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THE EFFECT OF VARIOUS CELL PHONE RELATED ACTIVITIES ON GAIT KINEMATICS

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Abstract

Background—With cell phone use and ownership on the rise, daily circumstances often require individuals to divide attentional resources between walking and a cell phone-related task. This division of attention has been found to detrimentally effect task performance, making pedestrian cell phone usage an increasing safety concern. However, most studies have investigated the impact of dual-tasks on situational awareness and few have focused on tasks other than texting. Therefore, this study aimed to investigate the effect of various cell phone-related tasks on lower limb kinematics during walking.

Methods—Fourteen healthy, college-aged subjects completed gait analysis trials in five walking conditions, one single-task walking condition and four dual task conditions: Walk+Converse, Walk+Read (Simple), Walk+Read (Difficult), and Walk+Text. Subjects' movements were recorded with a motion capture system and peak sagittal plane lower extremity joint angles, gait velocity, and stride length were calculated.

Results—Of the eight kinematic outcome measures analyzed, all but one revealed some significant ($p < 0.05$) differences between dual-task walking conditions. Gait velocity and stride length both decreased due to the addition of the dual tasking, with the magnitude of the reduction becoming more apparent with the increased difficulty of the cell phone-based task.

Conclusion—This study supports a fundamental change to gait kinematics in response to cell phone use while walking, with the magnitude of impact being directly related to the complexity of the secondary task. The significant changes to gait kinematics in complex dual-task situations could present a threat to balance.

Keywords

Gait; Cell phone; Dual task; Kinematics

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INTRODUCTION

Gait is not an automatic task as it requires both attention and executive function for execution.[28] These cognitive processes are vital in a person's ability to complete more than one task at a time, dual-tasks (DT).[28] Attention, or one's finite capacity to receive and select specific stimuli for awareness, is controlled by executive function, which permits the execution of goal-oriented behavior.[28] Daily circumstances often require focusing on processing, and responding to more than one stimulus at the same time, a concept called divided attention, which is most frequently tested via DT performance.[20] Because gait requires cognitive processing, theories of DT interference suggest that completing a secondary task while walking should have a significant effect on a subject's ability to walk.[28]

Dual tasking or multitasking is known to have effects on performance and accuracy. It was observed that these effects are dependent on the metric used and the difficulty of the primary task. However, these studies are done on computers and could be considered a static movement dual task.[1,2,4] Gait kinematics have shown increased variability with treadmill walking at self-selected speeds.[24] With more portable interactive technologies available, determining how dual taking effects over-ground gait is necessary.

Due the multitude of technological distractions available to individuals, current societal conditions have also made it necessary to study DT walking in the healthy, young population. The Pew Research Center suggests that 70% of adults and teens own a cell phone.[3] Observational research shows nearly 30% of pedestrians use mobile devices while crossing busy intersections, with 7% actively texting while crossing.[25] Experimental research has shown that when texting while walking, subjects experience a decrease in situational awareness and an increase in medial-lateral excursion, both of which threaten a subject's safety in the real world.[13] It is clear that there is an association between cell phone use and safety, as the number of pedestrian injuries related to cell phone usage increased by nearly 170% from 2004 to 2010.[16]

While these studies suggest significant DT interference in a healthy, young population when texting while walking,[13,14,17] few studies have looked into other cell phone related tasks that could serve as distractors (e.g. reading text or conversing aloud on the phone). Additionally, few studies have compared the degree of impact that these various DT combinations have on walking or investigated the DT effects of cell phone use on lower limb kinematics during walking.

This study compared the normal gait characteristics of nonpathological, college-aged subjects gait kinematics while performing various DT activities. It was hypothesized that differences in these variables compared to the control would become greater as the cognitive task became more demanding.

METHODS

Fourteen college-aged subjects were recruited from a small, private university, and surrounding community (Table 1). Participants were excluded if they had gait pathologies that would interfere with their ability to complete the required tasks. Participants were required to own a mobile phone with a touch screen, QWERTY keyboard, and the capability to turn the autocorrect function off. All subjects signed an approved informed consent form the University of Scranton's Institutional Review Board.

Subjects completed a total of five walking conditions during one lab visit. One single task (ST) walking, where the subjects walked normally and four DT conditions: sim_walk+read [simple], dif_walk+read [difficult], walk+text, and walk+converse. For the reading trials, subjects walked while reading aloud a passage sent to them via text message. Simple passages were written at a third grade level, and difficult passages were excerpts from reading comprehension sections of the Scholastic Assessment Test (SAT). For the texting trials, subjects typed a copy of a passage that was sent to them via text message with the autocorrect function turned off. The passage was written at a third grade reading level. At the conclusion of each texting trial, the subject sent the portion of the passage they completed to the researcher. For the conversation trials, subjects responded aloud to a prompt presented by the researcher.

Trials were completed at a self-selected pace across a level 10-m surface. Subjects were provided with no instructions regarding which task (walking task or secondary task) to focus on as they completed each DT trial. The ST protocol was always completed first and was repeated five times. Then, five trials of the four randomized DTs tasks were completed. All DT trial prompts were unrelated passages.

Kinematic data were collected at 120 Hz with a 12-camera motion-capture system (Kestrel Model, Motion Analysis, San Rosa, CA USA). A modified sixteen marker system was applied on the lower extremity of the subjects who were in wearing tight fitting clothes and in bare feet.[7,12] Joint kinematics were calculated with the KinRT software (Motion Analysis Corp).

Outcome variables used, which were previously used to describe gait and dual tasking,[6,11,19] included gait velocity, stride length, and peak joint angles in the sagittal plane for each lower extremity joint — specifically; plantarflexion in pre-swing, dorsiflexion at terminal stance, knee flexion during midswing, knee flexion at terminal swing, hip extension in terminal stance, and hip flexion at initial contact. Ensemble average data were used to determine statistically significant differences between conditions.

A repeated measures ANOVA — using SPSS 23 — with walking condition as the within-subject factor was used to analyze each outcome variable. The level of significance was set at $p < 0.05$ for all analyses and *post-hoc* pairwise comparisons were used to determine differences between groups.

RESULTS

The results indicate that more cognitively challenging secondary tasks (reading a difficult passage and texting) impact normal gait kinematics to a greater extent than less complicated cognitive tasks (conversing and reading a simple passage; Fig. 1 and Table 2).

There was a significant main effect of walking condition on peak ankle plantarflexion angle in pre-swing ($p \leq 0.001$). Peak ankle plantarflexion in the walking condition (27.67 ± 4.95°) was significantly greater than the dif_walk + read condition (23.79 ± 6.45°; $p = 0.002$) and the walk +text condition (19.83 ± 6.75°; $p = 0.006$; Fig. 1 and Table 2). There were no significant differences between DT conditions.

There was a significant main effect of walking condition on peak ankle dorsiflexion angle during terminal stance ($p = 0.011$). Peak ankle dorsiflexion in the walking condition (7.86 ± 3.23°) was significantly less than the dif_walk + read (9.09 ± 3.91°; $p = 0.013$) and walk + text (9.87±3.82°; $p = 0.006$) conditions (Table 2). Additionally, peak ankle dorsiflexion in the walk + converse condition (7.73 ± 3.99°) was significantly less than peak dorsiflexion in the dif_walk + read ($p \leq 0.001$) and walk + text ($p = 0.006$) conditions.

There was not a significant main effect of walking condition on peak knee flexion during midswing ($p = 0.654$; Table 2).

There was a significant main effect of walking condition on terminal swing knee flexion ($p = 0.005$). The peak terminal swing knee flexion in the walking condition (3.39 ± 5.75°) was significantly less than the sim_walk + read condition (2.25 ± 4.81°; $p = 0.035$) and the dif_walk + read condition (2.06± 5.01°; $p = 0.018$; Table 2).

There was a significant main effect of walking condition on peak hip flexion at initial contact ($p \leq 0.001$). The peak hip flexion in the walking condition (30.27 ± 5.66°) was significantly greater than the sim_walk + read (27.69 ± 5.23°; $p = 0.004$), dif_walk + read (27.43 ± 5.56°; $p \leq 0.001$), and walk + text (27.27 ± 5.45°; $p \leq 0.001$) conditions (Table 2). Additionally, peak hip flexion in the walk + converse condition (29.13 ± 5.66°) was significantly greater than the dif_walk + read ($p = 0.012$) and walk + text ($p = 0.015$) conditions.

There was a significant main effect of walking condition on peak hip extension in terminal stance ($p = 0.001$). Peak hip extension was significantly greater in the walking condition (13.08 ± 4.45°) than the dif_walk + read (11.62±4.41°; $p = 0.047$) and walk + text conditions (10.36 ± 4.28°; $p = 0.006$; Table 2). There were also significant differences between DT conditions: hip extension in terminal stance for both the sim_walk + read condition (11.62 ± 4.36°) and the dif_walk + read condition were greater than the walk + text condition ($p = 0.010$ and $p = 0.007$, respectively).

There was a significant main effect of walking condition on gait velocity ($p \leq 0.001$). Gait velocity was significantly greater in the walking condition (1.41 ± 0.13 m/s) than in the sim_walk + read (1.17 ± 0.13 m/s; $p = 0.002$), dif_walk + read (1.11 ± 0.10 m/s; $p \leq 0.001$), and walk + text (1.04 ± 0.09 m/s; $p \leq 0.001$; Table 2) conditions. Additionally, there were significant differences between DT conditions. Gait velocity in the walk + converse condition (1.26 ± 0.10 m/s) was significantly greater than the dif_walk + read ($p = 0.011$) and walk + text ($p \leq 0.001$) conditions, and gait velocity in the sim_walk + read condition was significantly greater than the walk + text condition ($p = 0.007$).

There was a significant main effect of walking condition on stride length ($p \leq 0.001$). Stride length in the walking condition (1.29 ± 0.06 m) was significantly greater than that of all of the DT conditions: walk + converse (1.21 ± 0.08 m; $p = 0.004$), sim_walk + read (1.17 ± 0.06 m; $p \leq 0.001$), dif_walk + read (1.16 ± 0.07 m; $p \leq 0.001$), and walk + text (1.09 ± 0.08 m; $p \leq 0.001$; Table 2). There were also significant differences between DT conditions: stride length in the walk + converse condition was greater than the dif_walk + read condition ($p = 0.018$), and stride length in the walk + converse, sim_walk + read, and dif_walk + read conditions were all significantly greater than in the walk + text condition ($p \leq 0.001$, $p \leq 0.001$, and $p \leq 0.001$, respectively; Fig. 1 and Table 2).

DISCUSSION

The results suggest that gait kinematics are affected by DT walking, due to a dual-task cost of using a cell phone while walking, as indicated by the significant changes in peak lower extremity joint angles in the sagittal plane, and a reduction in stride length and gait velocity during DT walking as compared to ST walking. Further, the significant differences between various DT activities suggest that the cognitive difficulty of a secondary task determines the degree of DT interference.

The differences in attentional resources necessary in the completion of each secondary task could account for the different degrees of change in the various outcome measures between the DT conditions. The level of cognitive difficulty associated with a secondary task has consistently been shown to impact the degree to which it affects the primary task, the changes being more drastic with more difficult tasks.[17] In a virtual street crossing situation, listening to music had a lesser impact on crossing duration and success rate than conversing on a phone for both the younger adult and older adult population,[17] and college students spent less time looking at the crossing environment while texting than while listening to music.[23]

The degree of DT interference cost associated with the four DT conditions can be explained based on the cognitive and motor input necessary for the successful completion of each task. While conversing only required subjects to respond to an auditory prompt through a speech task, the reading tasks required the collection and processing of visual information and the repetition of that information in the form of speech. The texting task required the collection and processing of visual input, the use of visual information to locate the correct keys, and the fine motor task of typing the passage, making it inherently more difficult than the other tasks.

Therefore, the order of conditions based on DT interference cost (walk + converse, sim_walk + read, dif_walk + read, and walk + text) is consistent with the capacity-sharing theory, as a more complicated secondary task would allocate more attentional resources to itself and more significantly impact the performance of the primary task.[28] Further, these findings support the bottleneck theory, which attributes the interference effects of DTs to the inability of a neural processor to manage more than a finite amount of motor information without decrements in the speed and effectiveness of the first motor task. A secondary motor task (texting) impacted the primary motor task (walking) performance to a greater degree than the more cognitive-based secondary tasks (reading and conversing).[28]

Many of these changes in peak joint angles are closely related, as they contribute to a shorter stride length in the DT conditions. This could be associated with the DT cost associated with using a cell phone while walking. Both peak hip flexion at initial contact and peak hip extension at terminal stance were significantly greater in the ST walking condition than the more challenging DT walking conditions. The reduction in the peak angle of hip motion in both directions of the sagittal plane implies a lesser range of motion (ROM). Gait can be described as the forward linear progression of the body due to the rotational motion of the individual joints.[19] Therefore, the reduction in angular motion at the hip joint, as indicated by the decreased ROM, is linked to a reduction in the linear progression of the body with each gait cycle, as indicated by a decrease in stride length.

The changes in peak angles of the ankle joint in the sagittal plane may also have contributed to a decrease in stride length. *Post-hoc* comparisons showed that peak ankle dorsiflexion in the ST walking condition was significantly less than in the dif_walk + read and walk + text conditions. This could suggest a greater potential for propulsion of the trailing limb to initiate swing, as passive dorsiflexion in terminal stance stretches the Achilles tendon to allow for elastic recoil in pre-swing.[19] Additionally, increased ankle dorsiflexion at terminal stance indicates reduced heel off, which leads to a reduced step length.

However, the *post-hoc* comparisons indicated that peak ankle plantarflexion during pre-swing in the DT conditions was less than the ST condition, which could explain the reduction in stride length despite the increased peak dorsiflexion. Though the potential for propulsion was enhanced due to increased peak dorsiflexion in terminal stance, the increased potential may not have been actualized due to the reduction in peak plantarflexion in pre-swing. Less plantarflexion in pre-swing can likely be attributed to a decrease in gait velocity, which is associated with decreased stride length. This combination could explain the overall reduction in gait velocity and stride length in DT conditions compared to the ST condition.

The decreases in gait velocity in the sim_walk + read, dif_walk + read, and walk + text conditions compared to the ST walking speed for the healthy, young population in this study (0.24, 0.30 and 0.37 m/s, respectively) were greater than those seen in populations with cognitive and motor deficiencies. Older adults and patients with Parkinson’s disease experienced a decrease of 0.17 m/s and 0.20 m/s, respectively when completing serial seven subtractions, and the gait velocity of patients post-stroke decreased by 0.12 m/s during a spontaneous speech task.[9,21,27] Even the least challenging of the DT conditions used in this study (conversing) elicited a greater DT cost to gait velocity than the most difficult DT used for individuals with concussion 2 days post-event (serial 7 s).[18] Though the type of secondary task used is different between studies, it is notable that the change in gait velocity during cell phone-based dual tasking in the healthy, young population is greater than that seen in other populations while completing other mental DTs.

The magnitude of the changes in stride length and gait velocity associated cell phone-based DTs in this study are large enough to warrant further investigation into the possibility of increased fall risk. A decreased gait velocity has a destabilizing effect, as it slows the progression of the center of mass (COM) and prevents it from “catching up” with the moving base of support (BOS).[26] Slower gait speed has been found to be associated with decreased stability at slip onset,[5] and a 10 cm/s decrease in gait velocity has been found to significantly increase fall risk of healthy older adults.[26] The results of this study reveal a minimum decrease of 24 cm/s in the sim_walk + read condition and a maximum decrease of 37 cm/s in the walk + text condition. These changes suggest an increased threat to balance, especially if the subjects were to encounter an unexpected perturbation leading to a slip or trip. Thus, this supports the classification of DT walking as a safety hazard.

Post-hoc comparisons also revealed that stride lengths in the DT walking conditions were significantly less than the ST walking condition, with a minimum decrease of 8 cm in the walk + converse condition and a maximum decrease of 20 cm in the walk + text condition. Though a 10 cm decrease in stride length increased fall risk in the older adult population,[26] shorter stride length in the young adult population was found to be beneficial for balance.[8] A shorter stride length brings the COM more in line with the leading foot’s BOS, thus eliciting a stabilizing effect.[8] Therefore, when slower gait occurs along with decreased stride length in a DT walking condition, that decrease in stability due to decreased velocity is offset.[8] As the subjects in this study experienced a concurrent decrease in gait speed and stride length, it is possible that the increased fall risk associated with decreased gait speed alone was averted. However, the addition of a DT could introduce additional threats to balance which could increase fall risk regardless of those protective effects previously supported. Further research quantifying gait stability during DT performance would be necessary to determine this.

The changes observed in the healthy individuals could be caused by the addition of a secondary task, which requires these individuals to devote some of the attention normally attributed to the balance and regularity of their gait to the secondary task. They likely do not make a conscious choice to change their gait kinematics, but rather experience these changes as a direct result of the dual-task cost. The changes observed could be greater than those seen the elderly or patients with neurological conditions because healthy individuals have a greater ability to recover from a perturbation and are therefore less likely to attribute attentional resources to balance during gait.[15] Whereas the elderly and patients with neurological conditions likely adopt a prioritization strategy focused on walking out of necessity due to compromised balance, the healthy population is less likely to adopt this strategy.

While it is possible that the observed reduction in gait speed is a ”cost” associated with completing a DT, another theory suggests that it is a conscious or subconscious decision made by the subject to ensure both tasks have adequate attentional resources allocated to them. Gait speed has been shown to change gait characteristics in children[22] as well as adults.[10] It is possible that individuals using a cell phone realize their balance is impaired and decide to slow down their gait speed, thus giving them more time to process both tasks. They change their gait by slowing down to give both tasks equal priority. It is possible that a synergistic couple exists between both theories and both contribute in some way to the gait changes. It is clear that using a cell-phone does alter gait kinematics and continued research is needed to gain a better understanding of these changes.

The lack of a real-world environment is a limitation to this study. It is possible that the changes to gait kinematics observed were due to the novelty of the testing situation in a laboratory environment, where external distractions are minimal and no real threat to safety is present. It would be interesting to complete this protocol in a real-world or virtual environment to determine whether the observed changes are stable across settings. Additionally, the texting task used in this study does not perfectly replicate real life texting tasks, as this study required subjects to copy passages rather than respond freely. This difference could make the results of this study less generalizable to real life texting situations. Future research could investigate the effects of cell phone-based DTs in other populations, such as patients with neurological pathologies, concussed individuals, and the elderly. Moreover, it would be beneficial to quantify gait stability, determine differences in muscle activation patterns, and consider prior texting behaviors. Furthermore, no test was available to determine if college students noticed a difference in reading and responding to the third grade versus the SAT level passages.

CONCLUSION

This study supports a fundamental change to sagittal gait kinematics, gait velocity, and stride length in response to cell phone-based DT walking. The magnitude of change observed in the outcome variables used to quantify gait performance was directly dependent upon the amount of attentional resources required for successful completion of the secondary task. Many of the changes in peak joint angles of the lower extremity joints contribute to a significant decrease in stride length, and a decrease in gait velocity. These changes could be a strategy to maintain balance and improve stability, but further research is necessary to determine this.

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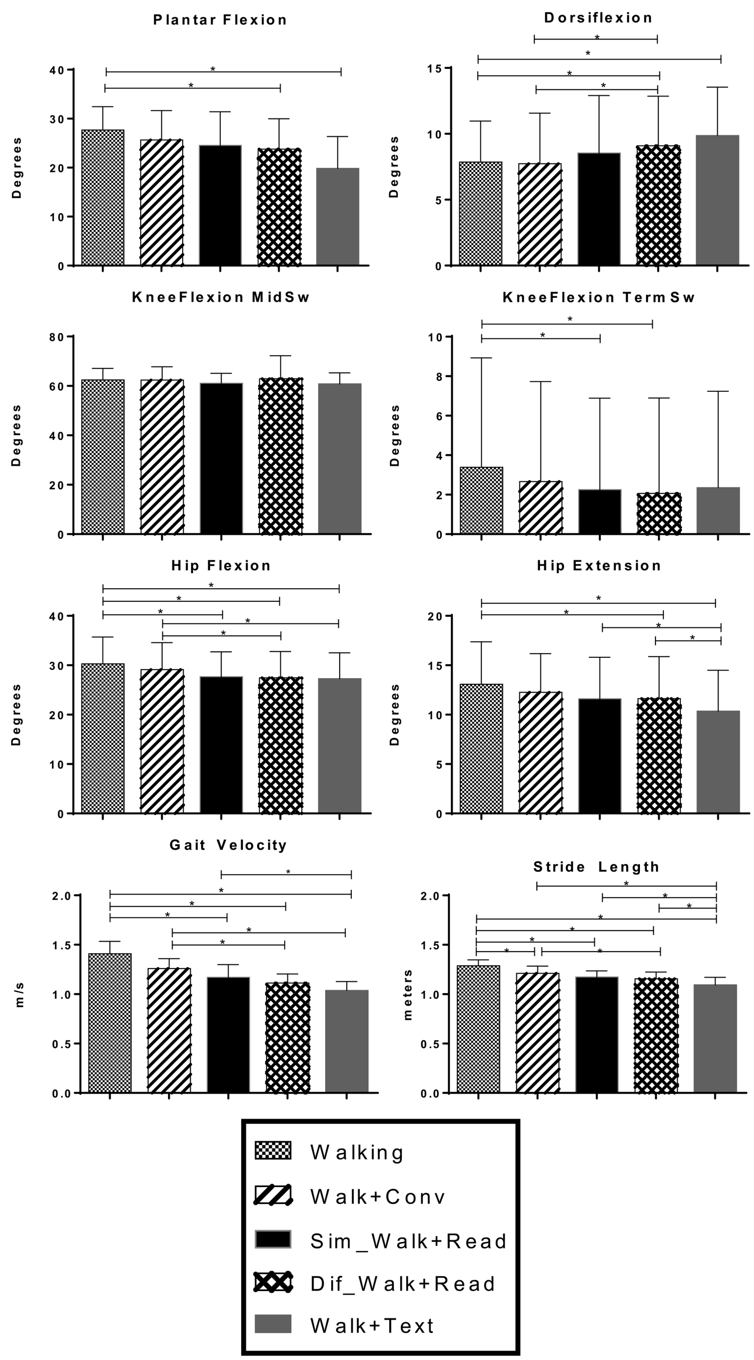

Fig. 1.
Lower extremity kinematics comparing different single and dual-task walking conditions. Horizontal bars with * represent statically significant differences between conditions.

Table 1

Demographic Characteristics, Average (SD).

Age (years)	19.64 (1.39)
Height (cm)	171.18 (8.34)
Weight (kg)	68.58 (10.23)
Sex	7 Female, 7 Male

Table 2

Comparison of Kinematic Measures between ST and DT Conditions, Averages (SD).

	Single Task Walking	Walk and Converse	Simple Walk and Read	Difficult Walk and Read	Walk and Text	*p*-Value*
Ankle plantarflexion (°)	27.67 (4.95)^{a}	25.64 (6.24)^{a,b}	24.56 (7.11)^{a,b}	23.79 (6.45)^{b}	19.83 (6.75)^{b}	0.000
Ankle dorsiflexion (°)	7.86 (3.23)^{a,b}	7.73 (3.99)^{a,b}	8.55 (4.52)^{a,b,c}	9.09 (3.91)^{c}	9.87 (3.82)^{c}	0.011
Knee flexion MidSw (°)	62.41 (4.88)	62.39 (5.57)	61.09 (4.14)	62.89 (9.73)	60.83 (4.67)	0.478
Knee flexion TermSw (°)	3.39 (5.75)^{a}	2.66 (5.26)^{a,b}	2.25 (4.81)^{b}	2.06 (5.01)^{b}	2.36 (5.06)^{a,b}	0.005
Hip flexion (°)	30.27 (5.66)^{a}	29.13 (5.66)^{a,b}	27.69 (5.23)^{b,c}	27.43 (5.56)^{c}	27.27 (5.45)^{c}	0.000
Hip extension (°)	13.08 (4.45)^{a}	12.26 (4.06)^{a,b,c}	11.62 (4.36)^{a,b}	11.62 (4.41)^{b}	10.36 (4.28)^{c}	0.001
Gait velocity (m/s)	1.41 (0.13)^{a}	1.26 (0.10)^{a,b}	1.17 (0.13)^{b,c}	1.11 (0.10)^{c,d}	1.04 (0.09)^{d}	0.000
Stride length (m)	1.29 (0.06)^{a}	1.21 (0.08)^{b}	1.17 (0.06)^{b,c}	1.16 (0.07)^{c}	1.09 (0.08)^{d}	0.000

Notes:

*The *p*-value indicates the significance of the main effect, while the superscripts indicate significant differences between conditions. Values with different superscript letters are significantly different from each other.