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Effects of Simultaneous Cognitive Task on Gait Event Accuracy with Auditory Stimuli: Comparison between Young Adults in Their 20s and the Elderly in their 70s

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Abstract: The purpose of this study was to compare the difference in the accuracy of gait events between young and older adults during metronomic walking by auditory cueing. Additionally, age-specific changes in the gait event accuracy according to additional simultaneous cognitive tasks were examined. The time interval (or temporal error) between the auditory cue (i.e., metronome) and the heel contact was used as the accuracy of the gait event. Fifteen young group (YG, 24.7 ± 0.8 years) and 14 elderly (EG, 78.4 ± 5.5 years) people participated in the experiment. The temporal errors under two gait conditions (MET: walking with metronome; MET + BC: walking with metronome while counting backward) were compared for each group. The results revealed that all the temporal errors of EG were significantly greater than those of YG. While the addition of simultaneous cognitive tasks resulted in a significant increase in temporal error in both age groups, the coefficient of variation (CV) of the temporal error significantly increased only in the EG group. In other words, although heel contact accuracy with auditory stimuli was affected by the simultaneous cognitive task in both groups, it was demonstrated that the variability of the error in the young adults remained constant. Therefore, the time error measurement used in this study has the potential to be used as a tool to judge the gait instability of the elderly compared with young adults.

Keywords: rhythmic auditory cueing; cognitive task; temporal error; elderly; metronome; heel contact timing

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1. Introduction

The gait mechanism is a complex process of the neuro-muscular-skeletal system that relies on the simultaneous interaction of motor, sensor, and cognitive systems [1,2]. In other words, as a human walks, the human body receives various sensory inputs from the visual, vestibular, and proprioceptive systems, and makes optimal joint movements controlled by the neuro-muscular-skeletal system.

Gait can be considered as a rhythmic movement created by the harmony of the neuro-muscular-skeletal system involved in upper and lower limb movements [3], and externally rhythmic cueing is used in gait rehabilitation. This cueing method has been mainly used as visual and auditory stimuli, and the most commonly used method in gait research and rehabilitation clinics is the metronome, which is a rhythmic auditory cueing method [4]. As a classic example, rhythmic auditory cueing has been widely used to rehabilitate Parkinson's disease patients with internal timing deficits from the neural network point of view [5–7]. In addition, a positive effect of rhythmic auditory cueing on the gait of healthy elderly has been reported [1]. As such, the metronome is widely used as a tool for gait rehabilitation.

In general, in studies on simultaneous cognitive task and gait, attention can be defined as the information processing capacity of an individual, and changes in gait conditions and/or aging have been reported [8]. For this reason, according to a study on dual task paradigms during walking, it is considered that reduced cognitive capacity does not sufficiently intervene in controlling cognitive loads during dual task walking [9]. From this point of view, the rhythmic auditory cueing can be used not only as a method for rehabilitation, but also as a tool for assessing gait. Generally, gait abnormalities in about 15% of the elderly population are not due to an underlying disease, and the rate of gait abnormalities increases rapidly with age [10]. It has already been established that the gait variables and strategies in the elderly population are different from those in young adults [1]. Adjustment of the foot position and the heel contact time during gait can be viewed as goal-oriented movement that involves the entire body [11,12], and a gait abnormality can be regarded as a gait disorder, which is a physical abnormality or change. This movement accuracy with cueing could lead to enhanced contrast between subject groups with different levels of body balance (i.e., age-difference) when the subjects are asked to perform additional simultaneous cognitive tasks [2]. Nevertheless, only few studies have compared the accuracy of gait timing with auditory stimulus in terms of body balance, with the exception of studies of local movements such as finger tapping or bimanual movement [13,14].

In our previous study, we developed a system to measure this time error to use the gait accuracy of the auditory rhythm, which can be quantified as the time error between the auditory rhythm and the heel contact, as an index to evaluate gait stability [15]. Therefore, as an additional study using this system, this study compared the gait accuracy of the elderly and young adults by performing additional simultaneous cognitive tasks when walking the metronome using auditory stimuli.

2. Materials and Methods

The participant groups consisted of a young adult group (YG) and an elderly group (EG). Both participants had not experienced medical issues in their lower extremity musculoskeletal function in the last year and were able to walk for more than 10 min. The YG group was comprised of 15 male college students in their 20s (24.7 $\pm$ 0.8 years; 173.5 $\pm$ 4.2 cm; 76.2 $\pm$ 9.8 kg) and the EG group was made up of 14 healthy male seniors (78.4 $\pm$ 5.5 years; 162.4 $\pm$ 6.8 cm; 65.3 $\pm$ 8.9 kg), where community-dwelling senior individuals recruited from the local senior citizens' center at Chungju city in South Korea participated in this study. They were determined as subjects of analysis considering their medical history (i.e., presence of cardiovascular problems, neurological disorders of the vestibular or cerebellar systems, history of lower-limb or spinal surgery in the previous 12 months), problems in communication and cognition indicated by a Mini-Mental State Examination-Korean (MMSE-K) version score >24, and no requirement to use any type of assistive walking device such as cane, crutch, or walker.

The protocol of this study was approved by the Ethics Committee of Konkuk University. The purpose and methodology of the study were fully explained to all participants, who were enrolled in the study after they gave their informed consent.

All experiments were conducted on a self-paced treadmill, where the belt speed was controlled by the participants [16]. The gait experiment, which was repeated three times, involved walking with the metronome (MET) and walking with the metronome while counting backwards (MET + BC). The experiment sequence was randomized, and the participants were required to match the metronome beat with their heel contact while walking. Backward counting was performed by consecutively subtracting three from the number 100 (e.g., 100, 97, 94, 91, and so on) [17]. Before each experiment, all participants had an adaptation period of 3 to 5 min on the treadmill. After the adaptation, the preferred walking speed of each participant was estimated from the average walking speed for one minute at the beginning, and the metronome beats per minute (BPM) for each individual was determined accordingly. Using this BPM, gait experiments under MET and MET + BC conditions were performed.

For both gait experiment conditions, a system implemented with an inertial sensor and LabVIEW programming was used to measure the temporal error between the metronome beat and the heel contact [15]. The system was configured to present the metronome rhythm synchronized to the participant's preferred walking speed, and measure the temporal error of the heel contact from presentation of the metronome rhythm. The metronome rhythm transmitted through speakers was implemented using LabVIEW software (National Instruments Corp., Austin, TX, USA). To record the heel contact events, a Delsys Trigno inertial sensor was attached to the participant's instep, and the data were stored using the Delsys SDK (software development kit). For convenience, the heel contact before and after the metronome beat was expressed as a negative (−) value and positive (+) value, respectively, and the absolute value was used when calculating the mean of the temporal error. The coefficient of variance (CV = standard variation/mean × 100) reflecting the variation (or distribution) in the mean value was used to compare the temporal errors.

The repeated measures ANOVA was used to determine differences in temporal error according to the gait conditions by age groups. SPSS software ver. 25 (IBM SPSS Statics Inc., Chicago, IL, USA) was used for statistical processing, and a significance level of 0.05 was applied.

3. Results

Figure 1 shows a representative distribution of the temporal error for a given metronome beat by age and gait conditions.

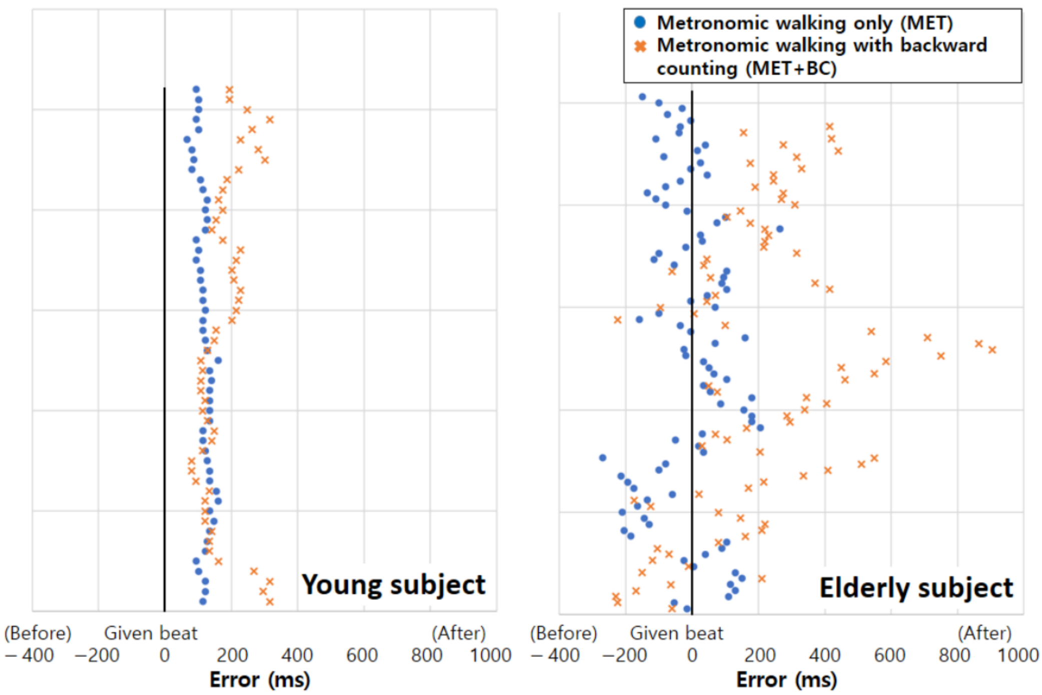

Figure 1. Examples of the temporal errors between the metronome beat and the heel contact for each gait condition by age (Young subject: subject #1, Elderly subject: subject #8).

Table 1 summarizes the repeated measures ANOVA results. The within-group difference according to the simultaneous cognitive task was found to be statistically significant (F (1.27) = 50.761, $p < 0.05$, $\eta^2 = 0.653$), and the interaction between the age and the simultaneous cognitive task was significant (F (1.27) = 10.841, $p < 0.05$, $\eta^2 = 0.287$). The effect between groups according to age was also statistically significant (F (1.27) = 13.109, $p < 0.05$, $\eta^2 = 0.327$).

Table 1. Statistical results for within-subject and between-subjects effects (*: Statistical difference according to gait conditions, age, and interaction between gait conditions and age).

Source	Type III Sum of Squares	df	Mean Square	F	P Level	Partial Eta Squared (η^2)
Gait conditions	255,034.757	1	255,034.757	50.761	* 0.000	0.653
Age	115,845.156	1	115,845.156	13.109	* 0.001	0.327
Gait conditions * Age	54,470.768	1	54,470.768	10.841	* 0.003	0.287

Figure 2 shows the mean, standard deviation, and CV of the temporal errors for each participant. In all cases, temporal errors from the EG group were statistically greater than those of YG. In both age groups, the mean and standard deviation of the temporal errors were significantly increased by a cognitive task (i.e., backward counting). While there was no statistical difference in YG in terms of CV, EG exhibited significantly increased CV with a cognitive task.

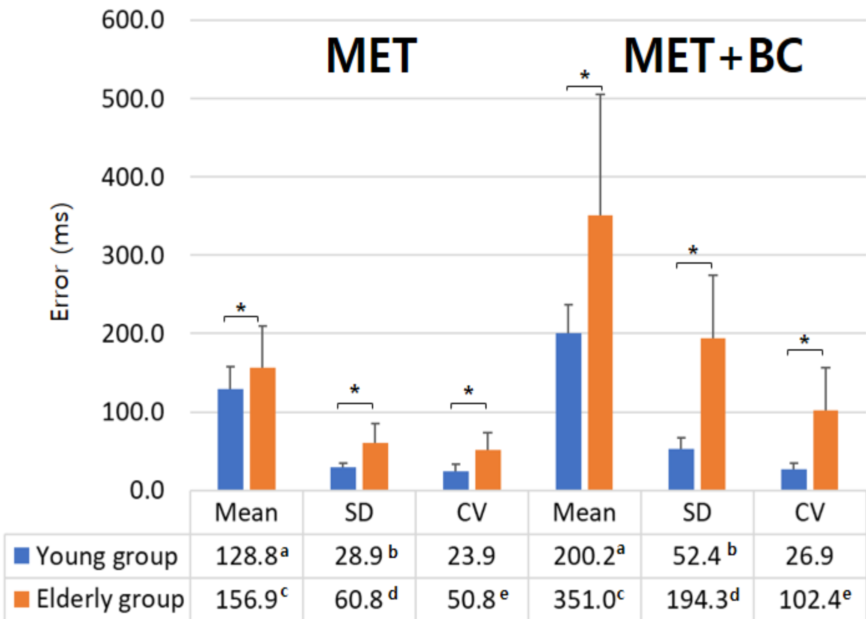

Figure 2. Mean, standard deviation (SD), and coefficient of variance (CV) of temporal errors between the metronome beat and the heel contact for each gait condition by age (*: Statistical difference between age groups by variable, a, b, c, d, e: Statistical difference by gait condition in each group; MET: walking with the metronome, MET + BC: walking with the metronome while counting backwards).

Figure 3 shows the cumulative distribution of all temporal errors by age and gait conditions. Overall, it can be seen that the older the participants, the wider the distribution of the temporal error becomes with the execution of additional cognitive tasks.

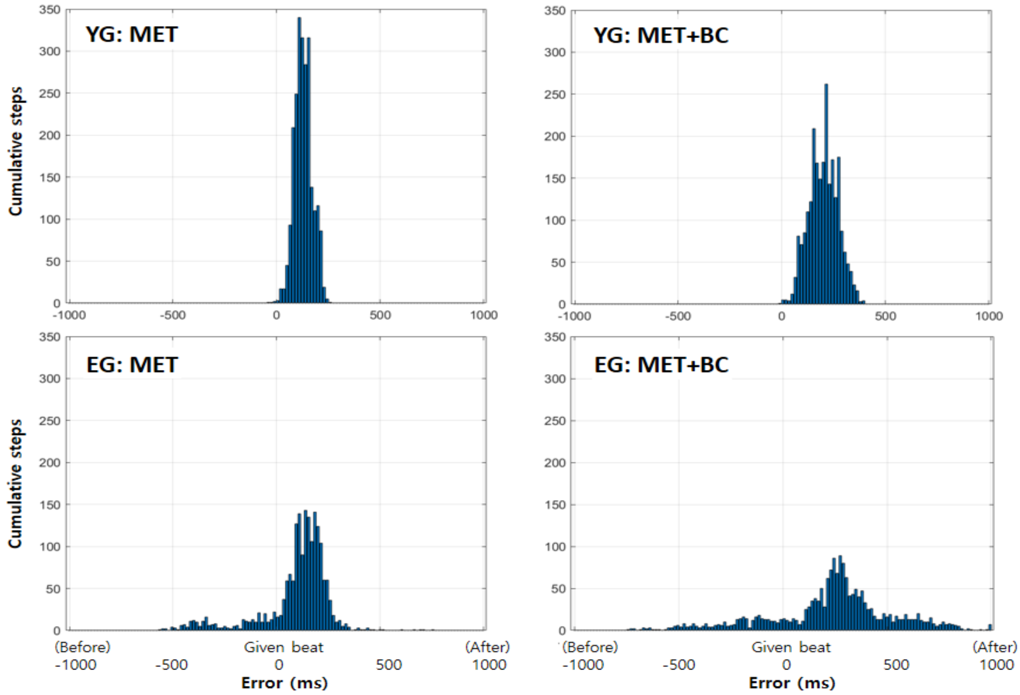

Figure 3. Cumulative distribution of the temporal errors between the metronome beat and the heel contact for each gait condition by age for all participants (15 time data bundles per bar; YG: young adults group, EG: the elderly group).

4. Discussion

This study determined the temporal errors of heel contact from the presentation of the metronome beat in the elderly and young adults. In addition, differences in between-group and within-group temporal errors when performing additional cognitive tasks were studied. The results revealed that there were significant differences in mean and CV of the temporal errors between the young adults and the elderly under both gait conditions. Furthermore, the mean temporal errors under MET and MET + BC conditions within each group were significantly increased in both young adults (MET: 128.8 $\pm$ 29.0 ms; MET + BC: 200.2 $\pm$ 37.0 ms) and the elderly (MET: 156.9 $\pm$ 52.2 ms; MET + BC: 351.0 $\pm$ 153.9 ms). However, while the CV of the temporal errors in the elderly was significantly higher under MET + BC conditions than under MET conditions (102.4 $\pm$ 54.0% and 50.8 $\pm$ 22.5%, respectively), the CVs in the young adult group did not change under both conditions (26.9 $\pm$ 8.0% and 23.9 $\pm$ 8.9%, respectively).

According to previous studies related to these results, the human body receives various sensory inputs from visual, vestibular, and proprioceptive systems while walking, and moves the joints, which are under tight regulation of the neuro-muscular-skeletal system, as required. Gait in the elderly exhibits decreased step length and symmetry compared to gait in young adults as well as an increased step time and step width. It is also known that gait variability increases with age [1,10,18]. This cause is considered to have changed the shape of the gait according to the overall compensatory adaptations as the muscle strength weakens and energy consumption increases with age [10]. According to Nutt et al., factors involved in gait disturbance can be broadly divided into lower-, intermediate-, and higher-level disturbances [1,19]. Based on such sequential categories, lower-level disturbances include peripheral effectors of locomotion, while intermediate-level disturbances include efferent and afferent sensorimotor pathways of the central nervous system. Higher-level disturbances include anxiety and cortical control involved in gait. According to previous studies, gait abnormality and disorder can occur due to deterioration in one or more of these categories, and even more severe disturbance may occur when performing a cognitive-motor dual-task [2,17,20,21]. In other words, gait reflects the overall state of the neuro-muscular-skeletal system, and changes in gait are closely related to physical health. Regarding gait control, it can be seen that the movement control of the lower extremities for gait indicates the ability to accurately control and determine the position and time point of the landing foot at the target point according to the throw-and-catch theory. [15,22]. In addition, the increase in cognitive load caused by performing additional cognitive tasks can be inferred as the difference in motion accuracy due to the difference in the cognitive-motor processing capacity [8]. From this point of view, it may be inferred that the error time of the walking time used in the results of the present study reflects the cognitive-motor processing capacity of each group according to the simultaneous cognitive task during walking of young adults and the elderly [8,15,22].

Therefore, gait disorders in the elderly could work as a predictor and diagnostic marker of physical abnormality due to aging. However, clinical diagnostics of aging or neuropathy using relative mean differences between subjects is yet to be attained. This calls for a clear distinction between healthy young adults and the elderly (or patients with neuropathy) [10]. From this perspective, it may be more effective to evaluate changes in gait variability under various conditions (i.e., dual tasks) within each group than evaluating group differences of various gait variables by age. In general, an increase in gait variability in a healthy older adult may be due to a decrease in musculoskeletal or motor control [23,24], and may also be considered as a means of maintaining physical stability against increased physiological noise [24,25]. Based on the results of the present study (Table 1 and Figure 2), maintaining body balance while lowering the stepping foot to the intended location at the correct time point can be an indicator reflecting the ability to balance one's body. While the variability (or distribution) of the temporal errors significantly increased with additional cognitive-motor tasks in the elderly, variability of the temporal errors in young adults remained constant (Figures 2 and 3). Thus, this can be regarded as a healthy state for maintaining body balance.

This study has the limitation of the walking experiment using a treadmill. Treadmills are used in various gait experiments, training, and rehabilitation, but there may be differences in gait spatio-temporal variables and kinematics of the lower extremities [26]. In the case of this experiment, treadmill walking was used only for comparison by age for the same condition experiment results using the previously developed system, but an experiment through a system that can be applied to over-ground will also be required. In addition, the effects of the types of cognitive tasks used in this study may differ [27], and further studies on this will be needed for use in various clinical and rehabilitation conditions.

5. Conclusions

This study compared the accuracy of the gait timing in young adults and the elderly according to auditory stimulation and additional cognitive tasks. As a result, each group showed a difference in the accuracy of the gait timing according to the additional cognitive task, and his difference was greater in the elderly than in young adults. In addition, from the viewpoint of the variability (i.e., CV) of the temporal error, it was confirmed that the magnitude of the variability was smaller in young adults than in the elderly, and was constant under both gait conditions. Additional research is needed, but this study demonstrated that the accuracy of the foot landing time following metronome beat with simultaneous cognitive task may have the potential to be used as a tool for evaluating gait performance in the elderly.

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Institutional Review Board Statement: The protocol of our study was confirmed by the Ethics Committee of Konkuk University (IRB No. 7001355-201507-HR-066).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The authors declare no conflict of interest.

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