Influence of Regular, Vigorous Physical Activity on the Accuracy of Stepping Movements in Individuals with Hearing Loss*

Mayumi Saito

Faculty of Health and Sport Sciences, University of Tsukuba
1-1-1, Tennodai, Tsukuba, Ibaraki, 305-8574, Japan
Corresponding author : saito.mayumi.gp@u.tsukuba.ac.jp

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The purpose of this study was to clarify the effectiveness of regular, vigorous physical activity on the performance of rhythm-synchronized stepping exercises in individuals with hearing loss. The study involved 58 male participants aged between 20 and 24 years; 23 of them (exercise group 15, general group 8) had hearing loss and 35 (exercise group 24, general group 11) did not. Alternating left and right steps, at a rate of 120/minute, were performed in the absence of cues, or in the presence of visual and visual/auditory cues. The results suggested that exercise group with hearing loss can perform simple, repetitive exercises more accurately than general group with hearing loss when visual cues are presented.

Keywords: audio cues, visual cues, exercise, hearing loss

1. Objective

The hearing-impaired may be able to use sensory modalities apart from audition to recognize rhythmic information. Vision is one useful strategy, especially for those whose hearing loss is severe or profound (deaf). Studies have found hearing-impaired subjects to perform well on certain visual function tests in terms of dynamic visual acuity (Masuyama 2008; Nakajima et al. 2010; Saito 2011), suggesting that this population may be able to effectively utilize visual cues to synchronize their movements to rhythms. Rhythmic perception is essentially the ability to discriminate temporal patterns of sound and silence, or sounds of different intensities. Various studies have demonstrated that even people with profound and severe hearing loss possess this capacity (Darrow, 1993; Ogata and Yoshino 1997; Kinemuchi et al. 2001; Hayashida 2015). According to Kato (2006): “Shows by the Wild Zappers, a professional dance troupe, and other deaf performers feature sign language interpreters who gesture with their fingers along with the music, having synchronized their motions to its rhythms through repeated practice.” Several

reports have claimed that adapted physical education programs can lead to improved rhythmic perception and movements among hearing-impaired children (Saburi and Inoue 1991; Saburi 1999; Fotiadou et al. 2006). Such evidence suggests that proper assistance can lower the barriers to participating in activities and in society generally, and that individuals with hearing loss could be aided to reach their full potential.

The Japan Audiological Society’s Hearing Loss Task Force (2014) defines a mean sensitivity threshold of 70-89 dB and ≥ 90 dB as “severe” and “profound” hearing loss, respectively. In their view, whereas, the term “hearing loss” refers narrowly to physiological dysfunction in the auditory system, the term “hearing impairment” better captures the various restrictions, inconveniences, and challenges that affected persons face in their daily lives. Considering this, the task force recommends using the name “Classification scheme of degree of hearing loss (impairment)”. In comparison, the International Classification of Functioning, Disability and Health (ICF) – the revised version of the International Classification of Impairments, Disabilities and Handicaps (2001) – notes that while social ac-

tivities and participation can be facilitated by individual and environmental factors among those with structural or functional hearing loss, various constraints due to their impairment act to limit their engagement in physical exercise. In other words, when such constraints are sufficiently restrictive, they could affect an individual's ability to learn and practice different types of exercise. For example, hearing-impaired children are less physically fit than their non-hearing-impaired counterparts (Oikawa et al. 2004); this disparity emerges from differences in the curriculums followed by schools for the deaf versus typical schools (Oikawa et al. 2005). In contrast, others have found no relationship between hearing ability and fitness test performance among school children with profound or severe hearing loss (Saito 2011), and that hearing-impaired children who perform well on such fitness tests tend to be more physically active during their school years (Oikawa et al. 2004; 2005; Saito and Muneta 2013). Thus, a person's exercise performance – captured by motor precision, technical proficiency, and fitness test scores – seems to be more closely associated with their exercise experience than with hearing status. However, the improvements in rhythmic perception and motor performance in physical education classes shown by previous studies were identified using only subjective appraisals and observations based on unclear evaluation criteria. The present study sought to experimentally determine whether a history of exercise affects the motor coordination of people with hearing loss (impairment); specifically, stepping in time with rhythms using visual and audio cues.

2. Method

Stepping (in place) was chosen as the exercise of interest; this repetitive motion, one of the most basic possible, was performed at a single frequency. Subjects were instructed to step in time with a rhythmic stimulus, supplemented with cues to compensate for any hearing dysfunction. Collectively, their stepping performance was assessed for associations with hearing status and exercise history.

2.1. Subjects

Fifty-eight adult men aged 20 to 24 y participated in the study (hearing loss, $n=23$; no hearing loss,

35). Hearing loss (impairment) was defined as “severe” disability or greater present from infancy (average threshold for all subjects: 90 dB).

2.2. Experimental method

2.2.1. Cue presentation conditions

(1) Condition 1: No visual or audio cues (“No Cue”)

In writing, subjects were instructed to watch a blue circle flashing at 120 Hz (bpm) on a display screen, and to step in place at the same speed after the cue disappeared.

(2) Condition 2: Visual cue; no audio cue (“Visual Only”)

In writing, subjects were instructed to watch a slightly different visual cue – a blue circle flashing at 120 bpm, while moving horizontally left to right across the screen – and to step in time with the flashing.

(3) Condition 3: Visual and audio cues (“Audiovisual”)

In writing, subjects were instructed to step in time with a drumbeat synchronized to the visual cue in Condition 2, which was presented at the same time. The drum sound was played from a speaker located 1.5 m above the floor; the volume was adjusted to a perceptible level for each subject before each trial began. Trials were run for 60 s for all conditions.

2.2.2. Exercise trials

Each trial consisted of stepping in place at 120 bpm – a repetitive movement at a single frequency – alternating the left and right legs. Each subject was randomly assigned to one of two presentation orders (1-2-3 or 1-3-2), and stepped for 60 s as directed in each of the three conditions.

Subjects performed their trials alone. First, the subject was placed in the designated area and instructed to perform the basic stepping motion at a speed of 120 bpm. Next, he was instructed to perform the same task in time with the cue on the screen in front of him, 1.25 m from the ground. The trials were recorded by two video cameras in two locations behind the subject; their field of view included the feet, the stimulus (displayed on mirror projector for subject), and a nearby computer (for the experimenter). Hearing-impaired subjects wore a hearing aid during all trials; an experimenter checked whether they could perceive the drum

sound in Condition 3 before beginning the trial.

2.2.3. Ethical considerations

This study was conducted with the approval of the author's university research ethics committee. During recruitment, participants were given verbal and written explanations of the study's objective, contents, and time required. They were also told how their individual human rights would be protected – i.e. how their personally identifying information would be managed, stored, disposed of, and disclosed; privacy protections; what format their data would be published in – and that their participation was entirely voluntary. Signing the consent form was considered to constitute informed consent.

2.3. Analysis

For each trial, the middle 40 s of footage was analyzed ($t=10$ -50 s). The timing of each step was determined using the Frame-DIAS V motion analysis system (IFS-23G/3D/2), defining it as the moment the subject's toes touched the floor. "Stepping error" was the measurement item of interest i.e. deviation in the timing of this movement from the basic beat. Stepping error in each condition was evaluated based on measurement data according to the following procedures. First, the time taken for each step in the 40-s window was calculated. Next, 0.5 s (i.e. the time interval between beats at 120 bpm) was subtracted from each step's time. The mean stepping error was calculated as the average of the absolute values of these differences. Smaller values were assumed to correspond to precise stepping in time with the target rhythm. This procedure yielded three stepping error values for each subject, corresponding to Conditions 1-3, which were then subjected to statistical analysis.

2.3.1. Grouping

This investigation examined whether subjects' performance on the rhythmic stepping task varied according to their exercise history and hearing status. Subjects with hearing loss were designated as "HH" and those without hearing loss as "NH". Subjects who had regularly exercised since their school years (3+ times per week, 1+ h each time) were analyzed as the Exercise group, while those who did not fulfill these criteria, as the Non-

Table 1 Group characteristics.

	Exercise group N = 39	Non-Exercise group N = 19
	20.6 ± 0.74 years	20.7 ± 1.05 years
$t = 0.286$, $df = 56$, n.s.		
HH n = 23		
group size	15	8
mean ages	20.3 ± 0.72 years	20.4 ± 0.52 years
NH n = 35		
group size	24	11
mean ages	20.8 ± 0.72 years	20.9 ± 1.30 years
$\chi^2 = 0.78$, $df = 1$, n.s.		

Exercise group. **Table 1** shows the group size and mean ages of the Exercise and Non-Exercise groups, along with those of the HH/NH subgroups in each group [Exercise: $n = 39$, age 20.6 ± 0.74 y (HH: 15, 20.3 ± 0.72 y; NH: $n = 24$, 20.8 ± 0.72 y); Non-Exercise: 19, 20.7 ± 1.05 y (HH: $n = 8$, 20.4 ± 0.52 y; NH: $n = 11$, 20.9 ± 1.30 y)]. These parameters were not significantly different between the Exercise and Non-Exercise groups (unpaired t-test).

2.3.2. Statistical analysis

Mean age was compared between the Exercise and Non-Exercise groups using an unpaired t-test. Group size was compared between the four subgroups using a χ^2 test (i.e. Exercise/HH, Exercise/NH, Non-Exercise/HH, Non-Exercise/NH). A one-way repeated-measures analysis of variance (ANOVA) with three levels (No Cue, Visual Only, Audiovisual) was used to evaluate for the differential effects of cue type between the HH and NH subjects, separately for the Exercise and Non-Exercise groups. Bonferroni correction for multiple comparisons was applied to confirm any significant differences observed. Another one-way repeated-measures ANOVA was used to compare the effects of stimulus type across the four subgroups; Bonferroni correction was again applied to confirm any significant differences observed.

Next, a two-way repeated-measures ANOVA was used to check for differential effects of exercise history and presentation stimulus between NH and HH subjects. For this analysis, presentation stimulus was only analyzed at two levels – Visual Only and Audiovisual – because these two conditions exhibited significant differences in a preliminary one-way repeated-measures ANOVA.

Table 2 Stepping error (s) in each presentation condition by hearing status and exercise history.

	HH		NH	
	Ex n = 15	Non-Ex n = 8	Ex n = 24	Non-Ex n = 11
Condition 1 No Cue	0.0678 ± 0.0759	0.0734 ± 0.0519	0.0399 ± 0.0620	0.0348 ± 0.0275
Condition 2 Visual	0.0213 ± 0.0159 ^{*a,*c}	0.0464 ± 0.0405 ^{*a,*c,*d,†e}	0.0126 ± 0.0137 ^{*a,*d}	0.0220 ± 0.0178 ^{*a,†e}
Condition 3 Audiovisual	0.0207 ± 0.0189 ^{*b}	0.0230 ± 0.0194 ^{*b}	0.0111 ± 0.0009 ^{*b}	0.0116 ± 0.0009 ^{*b}

mean ± SD (sec), ^{*a}, $p < 0.05$ Condition 1 vs Condition 2, ^{*b}, $p < 0.05$ Condition 1 vs Condition 3, ^{*c}, $p < 0.05$ Exercise/HH vs Non-Exercise/HH, ^{*d}, $p < 0.05$ Non-Exercise/HH vs Exercise/NH, ^{†e}, $p < 0.1$ Non-Exercise/HH vs Non-Exercise/NH

Finally, another two-way repeated-measures ANOVA was performed for the Exercise and General groups, using the two factors of hearing status (HH/NH) and presentation stimulus. This two-way ANOVA also adopted two levels for presentation stimulus (Visual Only, Audiovisual). An unpaired t-test was performed to check for simple main effects if any interactions were observed in the two-way ANOVA. SPSS version 24 (IBM, Armonk, NY) was used to perform all analyses. A significance level of 0.05 was adopted in this study.

3. Results

3.1. Stepping error between presentation conditions

Table 2 shows the means and standard deviations of stepping error for HH and NH subjects in the Exercise and General groups. Significant differences were observed between conditions among HH subjects in the Exercise and Non-Exercise groups, necessitating testing for multiple comparisons. In both groups, the stepping error was significantly lower in the Visual Only and Audiovisual conditions than in the No Cue condition [HH/Exercise: $F(1.08, 15.11) = 4.96$, $p < 0.05$, HH/Non-Exercise: $F(1.64, 11.49) = 5.816$, $p < 0.05$]. Similarly, significant differences were observed between conditions among NH subjects in the Exercise and Non-Exercise groups, necessitating testing for multiple comparisons. In both groups, the stepping error was significantly lower in the Visual Only and Audiovisual conditions than in the No Cue condition [NH/Exercise: $F(1.10, 25.35) = 4.477$, $p < 0.05$; NH/Non-Exercise: $F(1.36, 13.63) = 4.247$, $p < 0.05$]. Significant differences were observed between the four subgroups (exercise history × hearing status) in the Visual Only condition [$F(3,54) = 5.446$, $p < 0.05$], necessitating testing for multiple comparisons. Stepping error was significantly different

Figure 1a. Exercise experience and presentation stimulus (HH)

*Non-Ex group, Visual vs Audiovisual $p < .05$

*Visual, Ex vs Non-Ex $p < .05$

Figure 1b. Exercise experience and presentation stimulus (NH)

between the HH/Exercise and HH/Non-Exercise subgroups, and between the NH/Exercise and HH/Non-Exercise subgroups.

3.2 Two-factor ANOVA according to hearing status (exercise history × stimulus presentation)

Figure 1a shows the results of the two-factor ANOVA within HH subjects. Results were tested for simple main effects since an interaction was observed [$F(1,21) = 6.097$, $p < 0.05$], revealing a significantly lower stepping error in the Visual Only condition in the HH/Exercise subgroup than in the HH/Non-Exercise subgroup. In addition, stepping

Figure 2a. Hearing status and presentation stimulus (Exercise)
Hearing status $p < .05$

Figure 2b. Hearing status and presentation stimulus (Non-Exercise)
presentation stimulus $p < .05$

error was significantly lower in the Audiovisual condition than in the Visual Only condition in the HH/Non-Exercise subgroup ($p < 0.05$). **Figure 1b** shows the results of two-factor ANOVA within NH subjects. No interactions were observed [$F(1, 33) = 2.018$, n.s.]; the main effects of presentation stimulus were confirmed ($p < 0.05$).

3.3. Two-factor ANOVA according to exercise group (hearing ability $\times$ presentation stimulus)

Figure 2a shows the results of two-factor ANOVA for the Exercise group. No interactions were observed [$F(1, 37) = 0.353$, n.s.]; the main effects of hearing status were confirmed ($p < 0.05$). **Figure 2b** shows the results of two-factor ANOVA for the Non-Exercise group. No interactions were observed ($F(1, 17) = 1.592$, n.s.); the main effects of the presentation stimulus were confirmed ($p < 0.05$).

4. Discussion

We observed a significantly lower stepping error

in the Visual and Audiovisual conditions (compared with no cues), independent of hearing ability and exercise experience, revealing that both a visual cue and a combined audio/visual cue could effectively improve individuals' ability to step in time with rhythms. However, stepping error in the Visual condition did differ between the four subgroups (hearing status $\times$ exercise history), suggesting that such supplemental cues should be selected based on a given individual's auditory ability and exercise history.

Our two-factor ANOVA of exercise history and cue type revealed that a history of exercise affects the ability of individuals with hearing loss to coordinate their movements based on visual information. Notably, hearing-impaired subjects in the Exercise group had significantly lower stepping error than those in the Non-Exercise group in the Visual condition, suggesting that exercise history potentiates an individual's ability to step in time with rhythms based on supplemental visual cues. However, no such difference was observed among either HH or NH subjects in the Audiovisual condition, suggesting that exercise history has no influence over an individual's ability to step in time with rhythms supplemented by combined audio/visual cues. Previous work on visual and auditory cues reveals that the time it takes for a person to perceive a stimulus depends on the sensory modality involved, due to differences in the speeds at which nerves carry signals to their respective primary sensory areas. Attention is thus strengthened when visual and auditory signals are synchronized, and weakened when they are not (Lipscomb and Kendall, 1994). In an experimental setting, it is necessary to take into account these differential transmission speeds so that a subject perceives visual and auditory cues as simultaneous, even when they are presented relatively close by. In the present study, we adopted an existing method (Murakami et al. 2003) to correct for these speed differences in order to ensure the visual and auditory cues were perceived as simultaneous. Our observations lead us to conclude that our subjects performed the stepping exercise without any sense of incongruity or loss of attention due to perceiving the visual and audio cues as dyssynchronous in the Audiovisual condition. Past research has shown that adults with normal hearing benefit from intermittent feedback to rectify movement error when learning a repetitive motion

pattern based on visual cues (Ikegami et al. 2012). Once motor learning reaches the automaticity stage, such visual cues help people to intuitively understand the exercise, and thereby anticipate and perform the next movement in sequence. Perhaps the athletic experience of our hearing-impaired exercisers had well-prepared them to 'feel' the correct movements based on visual cues, helping them to perceive the rhythm from the same, anticipate the next cue, and move accordingly. Since auditory information was unavailable in the Visual Only condition, our hearing-impaired non-exercisers, in contrast, possibly needed to routinely synchronize their steps in time with the visual cues, limiting their ability to step smoothly, and thereby leading to greater stepping error. Thus, regular exercisers and non-exercisers with hearing loss seem to differ in their capacity to integrate visual information to guide their movements, which manifested in our task as unequal success in performing the stepping exercise with the assistance of visual cues. Our HH group members had limited hearing ability, meaning they need to deliberately incorporate auditory information in their daily lives; this is in contrast with the NH group, who can draw on visual information in addition to constantly available auditory information. Stepping error was reduced in the Audiovisual condition compared with the Visual Only condition in the HH/Non-Exercise subgroup, suggesting that these subjects may have utilized auditory information in addition to visual information to coordinate their movements. In other words, despite their hearing loss, they were able to utilize not only the visual cues, but also the audio cues, through their residual hearing ability, or the perception of vibrations. However, in both the HH/Exercise and NH/Exercise subgroups, stepping performance was not significantly different between the Visual Only and Audiovisual conditions, suggesting that they relied mainly on visual information to perform the stepping task. In other words, people who regularly exercise seem to have superior ability to utilize visual information to coordinate their movements, compared with those who do not. In contrast, since individuals without such an exercise history are unable to fully utilize visual cues to coordinate their stepping, audio-based support may be more effective. Accordingly, a history of regular exercise may allow individuals, especially if hearing-impaired, to better utilize visual cues to coordinate rhythmic

stepping movements.

Our two-factor ANOVA of hearing ability and stimulus type showed the former characteristic to have main effects on stepping performance in the Exercise group, while the latter influenced stepping performance in the Non-Exercise group. Thus, differences in stepping error between hearing-impaired and non-hearing-impaired subjects in the Exercise group were primarily attributable to differences in hearing capacity, but other factors played some role in the Non-Exercise group. In addition, stepping error was significantly different between the HH/Exercise and HH/Non-Exercise groups in the Visual Only condition based on the results of an unpaired t-test. These findings indicate that the divergent stepping performance between the HH/Exercise and HH/Non-Exercise groups is not attributable to motor dysfunction – i.e. the inability to step in place per se – due to hearing loss, but rather to the poor ability to apply cues to perform the motor task due to a lack of exercise experience. The ICF model provides several solutions for reducing this disparity, including promoting regular exercise for all, at both individual and societal levels, and bolstering information accessibility for the disabled in settings involving physical activity.

Since we did not consider the types of schools at which our subjects received their education (Oikawa et al. 2005), our work cannot offer any insight into the effects of the environment in which a person regularly exercised in their past. Moreover, our decision to only measure the timing of the repeated stepping motion prevented us from evaluating qualitative differences in subjects' movements or motor patterns during task performance. However, our work still holds significance for demonstrating how rhythmic perception and motion can be improved in individuals with hearing loss (impairment) based on their hearing status and exercise experience, a question which had previously only been evaluated in subjective terms.

5. Conclusion

The present study sought to examine the effectiveness of different sensory cues in facilitating the performance of a simple stepping exercise. Hearing-impaired subjects with a history of regular exercise seemed to better utilize visual cues to guide their stepping movements, suggesting that vision is a

superior modality for facilitating rhythmic stepping in those who exercise routinely. While the stepping task in this study involved only a simple repetitive movement, we still demonstrated that presenting cues helps people to step in time with rhythms that incorporate such simple repetition, regardless of their hearing ability. However, visual cues alone are insufficient in this task for hearing-impaired individuals without a history of regular exercise, necessitating some form of support in the auditory modality.

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Name:

Saito Mayumi

Affiliation:

Faculty of Health and Sport Sciences,
University of Tsukuba

Address:

1-1-1, Tennodai, Tsukuba, Ibaraki, 305-8574, Japan

Brief Biographical History:

1990-2003 Assistant Professor of Tsukuba college of Technology

2003-2008 Lecturer of Comprehensive Human Sciences, University of Tsukuba

2008- Associate Professor of Faculty of Health and Sport Sciences, University of Tsukuba

Main Works:

- Saito, M. (2018). Adapted Physical Activity and Education. Saito, M. (ed.), Tokyo: Taishukan (in Japanese)
- Saito, M. and Muneta, M. (2013). Relationship between Physical Activity and Motor Performance in the Deaf School Children. Bull. Fac. Health Sport Sci. Univ. Tsukuba, 36: 69-75 (in Japanese).
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