Accessory stimulus modulates executive function during stepping task

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Accessory stimulus modulates executive function during stepping task. J Neurophysiol 114: 419–426, 2015. First published April 29, 2015; doi:10.1152/jn.00222.2015.—When multiple sensory modalities are simultaneously presented, reaction time can be reduced while interference enlarges. The purpose of this research was to examine the effects of task-irrelevant acoustic accessory stimuli simultaneously presented with visual imperative stimuli on executive function during stepping. Executive functions were assessed by analyzing temporal events and errors in the initial weight transfer of the postural responses prior to a step (anticipatory postural adjustment errors). Eleven healthy young adults stepped forward in response to a visual stimulus. We applied a choice reaction time task and the Simon task, which consisted of congruent and incongruent conditions. Accessory stimuli were randomly presented with the visual stimuli. Compared with trials without accessory stimuli, the anticipatory postural adjustment error rates were higher in trials with accessory stimuli in the incongruent condition and the reaction times were shorter in trials with accessory stimuli in all the task conditions. Analyses after division of trials according to whether anticipatory postural adjustment error occurred or not revealed that the reaction times of trials with anticipatory postural adjustment errors were reduced more than those of trials without anticipatory postural adjustment errors in the incongruent condition. These results suggest that accessory stimuli modulate the initial motor programming of stepping by lowering decision threshold and exclusively under spatial incompatibility facilitate automatic response activation. The present findings advance the knowledge of intersensory judgment processes during stepping and may aid in the development of intervention and evaluation tools for individuals at risk of falls.

judgment; inhibition; postural control; accessory stimulus; executive function

TAKING A QUICK CORRECT STEP response while inhibiting an incorrect one to environmental stimuli is a fundamental human function, and failing to do so potentially leads to falls. Findings from previous studies revealed that falls were associated with delayed step initiation caused by increased demands of attention (Lord and Fitzpatrick 2001; Pijnappels et al. 2010; St George et al. 2007). Most previous studies, however, examined the stepping behavior using only one sensory modality, even though in reality humans receive information simultaneously from multiple sensory modalities. Moreover, the control of balance and posture in fall prevention is a complicated central sensorimotor function that integrates information from visual, vestibular, and somatosensory systems. Thus, to advance our understanding of the control of gait initiation and falls associated with it, it is necessary to investigate such executive functions as stimulus identification, response selection, and postural preparations during stepping movement in the context of multisensory integration.

Reaction time (RT), commonly measured in simple reaction time (SRT) and choice reaction time (CRT) paradigms, can be reduced when multiple modalities simultaneously present the stimuli. Acoustic stimuli presented at nearly the same time as a visual imperative stimulus can reduce RTs, and these facilitation effects were found with both startling and nonstartling accessory stimuli (Carlsen et al. 2004a, 2004b; Hackley and Valle-Inclán 1998, 1999; Valls-Solé et al. 1995, 1999). Regarding stepping, gait initiation, or walking, however, most previous studies presented RT reduction mainly with startling acoustic stimuli and relatively simple tasks (MacKinnon et al. 2007; Queralt et al. 2008, 2010; Reynolds and Day 2007). Thus clarifying the effects of accessory stimuli on RTs in complex stepping movements would inform us about the intersensory judgment processes during such movement.

Along with RT reduction, acoustic stimuli are reported to enlarge the interference effect in a Simon task (Böckler et al. 2011; Fischer et al. 2010; Soutschek et al. 2013), in which responses are made according to the direction (not the location) of an arrow that is presented to either the right or the left of a central fixation (Simon 1969). In addition, they can cause an increase in the error rates in CRT tasks (Carlsen et al. 2004a; Low et al. 1996; Schmidt et al. 1984). However, previous multisensory studies investigated only overt errors. Partial errors can be observed, prior to the correct response, in electromyographic activity of the side that is associated with the incorrect responses (Burle et al. 2002, 2008; Masaki et al. 2012; Vidal et al. 2000). A similar phenomenon has recently been found in stepping reaction. Errors in the initial weight transfer of the postural responses prior to a step [i.e., anticipatory postural adjustment (APA) errors], indicative of motor program errors, may occur when the direction of a stepping movement is not known in advance, and arguably inhibitory control is related to those APA errors (Cohen et al. 2011; Sparto et al. 2013, 2014; Uemura et al. 2013a, 2013b). These previous studies hence propose that motor programming possibly deteriorates further in the presence of acoustic stimuli. Thus it is important to examine stepping reactions to stimuli from multiple sensory modalities, as information from multiple sensory modalities is more indicative of everyday experience.

In this study, we presented the visual imperative and acoustic accessory stimuli simultaneously, using the Simon task because this task affects only premotor time while the flanker task (another response compatibility task used commonly in RT paradigms) affects both premotor time and motor time to
the overall RT (Eriksen et al. 1985; Hasbroucq et al. 1999). This means that the effects of acoustic accessory stimuli on RT could be examined without considering the task specificity with the Simon task. In addition, we applied the CRT task to examine whether task difficulty plays any role.

The purpose of the present research was to examine the effects of acoustic accessory stimuli simultaneously presented with visual stimuli on executive functions during forward choice stepping. We hypothesized that if an acoustic accessory stimulus influences stimulus identification and response selection as stated during step execution, then the APA error rate of trials with accessory stimuli would be higher than that of trials without accessory stimuli in CRT and Simon tasks, most notably in the incongruent condition (i.e., mismatch of the direction and location of the visual imperative stimuli) of the Simon task. Furthermore, RT of trials with accessory stimuli were hypothesized to be shorter than trials without accessory stimuli in CRT and Simon tasks. In addition, movement times after reacting to a stimulus were hypothesized to be lengthened by accessory stimuli, since accessory stimuli can increase response force (Kiesel and Miller 2007; Miller et al. 1999; Stahl and Rammsayer 2005).

METHODS

Participants. Eleven participants (5 men, 6 women; mean ± SD age = 22 ± 2.24 yr) without a history of hearing, neurological, or orthopedic disorders that could influence the balance function were recruited from Nagoya University School of Health Sciences. All participants had normal or corrected-to-normal vision. The study was approved by the Ethics Committee of Nagoya University, and written informed consent was obtained before participation.

Apparatus and procedures. Participants were required to maintain a stationary standing posture on a force plate (Tec Gihan, Kyoto, Japan) with their bare feet and stepped forward in response to a visual imperative stimulus that appeared on a computer screen set just below eye level at a 1.0-m distance from the participant. Acoustic accessory stimuli (1,000 Hz, 80 dB) were also delivered randomly and simultaneously with the visual stimuli from two speakers, one placed on each side of the monitor. Visual and acoustic stimulus generation and signal acquisition were performed in customized LabVIEW programs (National Instruments, Austin, TX).

The initial standing position was the same for all participants; each foot was placed 5 cm apart from a center line drawn vertically to the frontal plane on the force plate. Forward stepping distance was also determined to be 45% of the participant’s leg length, measured from the greater trochanter to the floor. Before each trial, they were instructed to balance the weight of their feet evenly, which was confirmed by the position of the center of pressure (COP) obtained online from the force plate. The visual stimulus was an arrow (< or >) appearing on either the right or left side of the fixation point on the computer screen, and the participant stepped forward with the leg that corresponded to the direction of an arrow (< was assigned to the left leg and > was assigned to the right leg) onto a wood plate placed right front of the force plate and brought the other leg alongside. Participants were instructed to execute the movement as quickly and accurately as possible, and after the stepping they were required to move back to the same starting position and prepare for the next trial.

Stimuli and tasks. The protocol for the presentation of visual and acoustic stimuli was the following: the fixation point (black plus shape) was displayed at the center of a white computer screen for 9,500 ms, which was followed by a visual imperative stimulus of a black arrow (500 ms long) and a randomly presented acoustic accessory stimulus (300 ms long). Thus the total presentation time for each trial was 10 s.

Each participant performed two blocks of the CRT task and four blocks of the Simon task (Fig. 1). For all blocks, acoustic accessory stimuli were presented randomly in 50% of the trials. In the CRT task, a right-pointing arrow on the right side and a left-pointing arrow on the left side of the monitor were displayed randomly. Each CRT block consisted of 20 trials in total, with 10 right-pointing and 10 left-pointing arrows. In the Simon task, cues indicating the step direction were congruent (< on the left side, > on the right side) or incongruent (< on the right side, > on the left side) and all stimuli were presented pseudorandomly. Each Simon block consisted of 40 trials in total, with 20 congruent and 20 incongruent trials. Since the location and direction of the arrows did not match during incongruent trials, the participant was required to inhibit the response toward the location of the arrows.

Data collection and analysis. The data of ground reaction forces during step executions were collected with a force plate at a sampling rate of 1,000 Hz, and several temporal parameters were identified off-line with programs written in MATLAB (MathWorks, Natick, MA). The obtained mediolateral COP data were low-pass filtered at a cutoff frequency of 50 Hz with a fourth-order zero-phase lag Butterworth filter, and the baseline was defined as the mean value over the period from −500 ms to 0 ms with respect to the imperative visual stimulus. All subsequent procedures were similar to previous studies (Melzer and Oddsson 2004). The following parameters were extracted from step execution data (Fig. 2A). The RT was detected as the time at which the COP deviated mediolaterally toward either the swing or stance leg for at least 4 mm from the baseline. Foot-lift time was detected as the time at which the mediolateral shift of the COP toward the stance leg ended (when the speed of the COP movement toward the stance leg becomes <100 mm/s twice in row). In addition, the time from the RT to foot-lift time was defined as APA duration. APA errors were identified by the first mediolateral deviation of COP toward the stance leg for at least 4 mm from the baseline, indicating the presence of two or more postural adjustments before the final mediolateral shift toward the stance leg in one step execution (e.g., COP shifted to the stance leg first and then to the swing leg, which was followed by the final COP shift to the stance leg) (Fig. 2B).

Statistical analysis. Prior to data analyses of the trials, trials in which 1) RTs were faster than 3 SD below the mean of each block (i.e., guessed response), 2) RTs were slower than 3 SD above the mean of each block (i.e., overthought response), 3) mediolateral sway was >4 mm during the baseline period, or 4) participants stepped with the wrong foot or failed to step were excluded. Additionally, before calculation of overall APA error rate, RT, APA duration, and foot-lift time, left and right steps were combined, since the mean RT, APA duration, and foot-lift times were confirmed not to be different (CRT: P = 0.47 for RT; P = 0.28 for APA duration, P = 0.21 for foot-lift

| Block 1-2 | < | > |
| Block 3-6 | > | < |

Fig. 1. Visual imperative stimuli used in each block. Choice reaction time task consisted of both a right arrow on the right side and a left arrow on the left side. The Simon task comprised congruent (a right arrow on the right side or a left arrow on the left side) and incongruent (a right arrow on the left side or a left arrow on the right side) conditions.
time; Simon task: $P = 0.87$ for RT, $P = 0.64$ for APA duration, $P = 0.67$ for foot-lift time). All statistical analyses were performed with SPSS (IBM, Armonk, NY), and $\alpha$ level was set at $P < 0.05$ for all tests.

First, two-way repeated-measures analysis of variance (ANOVA) was conducted to determine the effects of acoustic accessory stimuli and task conditions on APA errors. Since many of our analyses consisted of different numbers of trials in each cell depending on the task condition and the presence or absence of an APA error, we used a linear mixed model for all subsequent analyses. The effect of accessory stimuli and task conditions on RT, APA duration, and foot-lift time was examined with sound (off and on) and condition (CRT, congruent, and incongruent) as fixed factors and participant as a random factor. Next, to determine the effect of APA errors as well as accessory stimuli with respect to the presence or absence of APA errors on RT, APA duration, and foot-lift time, we constructed a series of linear mixed models with each of those temporal parameters (RT, APA duration, and foot-lift time) as dependent variables, APA error (present and absence) and sound (off and on) as fixed factors, and participant as a random factor. These models were administered for each of the task conditions. Bonferroni post hoc analyses were performed to test interaction effects and to determine the locus of the difference.

RESULTS

Anticipatory postural adjustment error rate. Each participant completed 40 trials of the CRT task and 160 trials of the Simon task. Thus there were a total of 440 trials of the CRT task and 1,760 trials of the Simon task (880 trials of the congruent condition and 880 trials of the incongruent condition). The total number of trials that were analyzed in this study was 2,131 (3.1% excluded). Figure 3 shows the changes in APA error rates for sound-off and sound-on trials in each condition. The analyses of the ANOVA revealed the significant interaction of sound and condition [$F(2,20) = 9.13, P = 0.003$]. Post hoc analysis revealed that APA error rates of trials with sound were significantly higher than trials without sound in the incongruent condition ($P = 0.001$) but not in other conditions, indicating that the sound’s effect on APA errors was robust only in the incongruent condition.

Reaction time, anticipatory postural adjustment duration, and foot lift. The linear mixed model revealed the significant main effect of sound [$F(1,2125) = 71.67, P < 0.001$] and condition [$F(2,2125) = 49.92, P < 0.001$] on the RT (Fig. 4A). Post hoc analysis confirmed that RTs of trials with sound were significantly shorter than those of trials without sound in all conditions ($P < 0.001$) and that all conditions were different ($P < 0.001$) except for the congruent and incongruent conditions.

An interaction of sound and condition on the APA duration was significant [$F(2,2125) = 7.09, P = 0.001$] (Fig. 4B). Also, the main effects of sound [$F(1,2125) = 15.04, P < 0.001$] and condition [$F(2,2125) = 91.92, P < 0.001$] were revealed. The interaction of sound and condition can be explained by longer APA duration in trials with sound compared with trials without sound only in the incongruent condition ($P < 0.001$) and not in other conditions. This could indicate that sound only affected the APA durations of the incongruent condition.

An interaction of sound and condition on the foot-lift time was significant [$F(2,2125) = 6.40, P = 0.002$] (Fig. 4C). Furthermore, a main effect of condition was found [$F(1,2125) = 191.40, P < 0.001$]. Post hoc analysis showed that the foot-lift times of trials with sound were significantly shorter than those of trials without sound in CRT ($P = 0.028$) and congruent ($P = 0.016$) conditions but not in the incongruent condition, which potentially resulted from the increased APA duration in the incongruent condition.

Influence of anticipatory postural adjustment errors on temporal parameters of stepping. The above results indicate that APA errors and APA durations were affected by accessory stimuli only in the incongruent condition while RTs were reduced with accessory stimuli in all conditions. Thus we next examined the influence of APA errors on the temporal param-

Fig. 2. Examples of force plate data for forward step execution with the right leg. A: no-anticipatory postural adjustment (APA)-error trial. B: APA-error trial. Vertical line represents mediolateral center of pressure (COPx), and timing of the visual imperative stimulus is indicated by C. Reaction time (RT) and foot-lift time were extracted from the data. APA duration was calculated as the time from RT to foot-lift time. The APA error can be identified by the initial incorrect COPx shift toward the stance leg. See text for details.

Fig. 3. Mean APA error rates for sound-off and sound-on trials obtained from all participants in 3 different conditions. CRT, choice reaction time; CON, congruent; INC, incongruent. Error bars show SE. *$P = 0.001$ between sound-off and -on trials.
revealed a significant reduction in RT for APA-error trials in the CRT condition, the interaction of sound and APA error was significant \(F(1,846.18) = 144.29, P < 0.001\) but not the main effect of sound or their interaction. Likewise, in the congruent condition, a significant main effect of APA error \(F(1,853) = 241.94, P < 0.001\) was revealed but no main effect of sound or their interaction was present. In the incongruent condition, a significant interaction between sound and APA error \(F(1,852.06) = 671, P = 0.01\) was indicated. Post hoc comparison indicated that the APA durations of the APA-error trials but not the non-APA-error trials were significantly lengthened by sound \(P = 0.008\).

Figure 5C illustrates the mean foot-lift time of the divided trials. The main effects of APA error \(F(1,420.65) = 88.32, P < 0.001\) and sound \(F(1,420.08) = 12.93, P < 0.001\), but not their interaction, were significant in the CRT condition. In the congruent condition, a significant main effect of APA error \(F(1,852.01) = 12.58, P < 0.001\) was present but no main effect of sound or their interaction. Similarly in the incongruent condition, the main effect of APA error was significant \(F(1,846.15) = 116.95, P < 0.001\) but not the main effect of sound or their interaction.

**DISCUSSION**

The present study investigated whether an acoustic accessory stimulus simultaneously presented with a visual imperative stimulus influences the executive functions by increasing APA errors and reducing RTs during forward choice stepping. We hypothesized that APA error rates would be greater in trials with an accessory stimulus for all conditions, particularly in the incongruent condition of the Simon task, and that the RTs would be shorter in trials with an accessory stimulus for all tasks. This hypothesis was partially supported: the RTs were reduced with accessory stimuli in all conditions as expected; however, we found that accessory stimuli caused an increase in the APA error rates only in the incongruent condition. Additionally, we observed that APA durations were increased with accessory stimuli in the incongruent condition and the foot-lift times were shortened with accessory stimuli in all but incongruent conditions.

Dividing the trials according to whether APA errors occurred or not further enabled us to interpret the stepping behavior with accessory stimuli in detail. The imperative stimulus of an arrow used in the present study has both directional and locational information. The directional information is the direction that the arrow is pointing to (left or right). The locational information is the side of the monitor where the arrow is presented (left or right). The accessory stimuli speeded the response toward both the location and direction of the imperative visual stimulus in the CRT and congruent conditions, whereas the accessory stimuli affected the response toward the location of the stimulus in the incongruent condition. This indicates that the accessory stimuli facilitated automatic response toward the stimulus location exclusively under spatial incompatibility, as discussed below in detail.

The APA error rates of conditions without accessory stimuli obtained in this study were similar to those in previous studies.
The present study revealed that accessory stimuli caused an increase in the APA error rates only in the incongruent condition (Fig. 3). In previous studies, overt errors, which are different from the partial errors that APA errors are considered to be, were investigated by presenting an accessory stimulus with an imperative visual stimulus in CRT paradigms. However, findings employing this method have been inconsistent. In some studies significantly increased overt error rates in the presence of accessory stimuli were observed (Low et al. 1996; Schmidt et al. 1984), while other studies showed no significant effect of accessory stimuli on overt error rates (Hackley and Valle-Inclán 1999; Jepma et al. 2009).

In regard to this inconsistency, Jepma et al. (2009) proposed task difficulty as a potential mechanism. In a two-choice decision process, a decision is made when evidence from sensory modalities reaches a decision threshold from a starting point that is set at half the magnitude of two decision thresholds if unbiased. Relatively easy tasks with short RTs (<350 ms) have a decision threshold close to the starting point of the decision process, while more complex tasks with somewhat longer RTs (>500 ms) have a decision threshold at a large distance from the starting point. Accessory stimuli are suggested to lower a decision threshold in the response selection process. Thus decisions are unintentionally and incorrectly made in the presence of accessory stimuli in easy tasks since the decision threshold is initially set close to the starting point, while in complex tasks error rates are not heavily influenced by accessory stimuli (Jepma et al. 2009).

In the present study, although the type of error was different from that in the previous works, APA error rates should be increased in the presence of accessory stimuli when considering the RTs. The obtained results indicated, however, that accessory stimuli affected the APA error rate only in the incongruent condition, indicating that the stimulus location may have impacted the outcomes. In studies by
Fischer et al. (2010) and Böckler et al. (2011), who investigated the influence of accessory stimuli on the Simon effect, which is the difference in RT between congruent and incongruent conditions, results supportive of this prediction were presented. These studies found a reduction in RTs for both congruent and incongruent conditions and further found an increase in the Simon effect as a result of the accessory stimulus. Fischer et al. (2010) argue that accessory stimuli generally decrease RTs and additionally lower the decision threshold based on the location of the visual stimulus regardless of whether the response is correct or not. This means that in the incongruent condition subjects initially responded based on the stimulus location incorrectly but to the degree of not making an overt error and later corrected the response based on the stimulus identity (i.e., direction of an arrow) more in trials with accessory stimuli than in trials without accessory stimuli. However, the previous research failed to examine partial errors that may have occurred on the side that initially responded incorrectly. In the present study, it is likely that the same mechanism (i.e., facilitation of automatic response activation) occurred, and an increase in the Simon effect by an accessory stimulus was indicated alternatively by the increased APA errors.

Beside the interference effect of accessory stimuli, the present study elucidates the facilitation effect of accessory stimuli on RTs during a stepping task. In all conditions, accessory stimuli significantly reduced the RTs (Fig. 4A). With the statistical analysis of RTs without taking the APA errors into consideration, however, it is not clear whether the stimulus location-based facilitation certainly occurred. In addition, there is a possibility that the lengthened APA durations in the incongruent condition were induced by the accessory stimuli affecting the motor execution process toward the location of the visual stimulus (Kiesel and Miller 2007; Miller et al. 1999; Stahl and Rammsayer 2005), although they appear to be caused by the increased APA error rate (Fig. 4B) (Uemura et al. 2013b). This may have further resulted in the reduction of facilitation effect by accessory stimuli on foot-lift time in the incongruent condition (Fig. 4C). To clarify the effects of accessory stimuli on the automatic response activation and thus the APA errors as well as the motor execution process, we analyzed the temporal parameters of trials that were divided according to the presence or absence of APA errors.

Additional analysis of RT with respect to APA errors confirmed that accessory stimuli generally lower the decision threshold irrespective of stimulus type and also lower it based on the locational information of the visual stimuli under spatial interference (Fig. 5A), which is consistent with the rationale for the increased APA error rate. In the CRT condition and the congruent condition of the Simon task, accessory stimuli reduced the RTs of both APA-error and non-APA-error trials, implying that the facilitation by accessory stimuli occurs regardless of the visual stimulus location or identity. In contrast, accessory stimuli reduced the RTs only for APA-error trials in the incongruent condition. This indicates that accessory stimuli modulated automatic response activation and reduced the RTs based on the visual stimulus location when there was a spatial incompatibility. In addition, the automatic activation of responses implies that accessory stimuli have potentially been unintentionally associated with the stimulus location and acted as a retrieval cue (Steinborn et al. 2009, 2010).

With regard to the APA durations, additional investigations suggested the possibility that motor execution processes were affected by accessory stimuli. In all conditions, regardless of the presence of accessory stimuli, APA durations were lengthened in APA-error trials (Fig. 5B), derived from the additional mediolateral weight shifts caused by APA errors (Uemura et al. 2013a, 2013b). In the incongruent condition, unlike the other two conditions, the accessory stimuli lengthened the APA duration only of APA-error trials. If the lengthened APA durations in the incongruent condition (shown in Fig. 4B) were solely caused by the increased APA error rates, then the APA durations of APA-error trials should not be affected by accessory stimuli. This suggests that accessory stimuli have effects on the motor execution stage of stepping movement when responding incorrectly to the stimulus location. However, APA durations of non-APA-error trials in the CRT and congruent conditions should have been lengthened by accessory stimuli, which was not evident in this study. Another possibility is that accessory stimuli may have hampered the process of noticing and correcting an incorrect response. Nevertheless, future research will be needed to clarify the mechanisms behind this phenomenon.

Analysis of foot-lift times with respect to APA errors revealed that accessory stimuli shortened the foot-lift times of both APA-error and non-APA-error trials in the CRT condition, and a similar tendency was seen in the congruent condition (Fig. 5C). In contrast, the response facilitation that primarily occurred toward the stimulus location as well as lengthened APA durations of APA-error trials in the incongruent condition reduced the effect of accessory stimuli on foot-lift time.

Increased APA errors in older individuals compared with younger adults have been reported. APA errors were considered related to executive function, especially inhibitory control (Cohen et al. 2011; Sparto et al. 2013, 2014). Furthermore, increased stepping reaction errors (Schoene et al. 2014) and delayed step initiation and completion of a voluntary step (Lord and Fitzpatrick 2001; Pijnappels et al. 2010; St George et al. 2007) were associated with falls in the elderly. The presence of an APA error can result in those situations. The present study broadened our understanding by presenting sound simultaneously with visual stimuli and revealed that acoustic accessory stimuli extend the degree of APA errors when spatial incompatibility is present. Thus it is conceivable that acoustic sound modulates executive function during stepping, leading to delayed completion of a step and, potentially, falls. Identifying the effects of aging on this particular matter may be a future research subject, since older individuals tend to set decision thresholds differently than younger adults (Forstmann et al. 2011). Moreover, the current fall assessment tools are not sensitive enough to detect early-stage impairments (Barr et al. 2014; Schoene et al. 2013). Therefore, the advances on this issue may aid in the development of clinical measures to identify individuals at risk of falls as well as prevention programs.

The limitation of the present study would be an extra cognitive load that was imposed upon the participants when they were trying to balance the weight of their feet evenly. Even though it was necessary to avoid a weight distribution on
one side in order to measure an initiation of APA accurately, the extra cognitive load might have interfered with the ability to perform the tasks. Also, the arrows used in the present study may have not been intuitive for some participants, which potentially slowed the reactions to the stimuli. In addition, we used a portable single force plate because it is convenient when applying the present research to individuals with disabilities at a clinic or hospital, leading to an indirect measurement of the foot-tilt time. Accordingly, experiments with two separate force plates may need to be performed to confirm our findings for the APA durations and foot-tilt times.

In sum, this study revealed that acoustic accessory stimuli simultaneously presented with visual imperative stimuli modulate the initial motor programming of stepping by lowering the decision threshold. More specifically, the accessory stimuli speeded the response regardless of the stimulus identity or location in the CRT task and the congruent trials of the Simon task, whereas reduction in RTs in the incongruent trials occurred based solely on the stimulus location. Consequently, the accessory stimuli caused an increase in the APA error rates under spatial incompatibility, and their facilitation effects on RTs did not remain until foot lift in the Simon task.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: T.W. and I.N. conception and design of research; T.W., S.K., and S.T. performed experiments; T.W. analyzed data; T.W. and I.N. approved final version of manuscript.

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