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Loudness constancy in healthy older adults

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Loudness constancy refers to the phenomenon by which loudness remains constant in the presence of substantial changes in a physical stimulus caused by varying the sound distance. When visual indications of musical performance are accessible, sound generation exhibits robust loudness constancy in adults aged 18–43 years; however, whether this result can be obtained for older adults is unclear. In this study, we aimed to assess whether older adults (aged ≥ 65 years) had strong loudness constancy. We used two adjustment approach methods to determine the degree of loudness constancy. One was “sound production,” which required listeners to play the musical instrument as loudly as a model musician. The other was “sound-level adjustment,” in which listeners changed the loudness of a loudspeaker’s output. Our results showed that when visual cues were present, older adults exhibited robust loudness constancy while playing a musical instrument. These findings provide evidence for the generalizability of previous results for older adults and extend the idea that audiovisual perception and imitation are important for music learning and skill acquisition in older adults.

Key words: loudness constancy, music learning, skill acquisition, musical instrument, older adults, audiovisual perception, imitation

Introduction

One of the perceptual constancies is loudness constancy, which remains constant in the presence of significant changes in the physical stimuli induced by shifting the sound distance (Florentine et al., 2011; Honda et al., 2019). Although it is well understood that perceived loudness is influenced by physical characteristics of the stimulus (sound pressure level at the listener’s ears) and subjective characteristics (visual information about the sound source) (Berthomieu et al., 2021; Rosenblum & Fowler, 1991), few studies have examined loudness constancy systematically and critically (Altmann et al., 2013; Berthomieu et al., 2021; Zahorik & Wightman, 2001). In particular, none of the studies examined loudness constancy in older adults.

Recently, Honda et al. (2019) discovered that audiovisual information and imitation are critical for maintaining loudness constancy while playing a musical instrument. In their experiments, college students (aged 18–43 years) were challenged to match the loudness of a target sound using two different methods of adjustment. One method was “sound production,” which required listeners to play a musical instrument as loudly as a model

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musician. The other method was "sound-level adjustment," which allowed listeners to control the loudness of a loudspeaker's output. When visual indications of musical performance were present, the results showed that sound production had a more robust loudness constancy than the sound-level adjustment approach. These findings supported prior findings that audiovisual perception and imitation are required for musical learning and skill acquisition (Haslinger et al., 2005). However, it is uncertain whether this finding can be applied to older adults.

In this study, we investigated whether older adults (aged ≥ 65 years) demonstrated substantial loudness constancy when visual cues of musical performance were present. If we could obtain results similar to those of Honda et al. (2019), the findings could be generalized to older adults and provide insight into their musical learning and skill acquisition. A recent review did not find sufficient evidence for age differences in the multisensory integration process (Jones & Noppeney, 2021), but several other studies reported enhanced audiovisual integration in older adults (Laurienti et al., 2006; Peiffer et al., 2007). Furthermore, there have been some recent studies on musical instrument training enhanced cognitive functions of older adults (Bugos & Wang, 2022; Guo et al., 2021; Reifinger, 2016). Considering these findings, we hypothesized that among healthy older adults, sound production would be more consistent than sound-level adjustment when visual indications of musical performance were present. To investigate this hypothesis, we performed two experiments identical to those of Honda et al. (2019). In Experiment 1, we evaluated whether healthy older adults observed musical performance before being asked to produce a level of sound pressure matching the stimulus. In Experiment 2, we investigated whether healthy older adults produced loudness constancy of sound when visual cues of musical performance were unavailable.

Methods and Results

Experiments

All participants were recruited from Silver Human Resources Center in Kofu city, Yamanashi. The university where this research was conducted did not have an ethics committee. Therefore, the study was conducted in compliance with the Declaration of Helsinki: Participants provided written consent after the experimental procedures were explained to them. The participants also received modest compensation (1,500 yen) for their participation. The apparatus, stimuli, and methods employed were identical to those described by Honda et al. (2019).

Experiment 1

Methods

Participants. Fourteen healthy older adults were recruited: six men and eight women. The mean age was 68.9 (range 65–75) years. No participants had any training or experience in the professional music industry. They reported having normal eyesight or vision that was corrected to normal levels. Their hearing levels were checked using a diagnostic audiometer (Rion AA-74; Rion Co., Ltd., Tokyo, Japan) before starting the experiments. Thirteen participants had normal hearing or mild hearing loss (0–40 dB); one listener with severe hearing loss (71–90 dB) was excluded from the experiment.

Apparatus, stimuli, and procedure. Yamanashi Eiwa College's gymnasium (Kofu City, Yamanashi) served as the testing ground, with ambient noise levels of 32–35 dB (A). A melodica musician played 2 s-tones at a G4 (393 Hz) pitch as stimuli (MX32C; Suzuki Musical Inst. Mfg. Co., Ltd. Hamamatsu-shi, Naka-ku, Japan). Melodicas (pianicas, melodyhorns, and key harmonicas) are free-reed aerophones that are comparable to harmonicas.

We measured the degree of loudness constancy using two different adjustment methods when the participants were permitted to observe the melodica played before being asked to match the stimulus's sound pressure level. One method was "sound production," which required listeners to play a musical instrument as loudly as a model player. In other words, under this condition, participants were asked to play the melodica (MX32C; Suzuki Musical Inst. Mfg. Co., Ltd.) at the same sound pressure level as the stimulus. The other method was "sound-level adjustment," in which listeners adjusted the loudness of a loudspeaker (MX-B55; Yamaha Music Japan Co., Ltd., Naka-ku Hamamatsu-shi, Japan) placed 50 cm in front of them. In other words, participants in this condition were instructed to match the loudspeaker volume to the stimulus. The sound pressure levels of the two method's reaction sounds were measured with a sound-level meter (NL-62; Rion Co. Ltd.) set 90 cm in front of the participants and placed 120 cm from the floor.

The distances between the performer and the participant were 2, 8, and 32 m, equivalent to near, middle, and long distances, respectively. The stimuli's sound pressure levels at the music performance were adjusted to 60, 75, and 86 dB (A), corresponding to soft, medium, and loud levels, respectively. The sound levels of the target stimuli were validated for each trial using a sound-level meter (LA-3260; Ono Sokki Co. Ltd., Kohoku-ku, Japan) located 60 cm in front of the performer and placed 90 cm from the floor. Throughout the trial, the musician kept an eye on the sound-level meter while producing tones and controlled the sound levels of the target stimuli.

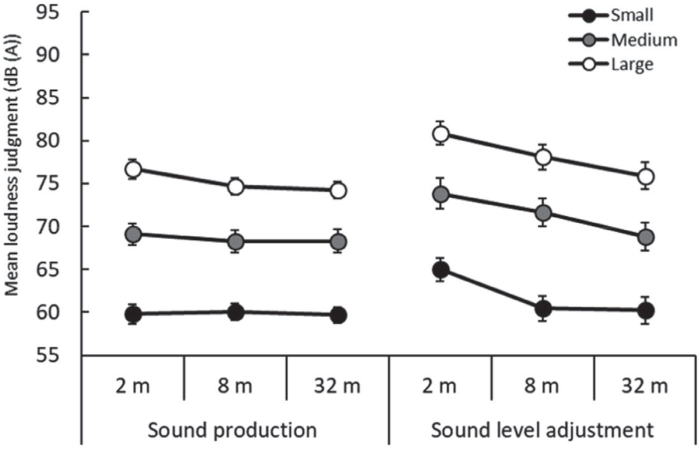
The stimulus's sound pressure levels (soft, medium, and loud) were presented in a randomized order. The participants' conditions (sound production and sound-level adjustment) and distance (2, 8, and 32 m) were counterbalanced. Before the 90 test trials, the experiment began with two practice sessions for both conditions.

Results

The results are presented in Figure 1. The mean loudness as dependent variable was calculated using the sound pressure levels of the reply sound. The mean loudness judgment was subjected to a three-way within-subject analysis of variance (ANOVA), with the condition (sound production and sound-level adjustment), sound pressure level (soft, medium, and loud), and distance (2, 8, and 32 m) as independent factors.

Results of a three-way ANOVA are summarized in Table 1. The results revealed a significant interaction between condition and distance (F (2, 24) = 12.25, p < .001, η_p^2 = .505). For the sound-level adjustment condition, we identified a distance-dependent main effect (F (2,

Figure 1
Results of Experiment 1



Notes. Black, gray, and white circles represent the stimuli's sound pressure levels at the music performance were soft, medium, and loud levels, respectively. Error bars represent standard errors of mean.

Table 1
Table of Analysis of Variance of Experiment 1

Source	*df*	*MS*	*F*	η_p^2
Condition (A)	1	417.94	4.35	.266
Error (A)	12	96.18		
Sound pressure level (B)	2	4953.64	241.51***	.953
Error (B)	24	20.51		
Distance (C)	2	185.23	14.40***	.546
Error (C)	24	12.86		
A × B	2	5.81	0.72	.056
Error (A × B)	24	8.12		
A × C	2	72.16	12.25***	.505
Error (A × C)	24	5.89		
B × C	4	4.43	0.99	.077
Error (B × C)	48	4.443		
A ×B × C	4	9.05	2.84*	.192
Error (A × B × C)	48	3.18		

***p < .001, *p < .05.

48) = 26.02, $p < .001$). The results from Bonferroni's post-hoc test ($p < .05$) showed a significant difference between the two group's mean loudness judgments for the sound-level adjustment condition (M = 73.24 on 2 m, M = 70.05 on 8 m, and M = 68.31 on 32 m). In contrast, no significant differences were found in loudness judgments for the sound production condition between distances. A simple main effect of condition was also found for the 2 m distance (F (1, 36) = 12.07, $p < .01$). The loudness judgments of the sound-level adjustment condition were significantly louder than the judgments of the sound production condition.

A significant main effect of the sound pressure level was found (F (2, 24) = 241.51, $p < .001$, $\eta_p^2 = .953$). Post-hoc comparisons (Bonferroni's method, $p < .05$) showed that the mean loudness judgments for each sound pressure level were significantly different from one another (M = 60.86 for soft, M = 69.99 for medium, and M = 76.74 for loud). There was also a significant main impact of distance: F (2, 24) = 14.40, $p < .001$, $\eta_p^2 = .546$. Post-hoc comparisons (Bonferroni's method, $p < .05$) showed that the loudness judgments at 2 m (M = 70.88) were significantly louder than the judgments at 8 m (M = 68.85) and 32 m (M = 67.86). Additionally, an unexpected significant interaction between condition, sound pressure level, and distance developed (F (4, 48) = 2.84, $p < .05$, $\eta_p^2 = .192$). Significant simple interactions were observed between condition and sound pressure level for 8 m distance (F (2,72) = 3.94, $p < .05$), condition and distance for medium sound (F (2, 72) = 7.46, $p < .01$), and condition and distance for loud sound (F (2, 72) = 11.99, $p < .001$). No other significant simple interactions were found.

Experiment 2

Method

Participants. Fifteen healthy older adults were recruited: eight men and seven women. Five participants (two men and three women) had already participated in Experiment 1. The mean age was 69.9 (range 65–75) years. These participants did not have professional music education or experience. They self-reported having normal or corrected-to-normal vision. Before the experiment, their hearing levels were evaluated using a diagnostic audiometer (Rion AA-74; Rion Co., Ltd.). Thirteen participants had normal hearing or mild hearing loss (0–40 dB), and two listeners with moderate hearing loss (41–55 dB), were excluded from the analysis.

Apparatus, stimuli, and procedure. In Experiment 2, we examined the degree of loudness constancy while participants were unable to see the musical performance. As in Honda et al.'s (2019) experiment, a stainless-steel screen curtain (60 cm length, 180 cm height) was placed 1 m in front of the melodica musician. Therefore, participants were able to listen to the sound stimuli but were unable to observe the musical performance. Using the same technique as in Experiment 1, the musician kept an eye on the sound-level meter while producing the tones and controlled the sound levels of the target stimuli.

We measured the degree of loudness constancy utilizing sound production and sound-level adjustment. The position of the loudspeaker was the same as in Experiment 1. The musical tone of the reply sound was identical in both conditions to that employed in Experiment 1. The sound pressure levels of the reaction sound were measured using the same sound-level meter as in Experiment 1.

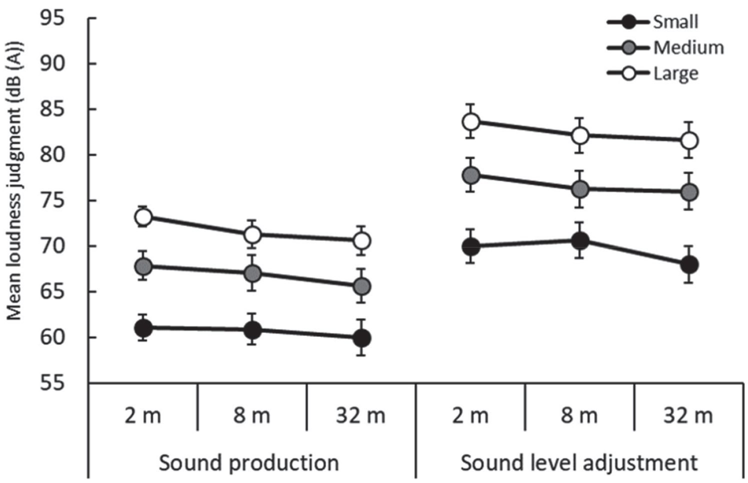
The sound pressure levels (soft, medium, and loud) presented were in a randomized order. The participants' conditions (sound production and sound-level adjustment) and distance (2, 8, and 32 m) were counterbalanced. The experiment began with two practice sessions for both circumstances, before the 90 test trials.

Results

The results are presented in Figure 2. The mean loudness as dependent variable was calculated using the sound pressure levels of the reply sound. The mean loudness judgment was subjected to a three-way within-subject ANOVA, with the condition (sound production and sound-level adjustment), sound pressure level (soft, medium, and loud), and distance (2, 8, and 32 m) as independent factors.

Results of a three-way ANOVA are summarized in Table 2. The results showed that the condition had a significant main effect, F (1, 12) = 14.54, $p < .01$, $\eta_p^2 = .548$, indicating that the mean loudness judgment of the sound production (M = 66.37) was weaker than that of the sound-level adjustment (M = 76.19). Furthermore, the major effects of sound pressure level, F (2, 24) = 297.81, $p < .001$, $\eta_p^2 = .961$, and distance, F (2, 24) = 5.14, $p < .01$, $\eta_p^2 = .300$, were also significant. Post-hoc comparisons (Bonferroni's method, p <.05) revealed that the

Figure 2
Results of Experiment 2



Notes. Black, gray, and white circles represent the stimuli's sound pressure levels at the music performance were soft, medium, and loud levels, respectively. Error bars represent standard errors of mean.

Table 2
Table of Analysis of Variance of Experiment 2

Source	*df*	*MS*	*F*	η_p^2
Condition (A)	1	5641.18	14.54**	.548
Error (A)	12	387.95		
Sound pressure level (B)	2	2820.70	297.81***	.961
Error (B)	24	9.47		
Distance (C)	2	76.44	5.14**	.300
Error (C)	24	14.85		
A × B	2	17.03	1.78	.130
Error (A × B)	24	9.52		
A × C	2	0.14	0.01	.001
Error (A × C)	24	8.54		
B × C	4	7.01	3.76*	.239
Error (B × C)	48	1.86		
A ×B × C	4	3.85	1.31	.099
Error (A × B × C)	48	2.93		

****p* <. 001, ***p* < .01, **p* < .05.

mean loudness judgments of the sound pressure levels differed significantly (M = 65.06 on the soft, M = 71.73 for the medium, and M = 77.06 for the loud). In terms of distance, the mean loudness assessment of the 2 m distance (M = 72.24) was significantly louder than that of other distances (M = 71.35 on 8 m and M = 70.26 on 32 m). Furthermore, an unexpected significant interaction between sound pressure level and distance was discovered, F (4, 48) = 3.76, $p < .05$, $\eta_p^2 = .239$. Significant simple main effects for sound pressure level were observed at 2 m (F (2, 72) = 249.11, $p < .001$), 8 m (F (2, 72) = 177.29, $p < .001$), and 32 m (F (2, 72) = 218.19, $p < .001$). Furthermore, significant simple main effects for distance were obtained for soft (F (2, 72) = 6.32, $p < .01$), medium (F (2, 72) = 4.37, $p < .05$), and loud sounds (F (2, 72) = 3.91, $p < .05$).

General Discussion

We investigated loudness constancy of sound with musical performance visual cues among healthy older adults. According to Reifinger (2016), musical learning happens at all ages; however, it is slower in older adults due to changes in cognitive and psychomotor functioning. Although musical learning involves audiovisual integration and imitation, some studies have reported enhanced audiovisual integration in older adults (Laurienti et al., 2006; Peiffer et al., 2007). Based on these findings, we expected that healthy older adults would have a higher degree of constancy in sound production than in sound-level adjustment when visual signals of the musical performance are accessible.

The acquired results are compatible with this hypothesis. In Experiment 1, we enabled participants to watch the musical performance before producing the sound pressure level that corresponded to the stimulus. Sound generation revealed a stronger loudness constancy than sound-level adjustment. Experiment 2 evaluated if identical results could be obtained in the absence of visual cues, when participants were not allowed to view the musical performance. In contrast to Experiment 1, no robust loudness constancy of sound output was detected in Experiment 2. These findings are consistent with those reported by Honda et al. (2019). Therefore, we conclude that when visual cues of musical performance are accessible, both younger and older adults exhibit robust loudness constancy.

This study has several limitations. Our experiments were conducted in a gymnasium. Previous research has shown that reverberation cues influence loudness constancy (Altmann et al., 2013; Zahorik & Wightman, 2001). Hence, there is a chance that our results were impacted by reverberation cues in the gymnasium environment. Similar tests conducted under diverse environmental circumstances should be included in future studies. In addition, other sound frequencies and/or musical instruments are required in future studies. To obtain more direct evidence, it may be necessary to conduct an experiment in which the presence or absence of visual cues is an independent variable. Nevertheless, our findings showed that when visual cues were present, healthy older adults exhibited robust loudness constancy while playing a musical instrument. These findings provide evidence for the generalizability of previous results from Honda et al. (2019) and extend the idea that audiovisual perception and imitation are important for music learning and skill acquisition in older adults.

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Declaration of Conflicting Interests

The authors declare that the research was conducted in the absence of any commercial and financial relationships that could be construed as a potential conflict of interest.

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