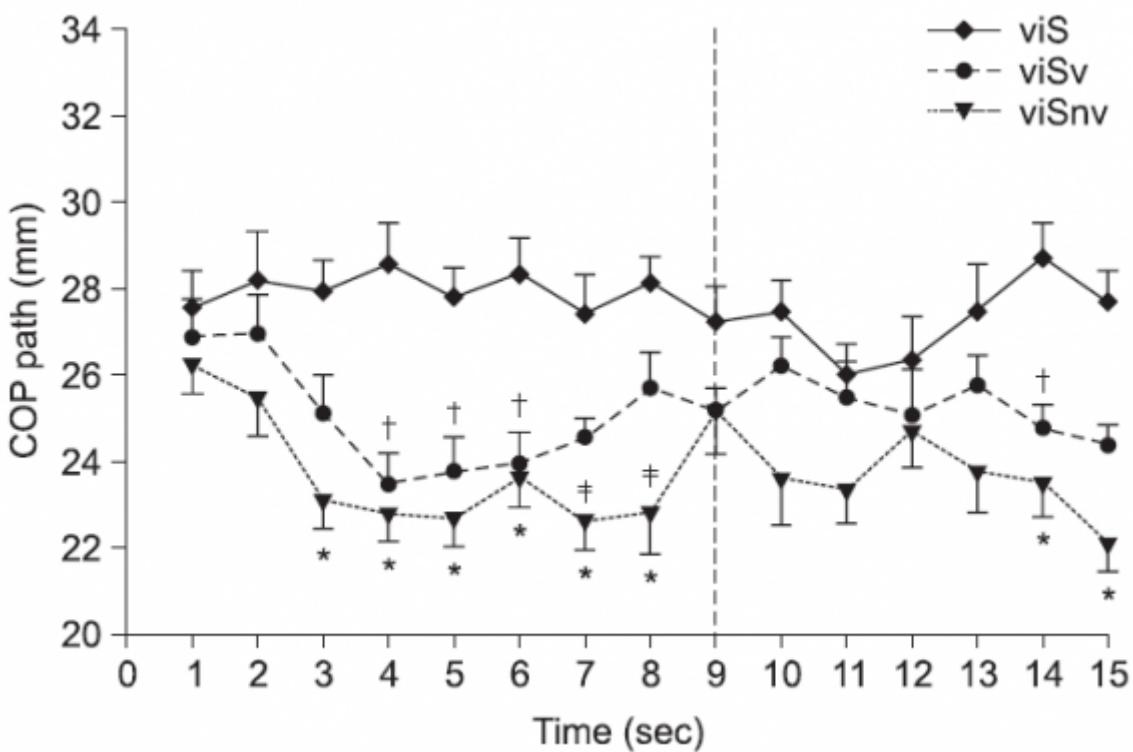
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Figure 3: Figure 3 :



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Figure 4: Figure 4 :



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Figure 5: Figure 5 :

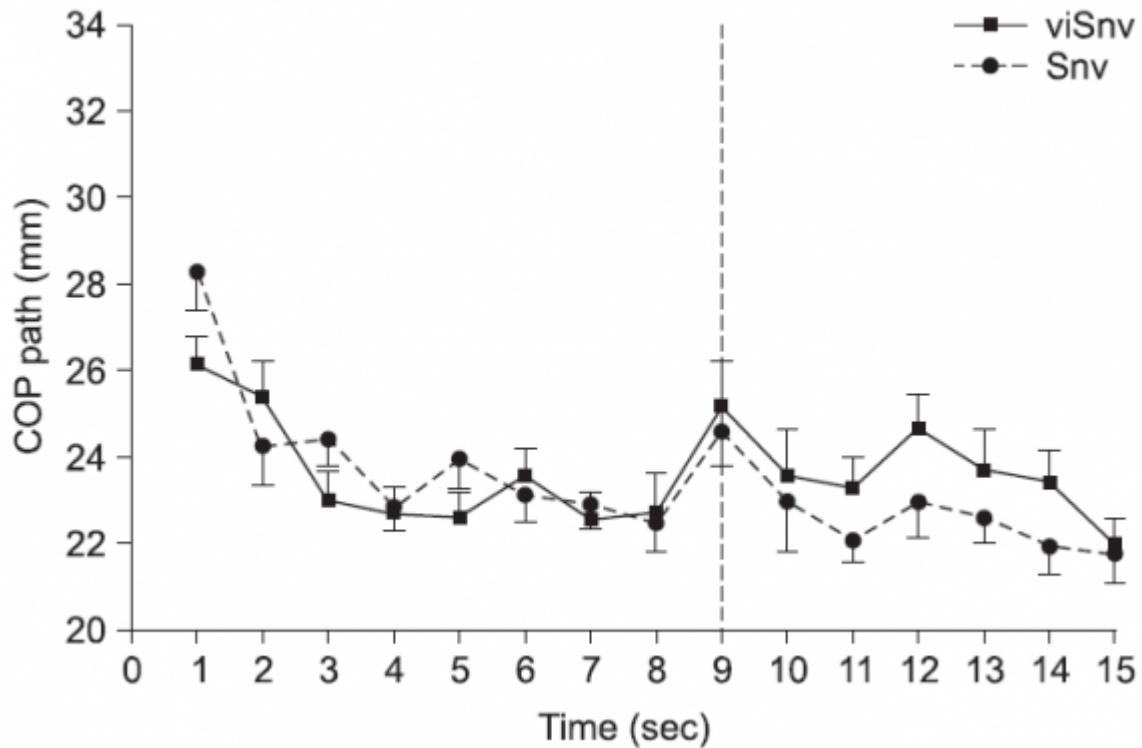


Figure 6:

1

	Verbal task	Nonverbal task
Sex(male/female)	11/9	
Age(year)	28.36±4.03	
Height(cm)	169.05±7.26	
Weight(kg)	59.94±12.16	
Accuracy of correction (%)		
Vibration off	0.84±0.09	0.78±0.14
Vibration on	0.83±0.09	0.80±0.12
Reaction time(ms)		
Vibration off	531.24±74.43	508.50±77.35
Vibration on (p<.05)	512.53±94.54	516.31±82.72

Figure 7: Table 1 :

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**2**

Name	Abbreviations	Condition	Sequence
Trial I	Trial II	S Sv	One leg standing
			One leg standing+verbal task
Trial III		Snv	One leg standing+nonverbal task
Trial I-1		viS	One leg standing+vibration on foot
Trial II-2	viSv	Trial III-3	One leg standing+vibration on foot+verbal task
		viSnv	One leg standing+vibration on foot+nonverbal task

Figure 8: Table 2 :



### 227 .1 Acknowledgments

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