The influence of an auditory–memory attention-demanding task on postural control in blind persons

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A B S T R A C T

Background: In order to evaluate the effect of an auditory–memory attention-demanding task on balance control, nine blind adults were compared to nine age–gender–matched sighted controls. This issue is particularly relevant for the blind population in which functional assessment of postural control has to be revealed through "real life" motor and cognitive function. The study aimed to explore whether an auditory–memory attention-demanding cognitive task would influence postural control in blind persons and compare this with blindfolded sighted persons.

Methods: Subjects were instructed to minimize body sway during narrow base upright standing on a single force platform under two conditions: 1) standing still (single task); 2) as in 1) while performing an auditory–memory attention-demanding cognitive task (dual task). Subjects in both groups were required to stand blindfolded with their eyes closed. Center of Pressure displacement data were collected and analyzed using summary statistics and stabilogram-diffusion analysis.

Findings: Blind and sighted subjects had similar postural sway in eyes closed condition. However, for dual compared to single task, sighted subjects show significant decrease in postural sway while blind subjects did not.

Interpretation: The auditory–memory attention-demanding cognitive task had no interference effect on balance control on blind subjects. It seems that sighted individuals used auditory cues to compensate for momentary loss of vision, whereas blind subjects did not. This may suggest that blind and sighted people use different sensorimotor strategies to achieve stability.

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1. Introduction

Postural control is maintained by a complex central sensorimotor system that integrates information from the vestibular, visual, and somatosensory systems (Nashner et al., 1989). Visual cues play a major role in posture control in healthy persons (Edwards, 1946; Paulus et al., 1984). In blind persons, a different central organization within the Central Nervous System (CNS) must take place as a reaction to the lack of visual input; thus, they would mainly rely on somesthetic, vestibular inputs to detect potentially disruptive postural sway and to correct balance. Because balance corrections occur rapidly, there must be CNS programs that organize balance information from different systems subconsciously, and automatically activate the appropriate correction strategies in such a way that neural commands to the posture stabilizing muscles can be corrected almost instantaneously for deviation in balance.

Studies (Pyykkö et al., 1991; Jeka et al., 1996; Rougier and Farenc, 2000) showed that blind people characteristically experienced greater postural sway than their sighted counterparts and relatively smaller sway when the sighted subjects were required to close their eyes (Schieppati et al., 1999; Schmid et al., 2007). However, these results are controversial, Ray et al. (2008) found that in the absence of vision, the vestibular and somatosensory systems function relatively the same both in blind and sighted individuals with closed eyes, indicating that vision plays a dominant role that cannot be replaced by other sensory inputs. Furthermore, Giagazoglou et al. (2009) found recently that the anterior–posterior postural sway in blind subjects was greater than in sighted subjects in eyes closed condition, whereas medial–lateral postural sway was similar.

In a real life situation, however, the requirement to control balance in blind persons occurs under more complicated circumstances and cognitive attention is focused elsewhere, e.g., listening or talking (e.g., a dual-task). To our knowledge the effect of auditory attention-demanding cognitive tasks on postural control in blind persons has been little studied. Consequently, there is a need to investigate balance...
function in blind persons during auditory attention-demanding tasks, a situation commonly encountered in real-life. Simultaneous performance of attention-demanding and balance tasks provides information that is different from that obtained from simple upright standing. This information could be interpreted in terms of automaticity of the acquired balance behavior in blind persons as an essential characteristic of the central organization process.

A dual-task procedure was developed to estimate the level of automaticity of a quiet upright standing task and to estimate the CNS processing speed (Neumann, 1984). Most theories on cognitive function conclude that the available processing resources are limited (Neumann, 1984). As a result, resource competition may occur during the performance of more than one task, leading to task interference and difficulty in performing one or both tasks (Brauer et al., 2002; Neumann, 1984; Wickens, 1989). Studies suggest that there are significant attentional requirements for postural control and that these requirements vary depending on the difficulty of the postural task and the balance abilities of the individual (Woollacott and Shumway-Cook, 2002). It was therefore predicted that the interference effect of a cognitive task would be low, or completely absent, in blind persons, who have a successful central organization and greater CNS processing speed of their balance control system.

The aim of the study was to explore whether a concurrent auditory memory attention-demanding cognitive task (i.e., dual task condition) would influence postural control in blind persons and compare this control with that of a group of age–gender-matched sighted persons in eyes closed and blindfolded condition. The following hypotheses were tested: (1) during a concurrent auditory–memory attention-demanding cognitive task, postural stability of blind and sighted subjects will be reduced compared with single task condition; (2) balance control in blind subjects would show less interference effect in dual task condition than sighted controls, suggesting that a successful central organization of balance control took place as a result of an everyday experience.

2. Methods

Our sample consisted of nine blind subjects, mean age 46.9 (SD = 12.9), height 164 cm (SD = 7.5), weight 72.2 kg (SD = 13.1), and Body Mass Index (BMI) 26.6 (SD = 3.1) who were diagnosed as suffering from blindness (B), and nine age–gender-matched sighted controls (C) (mean age 47.8 (SD = 12.9), height 168.2 cm (SD = 7.9), weight 75.1 kg (SD = 15), and BMI 26.4 (SD = 4.2).

The diagnosis of blindness was made following a complete evaluation by an experienced vision specialist (Dr. Y.R.) with more than 10 years of experience from the vision unit at Soroka University Medical Center, Beer-Sheva, Israel. The evaluation of vision loss was based on an ophthalmological examination. The blind participants had total blindness, inability to see anything with either eye (International Blind Sports Association, 2009), whereas the sighted participants had normal vision (i.e., visual correction where applicable). The cause of the visual impairment included optic nerve abnormalities, disorders of retina, congenital glaucoma, congenital cataract, and blindness caused by injury. All blind subjects had vision loss from early childhood or congenitally. None of the participants reported deficits in other sensory systems. All blind subjects were active as defined by being independent and proficient in their ability to move independently within their environment. All the participants passed a medical examination prior to the tests and had no other identifiable neurological, orthopedic, or psychiatric disability, and did not show signs of serious cognitive dysfunction (miniminal>24) that can affect motor control and postural stability. The subjects provided informed consent, in accordance with approved procedures by the Helsinki Ethics Committee in Soroka Medical Center (Clinical Trials Registration Number NCT00650676).

After eligibility was determined, the subjects were instructed to stand upright on a single force platform with the feet positioned as close as possible (heels and toes touching). They were also instructed to stand upright as still as possible, with their arms at their sides. A total of seven 30-second trials were conducted for each of the two task conditions: (1) single task — both blind and sighted subjects were required to stand blindfolded with their eyes closed; (2) dual task — standing upright as in (1) while performing an auditory–memory attention-demanding cognitive task. During the dual task trial the subjects were instructed to listen to a collection of 15 words (one word every 2 s) played through a single speaker that was placed 2–3 m in front of them (Fig. 1). The subjects were instructed prior to the 30 second trial to memorize and recall within the 30 s of the trial the number of words (out of the 15) that start with the specified capital letter after the completion of each of the 7 trials. The auditory–memory attention-demanding cognitive task was intended to divert attention. The number of memory task errors were counted in each of the 7 trials and presented as an average number of memory task errors. Memory task error is defined as number of words that the subject was not able to memorize.

Balance measurements were collected with a Kistler 9287 single force platform (Kistler Instrument Corp, Winterthur, Switzerland) that measures the time-varying displacement of the Center of Pressure (CoP) under the subject's feet. The force platform data were sampled at a frequency of 100 Hz and stored on a hard disk for later processing. Force platform data were analyzed using automatic code written in Matlab (Math Works Inc., Cambridge, MA, USA) to extract five commonly-used CoP traditional parameters of postural stability: 1) mediolateral CoP range (mm) (ML-sway range); 2) anterior–posterior CoP range (mm) (AP-sway range); 3) mean ML velocity of CoP sway (mm/s); 4) mean AP velocity of CoP sway (mm/s). Velocities were calculated by dividing the total excursion (sum of successive absolute displacements) in each direction by the duration of the trial; and 5) sway area (mm²) of the CoP points determined as the area enclosed by the CoP trajectory per unit time. These parameters were computed for each trial, and then averaged for each set of 7 trials to obtain an average value for each parameter and for each subject, in each experimental condition.

Stabilogramm diffusion analysis (SDA) was also performed on the CoP trajectories. SDA, as described by Collins and De Luca (1993) and Collins et al. (1995), provides a number of physiologically meaningful parameters. Among these are diffusion coefficients obtained by plotting the mean squared CoP displacement as a function of the time interval. This plot demonstrates two distinct regions: a short-term region and a long-term region. The short-term diffusion coefficients (D_s) and long-term diffusion coefficients (D_L), which characterize the effective stochastic activity of open-loop and closed loop postural control mechanisms, respectively, are derived from the slopes of the short-term and long-term regions of this plot (see example in Fig. 2). It has the form


Fig. 1. Set-up for measurements of postural sway in two task conditions: (1) single task — standing still with the eyes closed and blindfolded; (2) dual task — same as in (1) while performing an auditory–memory attention-demanding cognitive task played through a single speaker that was placed 2–3 m in front of the subjects.
been suggested that in the short-term region postural control system operates without feedback, whereas the long-term region reflects closed-loop control mechanisms that operate with sensory feedback (Collins and De Luca, 1993; Collins et al., 1995). The transition between short-term and long-term behavior has been termed the Critical Point, the coordinates of which would reflect the average time interval (Critical Time, Ctr) and sway displacement (Critical Displacement, Cdr) at which closed-loop control begins to dominate sway behavior. The scaling exponents Hrl and Hrs were calculated from the slopes of the resultant log–log plots of mean square CoP displacement versus time interval the interpretation described in details in Collins and De Luca (1993) and Collins et al. (1995).

### 2.1. Sample size

Sample size estimation was based on data presented by Giagazoglou et al. (2009), who have shown that the AP-sway range in blind subjects was 20 mm (SD = 7), whereas the AP-sway range of sighted subjects standing with their eyes closed, was 10 mm (SD = 6). Using the above numbers for a two-sided estimation at a significance level of 0.05 and 80% power, it was calculated that a minimum of 9 subjects in each group would be required to find significant differences.

### 2.2. Data and statistical analyses

Stabilogram diffusion parameters were calculated from the average CoP displacement versus time interval of all 7 trails computing a resultant SDA and taking advantage of the larger number of points of all 7 trails made in the study protocol, which is a critical issue especially for higher time-interval as described by Collins and De Luca (1993) and Collins et al. (1995). Post-processing of the collected data was carried out using customized software operating in the Matlab (The Mathworks, Natick, MA) programming environment. CoP time series were calculated from the ground reaction forces collected during each trial. CoP data were filtered using a 20th order zero-phase low-pass Butterworth digital filter with a cut-off frequency of 15 Hz. The initial and final 2.5 s of data were discarded. This eliminated transient effects of the filter and any “settling time” in the subject’s behavior, leaving 25 s trials for the calculation of stabilogram-diffusion parameters and summary CoP statistics.

Descriptive statistics are reported as mean and SD. We used the independent t-test to compare the experimental and control subjects with respect to different characteristics (age, weight, height, and number of memory task errors made during auditory–memory attention-demanding tasks between the two groups). Since postural stability parameters (ML-sway range, AP-sway range, mean ML sway velocity, mean AP sway velocity, and sway area) were not normally distributed (Shapiro Wilk statistic), non-parametric statistics, Mann–Whitney U-tests, and Wilcoxon signed rank test were performed to compare the differences between groups (blind vs. control) and task conditions (single vs. dual task). A significance level of 0.05 was used with Bonferroni adjustments ($P$ < 0.05/5 = 0.01). In addition, Mann–Whitney U-tests and Wilcoxon signed rank test were performed to compare the differences in SDA parameter (Drs, Drl, Ctr, Cdr, Hrl and Hrs) between groups (blind vs. controls) and task conditions (single vs. dual task). A significance level of 0.05 was used with Bonferroni adjustments ($P$ < 0.05/6 = 0.0083). All data analyses were performed using SPSS for Windows (SPSS Inc., Chicago, IL, USA).

### 3. Results

As shown in Table 1A, in the performance of single and dual tasks with eyes closed and blindfolded there were no significant differences between blind and sighted subjects in any of the traditional postural stability parameters.

### Table 1

**A. Postural stability parameters for both groups of subjects and both task conditions. Values are means (SD).**

<table>
<thead>
<tr>
<th>Effects of cognitive task</th>
<th>Blind (n = 9)</th>
<th>Sighted (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single task</td>
<td>Dual task</td>
</tr>
<tr>
<td>A. Postural stability parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sway area (mm$^2$)</td>
<td>81.8 (35.2)</td>
<td>77.9 (45.8)</td>
</tr>
<tr>
<td>ML sway range (mm)</td>
<td>32.5 (9)</td>
<td>30.5 (12.2)</td>
</tr>
<tr>
<td>AP sway range (mm)</td>
<td>28 (7.7)</td>
<td>27.3 (8.3)</td>
</tr>
<tr>
<td>Mean ML velocity (mm/s)</td>
<td>14.1 (4.2)</td>
<td>13.3 (4.2)$^a$</td>
</tr>
<tr>
<td>Mean AP velocity (mm/s)</td>
<td>15.9 (3.7)</td>
<td>14.7 (3.5)</td>
</tr>
<tr>
<td>B. Stabilogram diffusion parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-term effective diffusion coefficients in mm$^2$ s$^{-1}$ (Drs)</td>
<td>61.5 (13.9)</td>
<td>52.9 (13.6)</td>
</tr>
<tr>
<td>Long-term effective diffusion coefficients in mm$^2$ s$^{-1}$ (Drl)</td>
<td>3.1 (0.86)</td>
<td>3.8 (1.1)</td>
</tr>
<tr>
<td>Short-term scaling exponent (Hrl)</td>
<td>0.58 (0.05)</td>
<td>0.60 (0.48)</td>
</tr>
<tr>
<td>Long-term scaling exponent (Hrs)</td>
<td>0.12 (0.08)</td>
<td>0.16 (0.08)</td>
</tr>
<tr>
<td>Critical Time intervals in seconds (Ctr)</td>
<td>2.1 (0.9)</td>
<td>2.7 (1.2)</td>
</tr>
<tr>
<td>Critical Displacement in mm$^2$ (Cdr)</td>
<td>115 (21.4)</td>
<td>113 (30.6)</td>
</tr>
</tbody>
</table>

A significance level of 0.05 was used with Bonferroni adjustments ($P$ < 0.05/5 = 0.01) for traditional sway parameters and ($P$ < 0.05/6 = 0.0083) for stabilogram diffusion parameters. Note: there were no significant differences between groups.

$^a$ Between task conditions within groups.
For dual compared to single task conditions, sighted subjects showed a significant improvement in postural control. During a concurrent auditory–memory attention-demanding cognitive task (e.g., dual task condition), sighted subjects show a 24.75% decrease in the sway area (P = 0.001), 18% decrease in ML sway range, 14.5% decrease in AP sway range (P = 0.006 and P = 0.004, respectively), 15% decrease in mean ML velocity and 12.5% decrease in mean AP velocity (P = 0.002 and P = 0.007, respectively). However, blind subjects show no significant decrease in postural sway parameters for dual compared to single task, other than a 6% marginal decrease in mean ML velocity during the dual task condition (P = 0.025).

The blind and sighted subjects did not differ significantly in memory task errors during the performance of the auditory–memory attention-demanding cognitive task during dual task condition (0.87 vs. 0.33, respectively, P = 0.16).

The stabilogram-diffusion parameters demonstrated insignificant group differences during both single and dual task conditions (Table 1B). For dual compared to single task, sighted subjects demonstrated significantly lower short-term effective diffusion coefficients (D_{su}) and significantly lower Critical Displacement (C_{u}) (P = 0.002 and P = 0.002, respectively) during a concurrent auditory–memory attention-demanding cognitive task, while long-term effective diffusion coefficients (D_{u}), Critical Time Interval (C_{t}) and the Hurst exponents (H_{u} and H_{s}) were not significantly different (Table 1B and Fig. 2). Blind subjects show no significant decrease for dual compared to single task in all SDA parameters across task conditions.

4. Discussion

In this study we sought to quantitatively investigate effects of a concurrent auditory–memory attention-demanding cognitive task on postural stability of blind and sighted subjects. Sway-Area, ML-sway range, AP-sway range, mean-velocities, and SDA parameters in blind subjects were not different compared to sighted controls with eyes closed and blindfolded, indicating no differentiation between chronic- and momentary-term loss of vision. This suggests that there is no long-term compensation for vision loss by the increased use of alternative sensory modalities for balance control. In addition, a concurrent auditory–memory attention-demanding cognitive task used in the current study did not have an interference effect on postural sway in blind subjects, while postural sway in sighted subjects decreased significantly. This seems to oppose our hypotheses.

The use of dual task paradigms to examine the attentional requirements of balance control when performing a secondary task has shown that these are important contributors to instability; body sway typically increases in young and healthy old adults (Melzer et al., 2001; Pellecchia, 2003; Shumway-Cook et al., 1997b), as well as balance-impaired older adults (Maylor and Wing, 1996; Shumway-Cook et al., 1997a). Secondary cognitive tasks produced interference, with the most difficult cognitive task having the greatest influence on balance parameters (Lajoie et al., 1993). The results may suggest that the auditory–memory attention-demanding cognitive task used in the present study was a relatively simple, non-attentionally demanding, secondary task that does not present a significant threat to balance and thus resulted in no interference effect on postural stability in blind while sighted subject’s shows a clear reactivity to the auditory–memory attention-demanding cognitive task. Yardley et al. (1999) found that a silent counting task in eyes closed condition had no interference effects on stability in sighted young adults. Swan et al. (2004), who used spatial and non-spatial memory tasks in young and older sighted women, found that both tasks produced improvement in postural sway. Similarly we found that postural sway in sighted subjects was reduced in dual task compared with single task condition. Thus, the reasons that could explain the lack of interference effect seen in blind subjects are: (1) an auditory–memory attention-demanding cognitive task may not have an interference effect as do other cognitive tasks (e.g., verbal or visual tasks); (2) the memory task chosen was too easy; (3) the balance task chosen was too easy; (4) auditory input has a role for balance control.

Overall, the general effects of auditory information on postural stability in this experiment seem to be different for blind and sighted subjects. The data suggest that the auditory input might have a role for balance control in momentary-term loss of vision but not in blind persons. It is possible that momentary absence of vision in sighted participants resulted in a reliance on auditory input to maintain balance control. Stationary auditory information has previously been suggested to affect body sway (ase visual and haptic information) in sighted but also in congenitally blind people (Easton et al., 1998).

Examination of the SDA function of sighted subjects in the present study shows a decrease in postural sway over short-term intervals (D_{u} and C_{u}), during the concurrent auditory–memory attention-demanding task compared with single task condition. This indicates lesser sway displacement from an equilibrium point, before closed-loop feedback mechanisms are called into play. Sighted subjects in the current study were able to decrease the threshold by enhancing the auditory sensory feedback mechanisms contributions to posture during momentary loss of vision and close the loop at the same time interval (e.g. Critical Time intervals). In contrast to the open-loop/closed-loop control hypothesis, Peterka (2000) demonstrated that a simple linear proportion alintegral-derivative feedback model without the existence of sensory detection thresholds produced physiologically reasonable stabilogram-diffusion functions. From his results, it does not appear that modulation of any single parameter in the model can replicate the results of our study. For instance, if we assume that Peterka’s proportional element is analogous to ankle stiffness, our results are inconsistent with an increase in stiffness such as that seen in Laughton et al. (Laughton et al., 2003). A decrease in postural sway over short-term intervals was found to be correlated with a decrease in muscle co-activation, and less stiffening and rigidity during quiet standing (Laughton et al., 2003) and thus improvement in balance control. Results of our study suggests decreased muscle co-activation in sighted subjects during performance of auditory task and consequently show a better postural control over short-term in eyes close condition. These results suggest that auditory input may partially substitute for the momentary lack of visual input for postural control by taking the postural control system towards a new steady state associated with a different control strategy.

This study suggests that blind subjects may not customarily use auditory information for precise postural control. In their review, Hötting & Röder (2009) support the assumption that a reorganization of the auditory cortex in the blind results in superior auditory skills. In everyday life, blind humans rely more on auditory information than sighted humans to recognize people, localize events, or process language. However, Lewald (2002) found that under some specific conditions blind participants have been found to perform worse than sighted controls, including localizing sounds in the vertical plane. Our results may suggest that the central organization of the balance control system took place as blind subjects have the ability to maintain balance without the use of auditory information. This is in line with Hakkinen et al. (2006), who suggested that blind individuals rely mainly on proprioceptors for balance control.

In conclusion, the present study demonstrates that a concurrent auditory–memory attention-demanding task was too easy, not sufficiently attention-demanding, and did not have an interference effect on postural stability on blind subjects, furthermore it even reduce sway in sighted subjects during momentary loss of vision. The results based on this fairly simple study, with a relatively small sample size, may suggest that blind and sighted people use different sensorimotor strategies to achieve stability. The auditory cues seem to be used by sighted individuals to compensate for momentary loss of vision, helping the brain to actively change to a more feedback-based control activity over standing posture. Thus, it is concluded that the
different effects of auditory cues on blind and sighted individuals represent a central organization that took place in blind subjects who seems to rely less on auditory input for balance control.

References


