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Auditory cues behind congenitally blind subjects improve their balance control in bipedal upright posture

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ABSTRACT

Background: Congenitally blind subjects developed postural adaptations improving somatosensory and vestibular systems to maintain upright stability and auditory skills to orient them in environment. However, the influence of auditory cues on upright stability in congenitally blind subjects stays unknown.
Research question: The aim of this study is to define the influence of an auditory cue in congenitally blind subjects back space on their balance posture.
Methods: Eleven sighted subjects and eleven congenitally blind subjects performed upright bipedal and unipedal quiet stances on a force plate with two conditions of auditory cue played by a loudspeaker placed 2 m behind them. Mean CoP velocity were recorded. Student test was used to compare significant difference between blind and sighted subjects bipedal and unipedal postures stability in both conditions of auditory cue.
Results and significance: Results showed that congenitally blind subjects had no significant difference in mean sway velocity compared to sighted subjects in bipedal upright posture in auditory signal condition. However, blind subjects had significant lower mean sway velocity than sighted subjects in bipedal upright posture without sound. Blind subjects had significant increased mean sway velocity during unipedal quiet standing in both auditory cue conditions (with and without sound). The results showed that congenitally blind subjects used auditory cues placed behind them in order to improve their balance control in bipedal upright posture. In this case, blind subjects could better use compensatory mechanisms to perform quiet standing as sighted subjects. Without sound or in unipedal upright posture, congenitally blind subjects probably have sensory perturbations or limitations that impose them adaptations in order to avoid falling risk. Auditory cues should be study in the aim to better understand the compensatory mechanisms used by congenitally blind subjects to perform postural balance in usual environment.

1. Introduction

Predictions about total blindness prevalence could reach about 39 millions of people all over the world in 2020 [1]. For these people, various day life activities, like opening a door or waiting at crosswalk, need to maintain upright posture according to external constraints imposed by environment and without visual information. In this case, upright posture with visual impairment improve falling risk [2–4]. Because vision has major importance in balance control during quiet standing [3–7], various studies tried to describe upright posture center of pressure (CoP) fluctuation and body sway in blind subjects [7]. Blind subjects adopt postural strategies with modified perception of environment [7,8]. Visual impairment could be partly compensated by vestibular and somatosensory systems in order to maintain balance posture [3,9]. People with congenital or more than three years blindness developed postural control adaptations that could make up absence of vision [3,9,10]. As example, congenitally blind subjects have better balance control in bipedal quiet standing on different supports (solid and foam surfaces) than subjects with visual acquired impairment [3]. Congenitally blind subjects could compensate their visual impairment increasing the use of somatosensory and vestibular systems to maintain upright stability [3,10,11].

Blind subjects in quiet standing present lower difference between center of gravity and CoP displacements [10] and lower sway amplitude of their CoP than sighted subjects with closed eyes [3,10]. This reduced CoP sway amplitude has been notably observed in congenitally

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blind subjects [3]. According to these studies, Blind subjects have developed motor organization where somatosensory system changes muscular stiffness in order to maintain stance without external or environmental perturbation [3,10]. As consequence, blind subjects have faster reaction times to overcome balance control associated with ground platform perturbations compared to sighted subjects [12]. Blind subject showed better proprioceptive acuity of ankle dorsi-flexion than sighted subjects [13]. Blind subjects have similar muscle pattern activities compared to sighted subjects in various upright posture [12]. In all cases, Blind subjects could maintain their postural balance without influence on their muscular lower limb's strength that remains similar to sighted subjects [4]. As consequence, upright balance control in blind subject is nearby sighted subject with eyes closed in static and mobile ground platform [4,14]. As for sighted subjects with eyes closed, head and hip of blind subjects move together and follow floor's oscillations [14,15]. By not exploiting all body's degrees of freedom, blind subjects use a strategy to increase the vestibular system stimulation which may be related to the presence of anxiety [14,16]. However, some results about blind subject's skills in order to overcome visual impairment during balance control remain unclear [14]. As example, whereas blind subjects seems to develop specific haptic cues [11,12,15], their head kept larger movements than sighted subjects when postural control was associated with additional haptic aids [15]. In some other studies, blind subjects present lower antero-posterior bipedal upright stability than sighted subjects with eyes closed [4,13]. Few studies tried to understand the respective influences of vestibular and sensorimotor skills in blind subjects in single leg stance upright posture [4,13]. For these studies, vestibular and sensorimotor skills can't compensate the absence of vision in unipedal quiet standing. That the reason why blind subjects and sighted subjects with eyes closed present similar lower stability in single leg stance that sighted subject with visual cues [4,13]. As consequence, the effect of compensatory mechanism using only vestibular and somatosensory systems remains difficult to assume the whole role maintaining or improving postural balance in congenitally blind subjects.

In the other way, recent studies tried to understand how congenitally blind subjects take into account auditory cues to improve their postural sway and compensate visual deprivation [17,18]. Auditory skills could be developed by congenitally blind subjects as compensation mechanism that could help them to improve their spatial orientation and mapping environment [15,18]. Lessard et al have shown that early blind subjects can develop mapping information using auditory cues as least as accurate than sighted subjects [19]. According to Gori et al, congenitally blind subjects rely strongly auditory cues to orient them in environment [20]. Spatial representations of subjects have variations in accurate perception of the space using auditory cues around their body. In back space of the body, lack of visual stimuli increase noticeable brain selectivity of auditory information [21]. In this way, subjects present better accurate space mapping when they perceive auditory cues from their back chest than when they receive auditory information auditory cues coming in front of them [21]. Blind subjects present functional visual cortex activation of primary and secondary visual areas during auditory localization [22].

To our knowledge, any study focused on congenitally blind subjects in upright single and two legs standing posture taking into account auditory cues. The aim of the present study is to define the influence of an auditory cue in back space on one and two legs balance posture in congenitally blind subjects. We hypothesis that congenitally blind subject improves his postural stability in presence of sound in back space, compared to sighted subjects with open eyes.

2. Material and methods

Eleven congenitally blind subjects (10 males and 1 female) with respective mean ± standard deviation age = 22.9 ± 1.2 years, body mass = 76.4 ± 2.5 kg and height = 181.82 ± 3.43 cm participated in this study. Congenitally blind subjects had no vision from birth and were proficient in braille readers. Evaluation of severity of vision loss was based on ophthalmological examination. Blind participants had visual acuity less than 20/400 in better eye or visual field less than 10° around central fixation [23]. Eleven sighted subjects with similar weight and height characteristics (9 males and 2 females, age = 23.3 ± 1.4 years, body mass = 74.4 ± 5.2 kg and height = 173.36 ± 6.73 cm) were also enrolled. Sighted subjects were healthy without any visual impairment. All subjects (Sighted and blind) were right handed dominant and presented any deficit in other sensory system. All subjects were undergraduate and graduate students in caregiver or manual therapy and gave informed consent prior participation. The study was approved by the local ethic committee, and complied with the Helsinki declaration.

Each subject stood on a force platform (Neuro Com Balance Master) that recorded CoP at 100 Hz sampling frequency. Subject was asked to stand in upright posture on the force plate in natural position, with arms along his body, looking forward (with a target attached forward their eyes for sighted subject). A loudspeaker placed 2 m behind the subject at 1.2 m height was used in order to present a sound at 40 dB during each subject's upright posture. The loudspeaker's position was fixed approximately on behind the subject's chest in order to improve spatial representation around the body using auditory skill [21]. The sound stimulus delivered by the loudspeaker was an alarm beep with principal component at 1000 Hz [21].

During the experiment, participants were tested under four unipedal conditions and two bipedal conditions. For each condition, three trials were held, meaning a total of 18 trials. First, the subject performed 10 s trials of unipedal quiet stance [4,13] on each foot (left and right) on the force plate according to Neuro Com software recommendations. Three unipedal trials on each foot (left and right) were performed with auditory stimulus. Three other unipedal trails on each foot were performed without sound. The subject had two minutes' break between each quiet stance. Then, the subject performed six 30 s trials bipedal quiet standing with feet placed on the force plate with angle of 30 ° between midpoint of heel and distal end of great toe and 10 cm between internal malleolus. As for unipedal trials, the subject performed three trials with auditory stimulus and three others without sound. All trials with auditory stimulus were realized with a constant auditory signal during the whole trial time. Auditory stimulus was presented in randomized order for unipedal and bipedal conditions. Neuro Com software converts subject's CoP data into mean sway velocity ($deg.s^{-1}$) for each trial. Mean sway velocity of the three trials were computed in each condition (with and without sound in unipedal and bipedal conditions). In bipedal condition, only the 10 s at the middle time of the trial were used to compute mean sway velocity [24] in the aim to compare unipedal and bipedal conditions.

Shapiro-wilk test confirmed the normality of the mean sway velocities in each condition. Student test were used to compare significant difference between blind and sighted subjects with sound and without sound conditions. Statistical significance was accepted at $p < 0.05$.

3. Results

Student test results (Table 1) showed that blind subjects (B) had significant higher mean sway velocity than sighted subjects (S) in left unipedal upright posture without sound (V_{CoP} B = 1.47 ± 0.21 $deg.s^{-1}$ vs V_{CoP} S = 0.79 ± 0.13 $deg.s^{-1}$; $p = 0.001$). Blind subjects had also significant higher mean sway velocity than sighted subjects in left unipedal upright posture with auditory signal condition (V_{CoP} B = 1.7 ± 0.46 $deg.s^{-1}$ vs V_{CoP} S = 1.08 ± 0.32 $deg.s^{-1}$; $p = 0.001$).

Blind subjects had significant higher mean sway velocity than sighted subjects in right unipedal upright posture without sound (V_{CoP} B = 1.88 ± 0.27 $deg.s^{-1}$ vs V_{CoP} S = 0.95 ± 0.14 $deg.s^{-1}$; $p = 0.001$). Blind subjects had also significant higher mean sway velocity than sighted subjects in right unipedal upright posture with auditory signal

Table 1
Mean sway velocity (degree. m^{-1}) in congenitally blind subjects compared to sighted subjects in bipodal an unipodal upright posture with auditory signal versus without sound (Mean ± standard deviations). Level of significance: † for $p < 0.05$; ‡ for $p < 0.01$.

	Auditory stimulus		Without sound	
	Sighted subjects	Blind subjects	Sighted subjects	Blind subjects
Bipodal	0.38 ± 0.15	0.39 ± 0.28	0.4 ± 0.14	0.27 ± 0.11 †
Left foot unipodal	1.08 ± 0.32	1.7 ± 0.46 ‡	0.79 ± 0.13	1.47 ± 0.21 ‡
Right foot unipodal	1.02 ± 0.2	1.55 ± 0.49 ‡	0.95 ± 0.14	1.88 ± 0.27 ‡

condition (V_{CoP} B = 1.55 ± 0.49 deg.s^{-1} vs V_{CoP} S = 1.02 ± 0.02 deg.s^{-1}; p = 0.001).

Blind subjects had significant lower mean sway velocity than sighted subjects in bipedal upright posture without sound (V_{CoP} B = 0.27 ± 0.11 deg.s^{-1} vs V_{CoP} S = 0.4 ± 0.14 deg.s^{-1}; p = 0.02). Blind subjects had no significant difference in mean sway velocity compared to sighted subjects in bipedal upright posture in auditory signal condition (V_{CoP} B = 0.39 ± 0.28 deg.s^{-1} vs V_{CoP} S = 0.38 ± 0.15 deg.s^{-1}; p = 0.88).

The Results of sighted subjects mean say velocity of the present study were consistent with previous study of sighted healthy subject with similar age, height and mass [25].

4. Discussion

To better understand how auditory cues placed behind them influence congenitally blind subjects postural balance in quiet stance, we examined the differences in unipedal and bipedal upright posture in two auditory conditions (with auditory stimulus and without sound) between a group of congenitally blind subjects and a group of healthy sighted subjects. The overall results showed that congenitally blind subjects in unipedal quiet stance didn't use auditory cues ideally placed on their bodies back to improve their balance posture. However, in bipedal quiet stance, congenitally blind subjects presented similar balance posture as open eyes sighted subjects in quiet stance associated with auditory signal placed behind them.

The results of the present study in unipedal quiet stance are in agreement with results of Ozdemir et al, realized without sound where blind subjects increased their sway amplitude on each one leg stance more than sighted subjects with eyes open [13]. Although blind subjects could better involve their somatosensory systems, especially at ankle proprioception, they presented lower balance stability in one leg stance than sighted subjects [13]. In the present study, auditory cue didn't improve stability in one leg stance enough to permit blind subjects to improve the balance posture as sighted subjects. As already described in other studies, the use of compensatory mechanism seems to be limited for blind subjects [13,14]. In the case of one leg stance, auditory cues appear to have minor effect on balance posture. In this case, blind subject seems to use larger oscillations in order to maintain posture using especially somatosensory and vestibular functions [13,14]. As in other daily activities (walking with gait-assistance devices, gait initiation during crosswalk, etc.) congenitally blind subjects remains essentially dependent on somatosensory functions to control balance posture one leg quiet stance [11]. According to Nakata et al, congenitally blind subjects may have enhanced abilities that use somatosensory system in order to maintain postural balance in specific posture in order to prevent falling risk [12].

The results of the present study in bipedal quiet stance are in agreement with some previous studies realized without sound where blind subjects were characterized by lower sway amplitude than sighted subjects with eyes open [3,10]. Without auditory signal, congenitally blind subjects seem to be more stable than healthy subjects. This could be explain by compensatory mechanisms where blind subjects initiate early changes in cortex activations in order to better take into account somatosensory system [3]. If blind subjects seem to develop less energy expenditure in order to maintain upright posture, this lower sway could limit blind subjects to unpredictable perturbations [10]. Surprisingly, when an auditory cue was placed behind them, both blind and sighted subjects of the present study performed similar sway velocity. These results could be explained by some links between vestibular system and the expression of anxiety and emotion [26]. In absence of auditory cues, congenitally blind subjects can maintain their quiet stance only using somatosensory and vestibular systems. This situation could be source of anxiety that could change the parabrachial nucleus activity which has connection with the vestibular system [26]. For congenitally blind subjects, the lack of sound information limits the use of auditory cues and could disturb attention and emotional activities. These perturbations could modify blind subject skills to use his vestibular function. In this case, blind subject could only promote somatosensory system information that could limit the use of the compensatory mechanism using only joint stiffness [10,27]. In the present study, the increase of sway amplitude in congenitally blind subjects' upright posture associated with auditory cues compared to sighted subjects could be explain as a better using of auditory, vestibular and somatosensory systems. Using auditory cues, congenitally blind subjects could better use all compensatory mechanisms in order to better maintain their balance posture and to face environment perturbations [3,9,18]. These results are in agreement with the study of Weeks et al [28] and various other studies that have shown brain plasticity of blind subjects activating visual cortex areas associated with usual posterior parietal areas in order to map space using auditory cues [22,29].

The results of the present study could be limited by the low number of blind subjects that have participated. To our knowledge, the present study is the first that afforded more than ten congenitally blind subjects performing one leg stances [4,13]. Future studies with bigger sizes of congenitally blind subjects could be provided in order to better understand the influence of auditory cues on balance posture. Another limitation of the present study could be the absence of dominant leg in unipedal balance testing. Indeed, the present study only focuses on the influence of auditory cues on quiet stance in bipedal and unipedal posture. Due to the fact that the force plate was not able to estimate limb difference [30,31], complementary studies using kinematics assessment would be set up in order to investigate the influence of auditory cues on dominant one leg postural control [30,31].

5. Conclusion

The present study showed that auditory cues placed backward chest of congenitally blind subjects could increase their balance control in bipedal upright posture compared to sighted subjects. In this case, blind subjects could better use compensatory mechanisms to perform quiet standing as sighted subjects. Without sound or in unipedal upright posture, congenitally blind subjects probably have sensory perturbations or limitations that impose them adaptations in order to avoid falling risk. Congenitally blind subjects' skills to use auditory cues can't totally compensate somatosensory and vestibular systems perturbations in postural control on one leg stance. Congenitally blind subjects seem to be more dependent to the nature of the environment and the postural task than sighted subjects. In clinical application, add auditory cues at specific points (pedestrian crossing, hospital corridor, etc.) could help congenitally blind subject in daily activities in order to prevent falling risk [28].

Declaration of interest

None.

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