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Article

Sound Effects on Standing Postural Strategies in the Elderly via Frequency Analysis Approach

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Featured Application: The frequency analysis could identify the sound effects on postural sway in dual-tasking. Older adults prioritize the vestibular regulation for postural control when performing a hand task in standing.

Abstract: Sound and sound frequency could improve postural sway in the elderly. The power spectrum intervals of the center of pressure (COP) displacement are associated with different postural regulations, which could be revealed by frequency analysis. The aim of the study was to investigate the effects of sound on dual-tasking postural control and conduct frequency analysis to distinguish postural regulations in the elderly. Fifteen young and 15 older healthy participants were instructed to stand on a force platform and performed the Purdue Pegboard test while hearing 50 dB sounds with sound frequencies of 250 Hz, 1000 Hz, 4000 Hz, or no sound. The total excursion, velocity, sway area, and power spectrum of low-, medium-, and high-frequency bands of the COP displacement were calculated in the anterior–posterior and medial–lateral directions. The percentages of low-frequency and medium-frequency bands in both directions were significantly different between with and without sound conditions, but not affected by sound frequency. Older adults showed a smaller percentage of low-frequency, larger percentage of medium-frequency, larger total COP excursion, and faster velocity in the medial–lateral direction. The outcome of the study supports the frequency analysis approach in evaluating sound effects on postural strategies in dual-tasking and reveals older adults utilize vestibular regulation as the primary postural strategy when the dual-task required visual attention.

Keywords: postural control strategy; frequency analysis; dual-task; older adult

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1. Introduction

The standing position is the fundamental posture for humans to perform daily activities and requires a certain level of postural control for balance maintenance. Aging degrades sensory functions or declines the ability of sensory integrations, which further induces losing balance and falling in the elderly. Postural control involves the visual, vestibular, and somatosensory systems [1], and there could be reweighting between each system depending on external stimulations [2]. Auditory noise sound has been documented to improve postural control [3,4], and act as additional information to postural regulation [5]. In older adults, white noise sound reduces postural sway [6], and sound frequency has been documented to positively affect posture control [4]. Specifically, a high-frequency band, such as 1000 or 4000 Hz, could improve postural control and significantly decrease the sway area during extreme loudness [4]. Sakellari and Soames [7] also reported that high frequency sounds affected postural regulation in the anterior–posterior direction. The intensity and frequency of sounds influencing postural regulation of stability is associated with the relationship between the vestibular system and organs of Corti in the inner ear [8]. Vestibular modulation by hearing aids has been documented to improve postural control in individuals with hearing loss [9]. However, changes in postural regulations by vestibular interference induced by sound effects are not evident in the elderly.

For revealing postural regulations, one approach is to evaluate the spectral analysis of body sway, which has been employed in young, older adults, and individuals with neurological impairments [10–14]. Frequency domain analysis provides corresponding postural strategies in controlling body sway. Center of pressure (COP) excursions are transformed into the power spectrum and divided into low-, medium-, and high-frequency bands [10,11,13]. Low-frequency is associated with visual regulation, medium-frequency with vestibular and somatosensory regulation, and high-frequency with somatosensory regulation [12,13]. Redistribution of the magnitudes between low- and medium-frequency bands in the COP medial–lateral direction was observed in the absence of vision [12,13]. In addition, older adults also showed an increase in high-frequency band in COP anterior–posterior and medial–lateral directions [14]. The outcomes of these studies confirmed that the spectral analysis approach distinguished strategies of postural control. Hence, the spectral analysis approach might be useful to identify the effects of sound on changes in postural regulations. Although older adults have shown less efficient postural control [15], previous studies of postural control generally focused on body sway in quiet standing [16,17], and instant limb movements, such as pushing tasks [18,19] or gait initiation [20,21]. These instant limb movements have been considered as a dual-task perturbation to standing balance and significantly affected changes in COP displacements [18,19,21]. However, when performing daily activities, most hand tasks are continuous movements and require visual attention. This kind of voluntary movement as dual-tasking to postural control might superimpose the effects of perturbations and further affect postural regulations, particularly sensory degenerations in the elderly. However, the reweighting postural regulations might not be revealed by general COP displacement evaluations, thus an alternative approach is necessary, such as spectral analysis. Therefore, the objective of the current study was to investigate the effects of sound on postural strategy during a dual-task of continuous hand movement through spectral analysis of COP displacement. The experimental paradigm involved silence and sounds of 50 dB with three different sound frequencies, while performing a hand task using the Purdue Pegboard test. The first hypothesis was that sound frequency would influence COP displacement and a redistribution with decreased magnitude of low-, increased magnitude of medium-, and increased magnitude of high-frequency bands of COP displacement compared to the silence condition would be observed. The second hypothesis was that older adults would redistribute the percentages of three frequency bands with increase in magnitude of medium frequency band compared to young adults.

2. Materials and Methods

2.1. Participants

Fifteen young (age = 23.93 ± 1.66 years, height = 1.67 ± 0.03 m, mass = 62.73 ± 9.68 kg) and fifteen older (age = 67.80 ± 3.97 years, height = 1.56 ± 0.06 m, mass = 60.6 ± 4.62 kg) volunteers with right dominant hands participated in the experiment. The balance and mental functions of older participants were evaluated by the Berg Balance Scale (54.93 ± 1.06) and Mini-Mental State Examination (26.20 ± 1.22) prior to the experiment. All participants were free from any musculoskeletal disorders and neurologic diseases that could affect performing the experimental tasks. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of National Tsing Hua University (REC10710HE070).

2.2. Procedure and Instrumentation

The experimental protocol was shown in Figure 1. Participants were instructed to stand on a force platform (AMTI, Watertown, NY, USA) upright with feet shoulder-width apart for 40 s and conduct the Purdue Pegboard test (Lafayette Instrument Company, Inc. Indiana, IN, USA). The Purdue Pegboard was placed on a table, with a height that could be adjusted to match the waist level of each participant. Furthermore, the height allowed participants to reach and pick up pins from the cups at the top of the board with their elbow in full extension. The instructions were that participants picked up and placed the pins down the rows with their right hands as fast as possible. The mode of silence and the electronic guitar-based white noise with 50 dB at three different frequencies (250, 1000, and 4000 Hz) were played for four conditions. Five trials were collected in each condition. Each participant was given two practice trials prior to data collection to allow familiarization with the task. The randomization of four experimental conditions was applied.

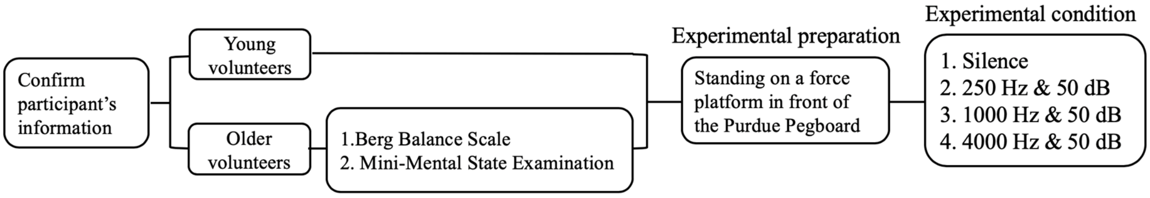

Figure 1. The flowchart of the experimental protocol.

2.3. Data Processing

All data were processed offline using MATLAB software (2018b, MathWorks, Natick, MA, USA), which were filtered with a 20 Hz low-pass, 2nd order, zero-lag Butterworth filter. Time-varying COP displacements in the anterior–posterior (COP_{AP}) and medial–lateral (COP_{ML}) directions were calculated using the approximations described in the literature [22]. For the spectral analysis, the COP displacements in both directions were calculated by fast Fourier transform to obtain the power density spectrum [23]. Subsequently, the power spectrum was divided into 0–0.3 Hz as the low-frequency (LF) band, 0.3–1 Hz as the medium-frequency (MF) band, and 1–3 Hz as the high-frequency (HF) band. The total spectral energy of each band was normalized by the sum of the three bands and presented as percentages [12]. The COP displacements in both directions were expressed as LF_{AP}, LF_{ML}; MF_{AP}, MF_{ML}; HF_{AP}, and HF_{ML}. Meanwhile, the displacements of COP_{AP} and COP_{ML} were used to calculate the total COP excursion, the mean COP velocity in both directions, and the sway area, respectively, and referred to as excursion_{AP}, excursion_{ML}, velocity_{AP}, velocity_{ML}, and sway area [24]. The number of pins from the Purdue pegboard test was recorded as task performance. All variables were calculated for each trial and averaged across five trials for each condition.

2.4. Statistics

Two-way repeated-measures Analysis of Variance (ANOVAs) were performed with one within-subject factor: sounds (4 levels: silence, 250, 1000, and 4000 Hz), and one between-subject factor: group (2 levels: young and old) on LF_{AP}, LF_{ML}, MF_{AP}, MF_{ML}, HF_{AP}, HF_{ML}, excursion_{AP}, excursion_{ML}, velocity_{AP}, velocity_{ML}, sway area, and task performance. Post hoc comparisons were done using Tukey's Honestly Significant Difference test for significant interactions. Statistical difference was set at $p < 0.05$. Means and standard errors are presented in the results and figures.

3. Results

The effects of sound and group on the percent COP displacements for the three bands (low-, medium-, and high-frequency) in the AP and ML directions are shown in Figure 1. The main effect of sound significantly affected the low-frequency and medium-frequency in both directions (Table 1). In the AP direction, the main effect of sound was significant for the low-frequency band ($F(3,84) = 5.185$,

$p = 0.002$) and the medium-frequency band ($F(3,84) = 4.851$, $p = 0.004$). In the ML direction, the main effect of sound was significant for the low-frequency band ($F(3,84) = 4.802$, $p = 0.004$) and the medium-frequency band ($F(3,84) = 5.011$, $p = 0.003$). While comparing the silence and other sound conditions, a significant decrease percentage of the low-frequency band and a significant rise percentage of the medium-frequency band in both directions were seen in the silence condition (Figure 2). For the comparison of the group effect, the percentages of the three bands were not significantly different between the older and young groups in the AP direction. In the ML direction, the older group showed a significantly smaller percentage of the low-frequency band and larger medium-frequency band compared to the young group (Figure 2).

Table 1. The results of repeated measure ANOVA for the low-frequency, medium-frequency, and high-frequency band in the anterior–posterior and medial–lateral directions.

	AP Direction			ML Direction		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
	Sound (within-subject Factor)					
F(3,84)	5.185	4.851	1.435	4.802	5.011	0.415
p	**0.002**	**0.004**	0.238	**0.004**	**0.003**	0.743
	Group (between-subject Factor)					
F(1,28)	0.995	0.768	1.400	4.236	4.759	0.102
p	0.327	0.388	0.247	**0.049**	**0.038**	0.752

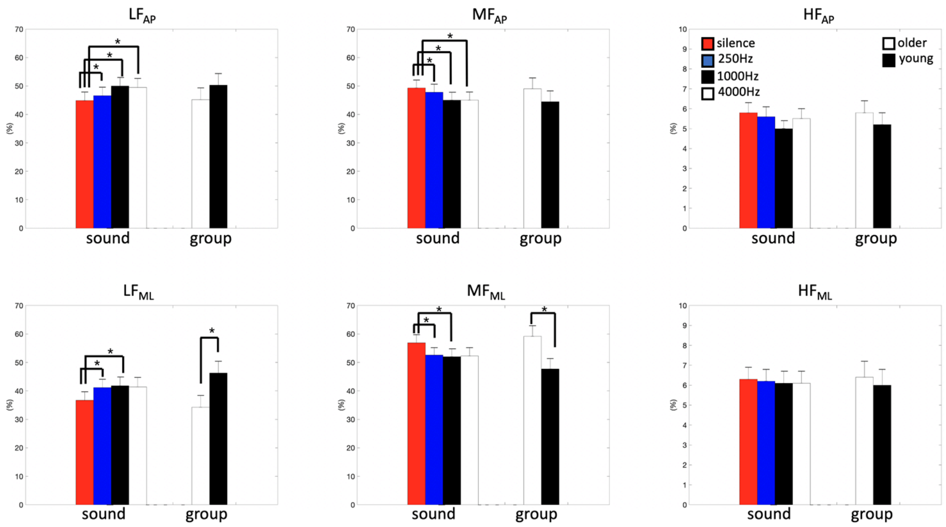

Figure 2. The effects of sound and group on the low-frequency (LF), the medium-frequency (MF), and the high-frequency (HF) bands of the center of pressure (COP) power spectrum in the anterior-posterior (AP) (upper panels) and medial-lateral (ML) (lower panels) directions. Mean and standard errors are shown. * shows statistical significance ($p < 0.05$).

The main effect of sound was not significant for the total COP excursion and COP velocity in both directions but significant for the sway area (Table 2). A significant decrease in the sway area was observed in the silence condition (10.92 ± 1.62 cm^2) compared to the 1000 Hz (14.92 ± 1.81 cm^2) and 4000 Hz (16.37 ± 2.23 cm^2) conditions. While pairwise comparisons of the group effect, the total COP excursion and COP velocity in the AP direction were not significantly different between the older and young groups. The grand mean of total COP excursion and the COP velocity in the AP direction was 217.79 ± 4.92 cm and 5.45 ± 0.12 cm/s. In the ML direction, the total COP excursion and the COP velocity were significantly larger in the older group (235.41 ± 7.82 cm; 5.89 ± 0.20 cm/s) compared to the young group (204.51 ± 7.82 mm; 5.11 ± 0.20 mm/s). The grand mean of the sway area was 14.87 ± 2.53 cm^2 in the older group and not significantly different from the young group (13.44 ± 2.53 cm^2).

Table 2. The results of repeated measure ANOVA for $excursion_{AP}$, $excursion_{ML}$, $velocity_{AP}$, $velocity_{ML}$, and sway area. The mean and standard errors cross both groups for each condition.

	Sound F(3,84)	Sound *p*	Silence	250 Hz	1000 Hz	4000 Hz
$excursion_{AP}$ (cm)	2.059	0.112	216.83 (4.96)	217.25 (4.82)	218.48 (5.06)	218.61 (4.97)
$excursion_{ML}$ (cm)	0.615	0.607	220.19 (5.73)	219.38 (5.46)	220.32 (5.59)	219.96 (5.39)
$velocity_{AP}$ (cm/s)	2.059	0.112	5.42 (0.12)	5.43 (0.12)	5.46 (0.12)	5.47 (0.12)
$velocity_{ML}$ (cm/s)	0.615	0.607	5.51 (0.14)	5.48 (0.14)	5.51 (0.14)	5.60 (0.14)
sway area (cm^2)	6.284	**0.001**	10.92 (1.62)	14.43 (2.12)	14.92 (1.81) *	16.37 (2.23) *

* $p < 0.01$ compared to the silence condition.

The task performance was significantly affected by the effect of sound ($F(3,84) = 8.149$, $p < 0.001$) and the number of pins were significantly more in the silence condition (20.26 ± 0.32) compared to the other sound conditions (250 Hz: 19.59 ± 0.31; 1000 Hz: 19.38 ± 0.32; 4000 Hz: 19.80 ± 0.31). However, the task performance was not significantly different between the older and young groups and the number of pins was 19.49 ± 0.41 in the older and 20.03 ± 0.41 in the young groups.

4. Discussion

The current study was conducted to investigate how sound influences COP displacement during a hand task in standing via spectral analysis. The sound effect was observed in the low-frequency and medium-frequency band in the AP and ML direction. The LF_{AP} and LF_{ML} were decreased and MF_{AP} and MF_{ML} were increased in the silence condition compared to the other three sound frequency conditions. The smaller percentage of the low-frequency band and the larger percentage of the medium-frequency band in the ML direction were observed in the older group and significantly different from the young group. The larger number of pins and small sway area were also observed in the silence condition than the other conditions.

The hand task was aimed to simulate daily activities and increase the challenges as a dual-task to postural control. The hand task conduced in the present experiment was the Purdue Pegboard test, which was designed to evaluate finger/hand dexterity and has been employed in neuropsychological assessments in older adults as a clinical measurement [25]. According to the user instructions of the Purdue Pegboard test, the number of pins was 15.44 in the age group of 21–25 and 14.6 in the age group of 60–69 when performing in 30 s. It was comparable with 20.69 in the young groups and 19.83 in the older group for performing 40 s in the silence condition. This comparison confirmed that the participants correctly executed the Purdue Pegboard test. The comparable performances of Purdue Pegboard test with previous studies could indicate changes in the COP displacements, postural regulation, and task performance were due to the factor of sound or age in performing the dual-task.

During quiet standing without conducting a dual-task, it has been reported that sound and sound frequency substantially affect the postural sway length and the position variability of COP [8] and significantly decrease the sway area during extreme loudness [4]. In the current study, the sway area was decreased and improved task performance with a greater number of pins was observed in the silence condition compared to the other sound conditions. Likewise, when individuals were exposed to a noisy environment, worsened task performance, such as the scores of the balance error scoring system, has been reported [26]. Therefore, the sound did not act positively to the vestibular system as expected on the medium-frequency band. On the contrary, it might be considered as an external disturbance to sensory integration, which further resulted in the increased postural sway [27]. On the other hand, potential benefits of sound frequency influencing the vestibular system might also be compromised. The frequency analysis revealed changes in postural regulations in the sound conditions. It showed that the low-frequency and medium-frequency bands in both directions were significantly different between the with and without sound conditions. The low- and medium-frequency bands are associated with vision and vestibular regulations [12,13]. The dependence on vision was increased, and the role of vestibular regulation was diminished in the sound condition compared to the silence condition. Regardless of differences in sound frequency, the sound might be treated as noise to participants and reweighting the postural regulation from the vestibular system to the visual system. Compared with previous studies of quiet standing only, the sound effects might not be beneficial to postural control when conducting a hand task while standing.

The older participants in the current study had been screened for their mental and basic balance functions using the Mini-Mental State Examination and Berg Balance Scale, respectively. It indicated that changes in the COP displacement were due to dual-tasking from the experimental design. Performing the hand task in standing was a dual-task to postural control, which has been widely studied and shown difficulties of postural adjustments in the elderly [28,29]. The larger COP displacement and fast sway were observed in the medial–lateral direction, but not in the anterior–posterior direction. It reflected that older adults might have difficulties to control stability steadily in both directions and select to maintain the anterior–posterior stability when performing hand tasks. Older adults have also been reported to have diminished medial–lateral postural stability [30,31] and declined peripheral sensory function, such as the vestibular function [32]. In addition, the frequency analysis revealed that the smaller low-frequency and the larger medium-frequency bands in the medial–lateral direction were significantly different from the young group. It implied that when performing hand tasks in standing, the visual system might be assigned to focus on the task and not on postural regulation, which might explain the comparable task performance with the young group. Alternatively, older adults relied more on vestibular information and similar proprioceptive information to regulate postural control compared to young adults [12,13]. Therefore, it suggested that when performing a dual-task that required visual attention, the poor postural control observed in older adults was the result of the visual information being assigned to the task and the vestibular information dominating the postural regulation. Dual-tasking has been employed as a balance training program to improve mobility performance in older adults [33], or other neurologically-impaired persons [34]. This redistribution of postural regulations could provide insights for further development of dual-task to train specific postural regulation strategies accordingly.

5. Conclusions

Frequency analysis of COP displacement successfully revealed the postural regulations when performing a dual-task in standing. The sound effect redistributed the magnitudes of low- and medium-frequency bands in the anterior–posterior and medial–lateral directions, but not sound frequency. Furthermore, it disclosed that older adults rearranged sensory integration for assigning the visual information to the hand task and primarily utilized vestibular regulation for postural control when performing a dual-task in standing. The outcome of the current study highlights that redistributions of postural regulation could be used in the development of postural strategy retraining paradigms involving alternative dual-tasks in the elderly.

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