Dual-task interference slows down proprioception

Abstract

It is well-known that multitasking impairs the performance of one or both of the concomitant ongoing tasks. Previous studies have mainly focused on how a secondary task can compromise visual or auditory information processing. However, despite dual tasking being critical to motor performance, the effects of dual task performance on proprioceptive information processing have not been studied yet. The purpose of the present study was therefore to investigate whether sensorimotor task performance would be affected by the dual task and if so, in which phase of the sensorimotor task performance would this negative effect occur. The kinematic variables of passive and active knee movements elicited by the leg-drop test were analyzed. Thirteen young adults participated in the study. The dual task consisted of performing serial subtractions. The results showed that the dual task increased both the reaction time to counteract passive knee-joint movements in the leg drop test and the threshold to detect those movements. Speed, time during the active knee movement, and the absolute angle error between the final angle and the target knee angle were not affected by the dual task. Furthermore, the results showed that the time to complete the sensorimotor task was prolonged in dual tasking. Our findings suggest that dual-tasking reduces motor performance due to slowing down proprioceptive information processing without affecting movement execution.

Keywords: dual-task interference, proprioceptive information processing, movement execution, motor performance, working memory, joint movement

Introduction

Many activities in daily life involve dual- or multitasking; for example, talking while walking, cooking, or driving. When a primary task coexists along with other tasks, it requires considerable attention to simultaneously perform both the primary and the secondary task successfully (Theill et al., 2011). In general, the performance of either the primary or secondary task is compromised in dual tasking, and this is more noticeable in older adults (Verhaeghen et al., 2003; Wasylyshyn et al., 2011).

Dual task paradigms are mostly used in research of concurrent cognitive and motor tasks. Most dual-task studies have exploited visual or auditory information as input modalities and speech or limb movements as output modalities (Guerreiro et al., 2014; Wollesen & Voelcker-Rehage, 2014). "Stop walking when talking" is a well-known admonition referring to the typical compromising effects of dual tasks, as remarked by Lundin-Olsson et al. (1997). Indeed, older adults are often unable to keep walking properly when they are called by someone, whereas young adults can. Since the aforementioned study, many researchers have investigated the effect of dual-task interference on walking and maintaining balance in rehabilitation and sports (Bayot et al., 2020). The dual-task effects on balance and gait have indeed gained a certain reputation as a predictor of fall risk in older adults (Verhaeghen et al., 2003). Surprisingly, some studies have reported that dual tasks sometimes improve motor performance, in particular during rehabilitation patients with motor disorders in clinical settings (Abdallat et al., 2020; Bishnoi & Hernandez, 2021; Ness et al., 2020; Shi et al., 2021). However, dual-task effects do not always agree with those reported in earlier studies (Deblock-Bellamy et al., 2020; Ness et al., 2020; Shi et al., 2021; Shumway-Cook & Woollacott, 2000; Resch et al., 2011) and it is suggested that diverging results may be due to problems of the reliability and measurement accuracy issues in motor performance assessments (Ness et al., 2020). Accordingly, the superiority of dual-tasks over single task in improving motor performance remains a topic of discussion (Bayot et al., 2020).

As mentioned, other studies have raised concerns over the methodology in testing or the measurements for each task (Bishnoi & Hernandez, 2021; Verhaeghen et al., 2003). In most previous studies, descriptions have been limited to motor performance results, for example, measuring the velocity and step length in walking and the trajectory length of the center of pressure changes within a rectangular area in balancing (Resch et al., 2011; Shumway-Cook & Woollacott, 2000). Motor performance, however, almost always also requires sensory information processing during movement execution. There is no evidence to demonstrate that dual-task performance hampers sensory information processing during movement execution.

The link between sensory information processing (visual, vestibular, and somatosensory sensation processing) and movement execution is essential to the accurate accomplishment of many sensorimotor tasks in which sensory information is essential to monitor one's own performance (Parker et al., 2020; Bertucco & Cesari, 2010). However, previous studies have focused on sensory input only as separate auditory or visual tasks (Deblock-Bellamy et al., 2020; Humes & Young, 2016; Verhaeghen et al., 2003), while only a few studies (Relph et al., 2014; Skinner & Barrack, 1991), despite the key role of such sensory-information processing in postural control (Baert et al., 2018; Relph & Herrington, 2016; Yasuda et al., 2014; Zandiyeh et al., 2019; Witchalls et al., 2012). The purpose of the present study was to investigate whether dual-task interference would also affect sensory information processing in have examined dual-tasks' effects on proprioception (joint-position sense and kinesthetic sense) movement execution. Specifically, we focused on movement execution and proprioceptive sensation related to postural and motor control as measured with the leg drop test. Magrini et al. (2018) emphasized that two senses are inextricably implicated in knee motion, that is, joint position sense and kinesthetic sense (Relph et al., 2014; Skinner & Barrack, 1991). We hypothesized that dual tasking would interfere with sensorimotor performance, possibly through interference with sensory information processing. Kinematic variables obtained in the leg drop test allowed us to differentiate between sensory information processing and movement execution because the task consists of an alternation between active movement generation and passive movement control.

Methods

Participants

Thirteen healthy young adults (8 males and 5 females, mean age ± standard deviation: 25.3 ± 2.0 years, age range 23–30 years) participated in this study. Sample size and significance level were verified as adequate by G*Power, with the effect size set at 0.4, power at 0.8, and alpha at 0.05 (Faul et al., 2007), according to Cohen's criteria (Cohen, 1988). Participants with any current or history of orthopedic or neurological diseases were excluded from this study. Prior to inclusion, the participants were provided with information regarding this study and were required to sign an informed consent form. This study was approved by the review board of the Faculty of Health Sciences, Hokkaido University (20–18) and was conducted in accordance with the principles of the 1964 Declaration of Helsinki.

Procedure

The leg drop test

This study used the leg drop test (Magrini et al., 2018) to assess two senses during knee flexion as the dual-task's primary task: kinesthetic sense and joint-position sense (De Jong, 1993; Lund et al., 2008; Ouattas et al., 2019; Relph et al., 2014; Skinner & Barrack, 1991). The participants sat on a chair with a height adjustment function, with their arms crossed. The participants wore headphones and an eye mask to block any visual and auditory input regarding knee movement. The distal part of the lower leg on the dominant side (the kicking ball side) was fixed at 30° of knee flexion (Ouattas et al., 2019; Smith et al., 2013) using a customized fixation-and-release device with an electromagnet (Fig. 1) and participants were asked to memorize this knee angle (the reference angle) for assessing the joint-position sense (Zandiyeh et al., 2019). Then, the lower leg was dropped at a random time to make knee motion unpredictable. The distal part of the lower leg was not allowed to move laterally (in the direction orthogonal to the vertical direction of flexion) in order to maintain the starting knee position and minimize cutaneous sensory input. Following the leg drop, participants were instructed to return their knee to the reference angle (30° of knee flexion) as quickly as possible and then maintain it there (Relph et al., 2014; Skinner & Barrack, 1991).

Cognitive task

This study used the serial subtraction task (serial subtraction in sevens from 100) as the dual-task's secondary task (Bishnoi & Hernandez, 2021). The instruction regarding the cognitive task was to name the correct numbers as quickly as possible. Examiners monitored right, wrong, and delayed responses. Thus, the primary task was the sensorimotor one, while the secondary task added was the serial subtraction task. Each such dual task was performed three times, that is, each participant underwent three subsequent leg drop tests, each time with the same instructions regarding the motor and cognitive tasks and with the experimenter letting go of the leg at a random time to make it unpredictable. If participants requested it, rest was allowed between the tasks.

Kinematic data and data analysis

The knee angle was measured with an electronic goniometer (MLTS700 Goniometer, ADInstrument, Castle Hill, Australia). Knee motion was digitized with sensors attached to the thigh and shank, as recommended by the Biometrics guidebook (Biometrics, 2002). Each sensor was firmly fixed to the skin with double-sided medical tape and covered with single-sided tape to minimize displacement of the sensors. PowerLab system (PowerLab/16sp, ADInstrument, Castle Hill, Australia) was used for analog-to-digital conversion, and all signals from the electronic goniometer and electromagnet were sampled at 1 kHz and stored for further analysis using PowerLab system's Chart software (Chart version 5.4.2, ADInstrument, Castle Hill, Australia).

Data processing and analysis of knee angle and electromagnet data were performed using a customized MATLAB program (R2018, MathWorks, Eindhoven, Netherlands). If the participant did not perform the motor task during one of the three trials in the sensorimotor task, that trial was excluded from data analysis, and another trial would added to complete the study. This accident occurred in less than one trial per subject (the added trial was designed to have three analytical data per person for each condition). The knee angle data were smoothed with a second-order low-pass bidirectional Butterworth filter with a cut-off frequency of 10 Hz (Kasahara &

Saito, 2021). Figure 2 shows a prototype sample of the collected data. The onset of knee motion (D1) was defined as the first point at which the knee flexion angle exceeded 5% of the maximum knee flexion from baseline. The endpoint of knee motion (D4) was defined as the first point where the knee flexion angle decreased within the range of 5% of the maximum knee flexion in its trial and continued for over 500 ms (Kasahara & Saito, 2021). Kinesthetic sense was defined as the ability to detect passive motion (Ramstrand et al., 2019; Proske & Gandevia, 2018; Relph et al., 2014) and was assessed as reaction time and angle amplitude (angle threshold) between the reference angle at D1 and the point of maximum knee flexion at D2 (Fig. 2). Joint-position sense was assessed as the absolute difference (the error) between the final angle at D4 and the reference angle at D1 (Ramstrand et al., 2019; Proske & Gandevia, 2018; Relph et al., 2014). Active knee movement was assessed by the average angular velocity from D2 to D4. In addition, the return time was defined as the time from D2 to D4, including both joint-position sense and active knee movement. Knee movement during the leg drop was passive, while knee movement during the return time was active. The total time for the sensorimotor task was defined as the time from the onset (D1) to the endpoint of the knee motion (D4) including kinesthetic sense, joint-position sense, and active knee movement.

Ten of the thirteen participants performed the secondary experiment after 1 week to examine test-retest reliability of the original sensorimotor task, and the interclass correlation coefficients in all measurements were 0.62–0.91. The lowest return time was assessed as modest (Shrout & Fleiss, 1979).

Statistical analysis

All statistical analyses were performed using SPSS Statistics version 18.0 (IBM Corp., Armonk, NY, USA). All data are presented as mean ± standard deviation. Normality of the data was examined using the Shapiro–Wilk test, and the comparison between the single and dual task was performed using a paired t-test or the Wilcoxon signed rank test. Cohen's d was calculated as the effect size for paired t-test and interpreted as small (0.2), medium (0.5), and large (0.8). For Wilcoxon signed rank test, effect sizes r were calculated and interpreted as small (0.1), medium (0.3), and large (0.5) (Cohen, 2013). To confirm the strength of evidence of the null hypothesis (there are no differences between the two conditions) and alternative hypothesis (differences exist between the two conditions), the Bayes factor (BF) was calculated assuming uninformative priors for all statistical analysis. Data for BF are presented as BF01 (null hypothesis given alternative hypothesis) and can be interpreted as evidence to support the hypotheses based on previously defined thresholds. BF01 = 1–3 and 3–10 represent anecdotal and moderate strength evidence for H0, respectively; whereas BF01 = 0.33-1. 0.1–0.33, and less than 0.01 represent anecdotal, moderate, and extreme evidence for H1, respectively (Lee & Wagenmakers, 2014). All statistical significance levels were set at a p-value of <0.05.

Results

The reaction time for knee motion was significantly longer in dual tasking (473.5 ± 137.2 ms) compared to single tasking (384.7 ± 133.7 ms) ($Z = -3.18$, $p < 0.001$, $r = 0.88$, BF01 = 0.002) (Fig. 3A). No significant difference was found in return time between the dual task (730.2 ± 208.7 ms) and single task (637.8 ± 176.6 ms) ($t = -1.36$, $df = 12$, $p = 0.204$, $d = 0.37$, BF01 = 2.157) (Fig. 3B). A significant difference in mean total time for the sensorimotor task between the dual task (1203.7 ± 270.1 ms) and single task (1022.5 ± 252.5 ms) ($t = -2.34$, $df = 12$, $p = 0.038$, $d = 0.65$, BF01 = 0.567) was shown (Fig. 3C).

The angle threshold in the dual task (30.3° ± 14.3°) was significantly larger than that in the single task (25.0° ± 16.4°) ($Z = - 2.38.03$, $p = 0.017$, $r = 0.66$, BF01 = 0.187) (Fig. 4A). There was no significant difference in absolute errors of joint-position sense between tasks (single task: 1.8 ± 1.2°; dual task: 2.0 ± 1.4°, $t = 0.35$, $df = 12$, $p = 0.732$, $r = 0.10$, BF01 = 4.552) (Fig. 4B). No significant difference was found in the average angular velocity of active knee movement during D2-D4 between the dual task (33.3 ± 12.5°/s) and single task (31.9 ± 15.6°/s) ($t = -0.72$, $p = 0.488$, $d = 0.20$, BF01 = 3.79).

Discussion

This study aimed to verify the dual-task interference on sensorimotor performance using the overlapping dual task which consists of the original leg drop test sensorimotor task as the primary task with an added cognitive task as the secondary task. In agreement with previous studies, the current kinematic data-based study showed that sensorimotor performance was affected during the dual task. Furthermore, our findings revealed that interference in sensorimotor performance during the dual task resulted from the delay in kinesthetic sense responsiveness rather than an impairment in movement execution.

In the overlapping dual task (Brisson & Jolicoeur, 2007; De Jong, 1993; Schubert & Szameitat, 2003) of this study, the cognitive task preceded the sensorimotor task. In agreement with a previous study (Kim & Brunt, 2007), the reaction time for the latter task (i.e., the sensorimotor task) was delayed. Kinesthetic sense is generally assessed using the threshold to detect passive movement (Relph et al., 2014; Skinner & Barrack, 1991). Instead of pressing a stop button switch (Naderi et al., 2020; Zandiyeh et al., 2019), participants were instructed to stop the knee movement and then return to the original knee position as quickly as possible. Our participants could concentrate on their knee joint movement because our task did not require any motion, except knee motion. Therefore, participants could detect joint movements with a high level of concentration during a single task. However, owing to the dual task, participant's attention was given to processing the preceding (or ongoing) task and therefore, attention given to the secondary task was reduced. Regarding the sensorimotor test, previous studies (Relph & Herrington, 2016; Skinner et al., 1984; Yasuda et al., 2014) have reported that results were affected by the magnitude of attention to the movement. Hospod et al. (2007) suggested that proprioceptive attention may induce fusimotor control of the muscle spindle sensitivity. Furthermore, if sensory input is added, a central bottleneck has already been built due to the limitation exerted on the information processing system, according to Treisman's model (Treisman, 1964). The central bottleneck delays subsequent sensorimotor processing, including the identification of the stimulus, response selection, and transformation from sensory input to motor output (Brisson & Jolicoeur, 2007; De Jong, 1993; Pashler, 1994; Wickens, 2002). Therefore, it is considered that the decline in attention and processing capacity due to dual-task interference causes a raised threshold in kinesthetic sense, resulting in a reaction delay.

General clinical methods for the joint-position sense require participants to temporarily memorize the knee position (Lund et al., 2008; Naderi et al., 2020; Wickens, 2002; Zandiyeh et al., 2019). This temporary memory is called “the working memory” (Yasuda et al., 2014; Wickens, 2002). The sensorimotor task in the current study also required participants to memorize their original position during the preceding task (the first task) of the dual task. Previous studies have suggested that the working memory is important for encoding proprioceptive inputs (Yasuda et al., 2014; Wickens, 2002). It is documented that older adults with poor working memory perform worse in the joint-position sense test during dual-task which suggests that the attention demand of the cognitive task might influence the working memory during the joint-position sense-based task aspect (Goble et al., 2012; Yasuda et al., 2014). Although our study expected that the working memory in young adults would also be affected by the presently concomitant exploited dual task and the joint-position sense would decrease, no dual task effect on joint-position sense was shown. This is possibly due to the content to be memorized being straightforward and single task aspect, i.e. participants only needed to memorize a particular (reference) joint angle. Moreover, all participants were young adults.

Active muscle contraction increases the muscle spindle and Golgi tendon organ responsiveness, and may consequently increase the sensitivity of Ia ending to small motion (Taylor & McCloskey, 1992). Several studies have reported that the error in joint-position sense during active motion is small compared to that during passive motion (Laufer et al., 2001; Stelmach et al., 1975; Yasuda et al., 2014). A possible explanation for these results is the concomitance of an efferent copy (Kawato & Wolpert, 1998; Wolpert & Ghahramani, 2000) with an afferent proprioceptive information from the fusimotor system (Granit, 1972). Moreover, increased co-contraction is thought to contribute to declined sensory input in patients with anterior cruciate ligament reconstruction (Song et al., 2018) and in older adults (Madhavan & Shields, 2005). In this study, we did not find any dual-task interference with joint-position sense, which suggests that active muscles may contribute to joint position sensory input such that it is more difficult to observe joint position sensory interference by dual tasks in young adults. This provides further theoretical support for muscle training to improve balance and sports performance.

Recently, walking and balancing tasks have been used to analyze how cognitive loads may sometimes improve motor performance in rehabilitation and sports (Bayot et al., 2020; Bishnoi & Hernandez, 2021; Deblock-Bellamy et al., 2020; Fritz et al., 2015; Sobol et al., 2016). However, to the best of our knowledge, the benefit of dual-task exercises on motor performance is still debatable in clinical settings, and the specific training to compensate for the deficit of motor performance during the dual task is not known. Shumway-Cook and Woollacott (2000) used the dual task of a standing balance task and auditory task and reported that cognitive and attention load did not influence balance stabilization among various degrees of sensory impairments. On the other hand, it has been reported that motor performance declines significantly during dual tasks in older adults (Bayot et al., 2020; Shumway-Cook & Woollacott, 2000; Wasylyshyn et al., 2011) and in patients with stroke (Deblock-Bellamy et al., 2020) and Parkinson's disease (Yang et al., 2019). The return time after passive knee movement (e.g., of quadriceps as knee extension) and angular movement velocity in this study reflect movement execution ability (Ifft et al., 2011; Gold & Shadlen, 2007). In this study, the average angular velocity and return time during active knee movement did not differ between the single task and dual task, suggesting that movement execution ability may have a positive effect on the delay due to dual-task interference. Therefore, it is possible that improved movement execution (owing to muscle strength, central motor processes, etc.) counteracts decreased motor performance during the dual task, thereby helping to prevent falls.

Our study has important limitations. The current study included healthy young participants. As the dual-task interference becomes particularly evident in the elderly, it is necessary to investigate other age groups in the future (Bayot et al., 2020; Shumway-Cook & Woollacott, 2000). Nonetheless, our results are partially consistent with those of previous studies, although they require considerable attention before generalization can be made to all ages. The second limitation is the difficulty of the cognitive task. Participants in the current study were young, and their prior cognitive function was normal (MMSE and TMA-B scores are not shown in this study). The subtraction task was used as cognitive task in this study and however, it is necessary to verify the validity of this cognitive task in young healthy adults because the interference effect of the dual task is affected by the participants' characteristics and the difficulty of the task. Also, whether movement production during verbal answers (naming numbers counting backwards) interferes with the performance of the leg-drop task remains unclear and this point needs to be addressed by further studies.

This study suggests that dual tasking affects sensorimotor information processing similar to how it affects vision and auditory senses in young adults. Our findings also indicate that dual tasks interfere with the kinesthetic sense. Joint position sense and movement execution remained normal in young individuals.

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Figure Captions:

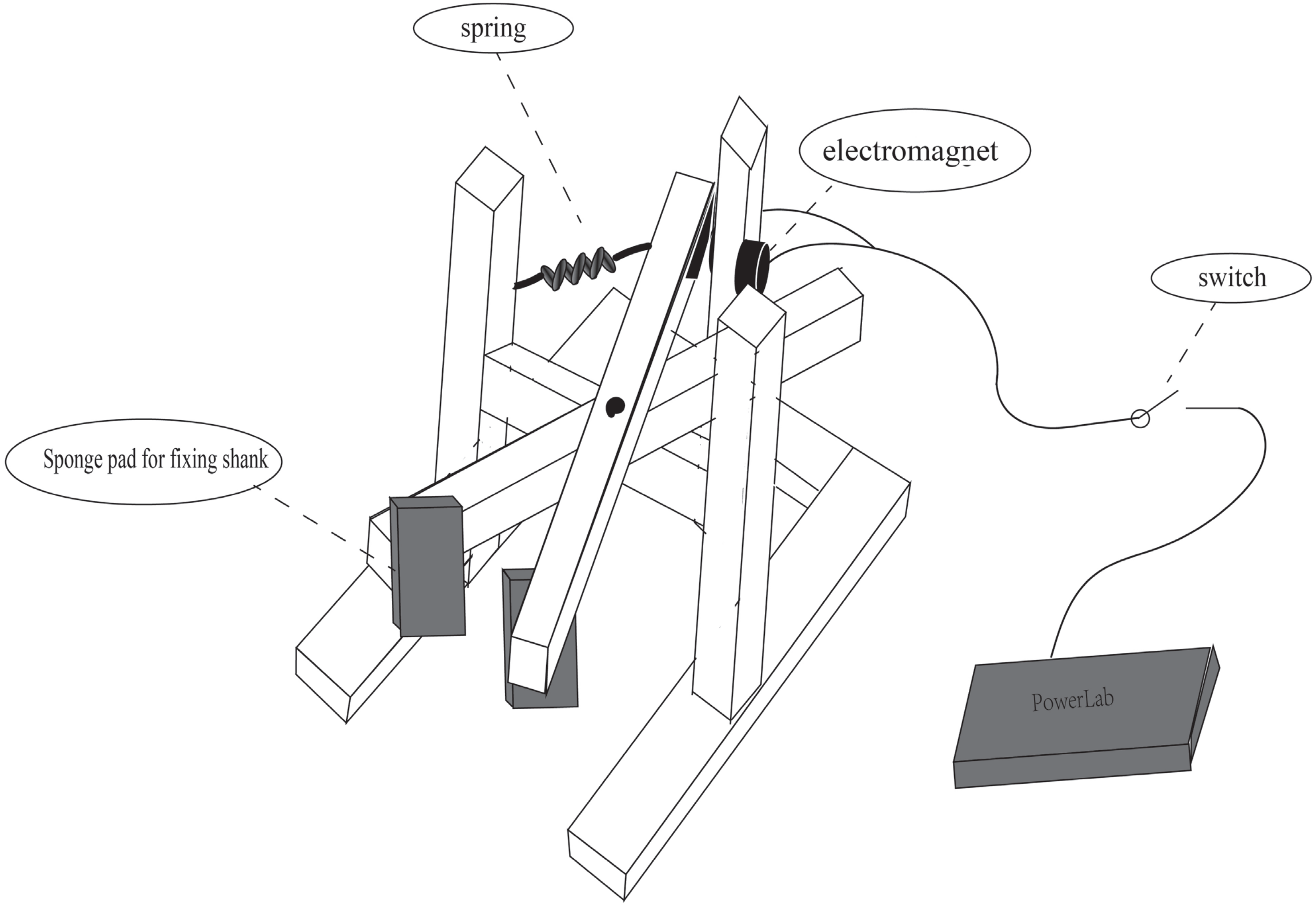
Fig. 1 Fixation and release device. When the switch is on, the electromagnet is active, and the sponge pad fixes the shank. When the switch is off, the electromagnet is not active, and the device releases the shank, allowing it to drop.

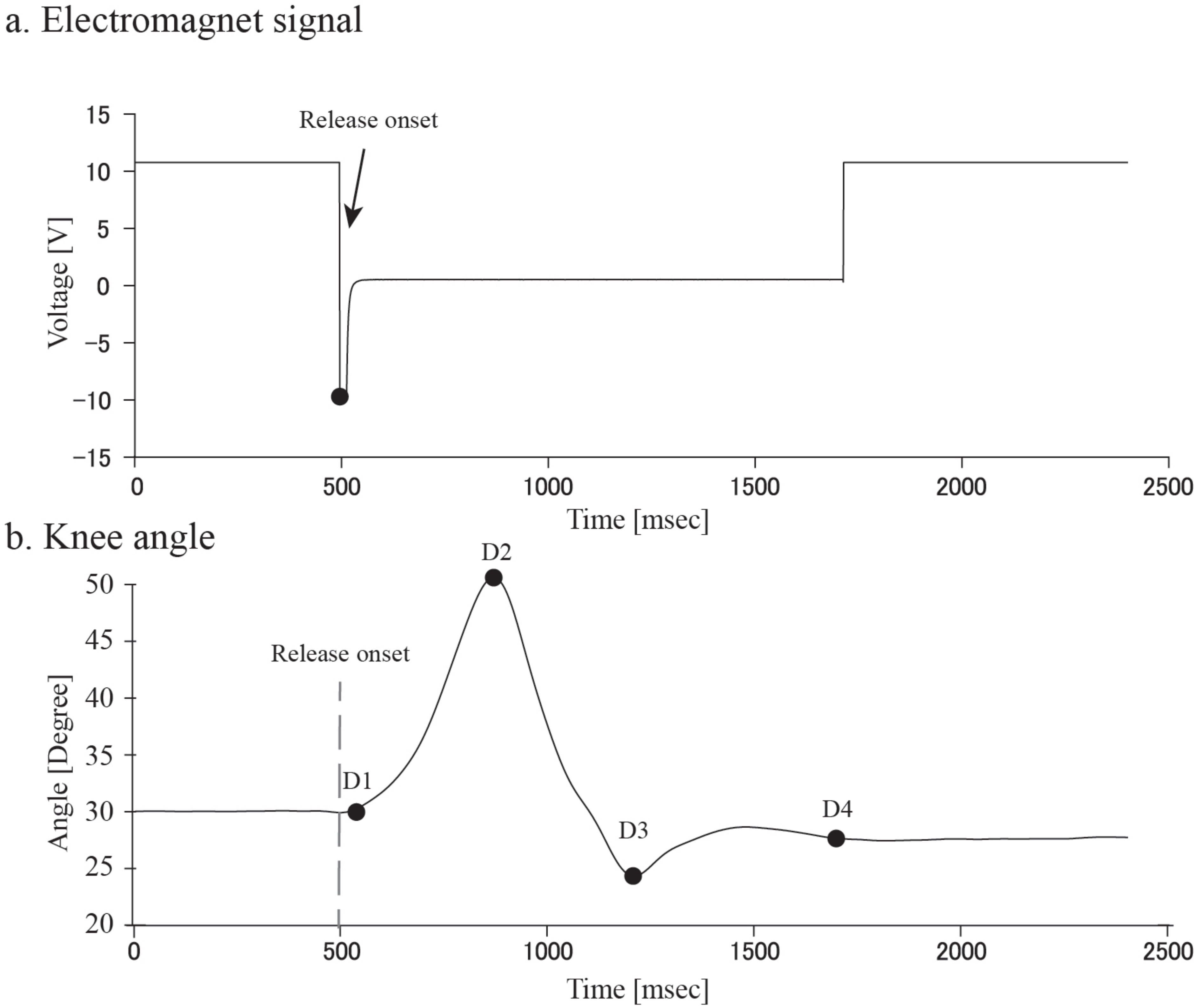
Fig. 2 Raw data sample from an experiment. (a) The voltage signal of the electromagnet in the sample trial: When the switch changes from on to off, the electromagnet signal drops rapidly, and we record this as the release onset. (b). The knee flexion angle in the sample trial: D1 is the onset of the knee motion; D2 is the point of maximum knee flexion; D3 is the maximum knee extension; and D4 is the endpoint of the knee motion.

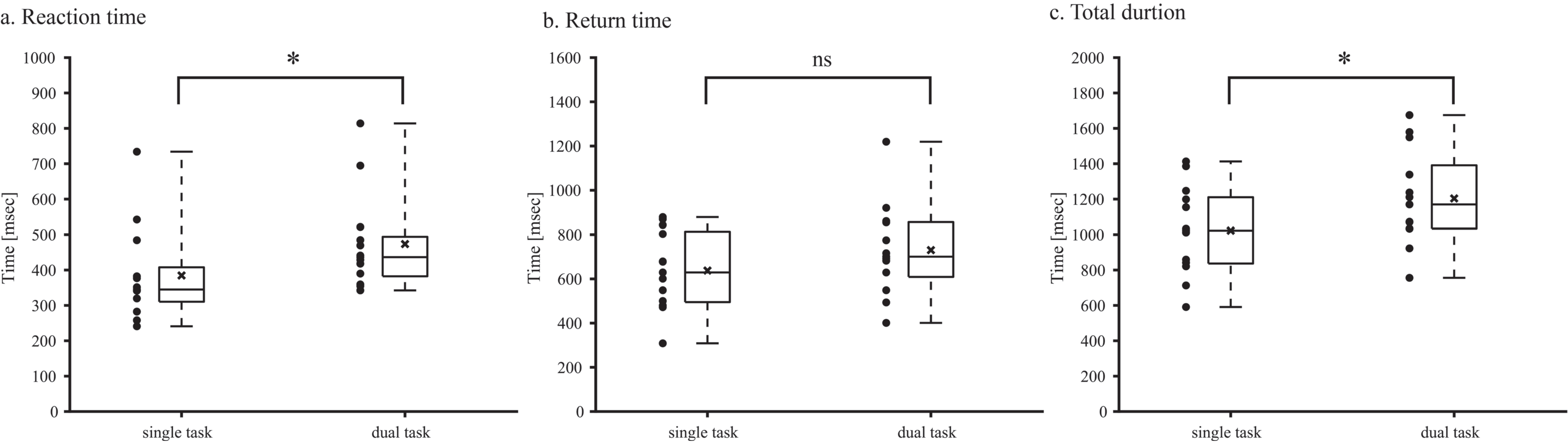
Fig. 3 Comparisons of temporal measurements between the single task and dual task. (a) Reaction time, (b) return time, and (c) total duration. The line in the middle of the box-and-whisker is the median, and the (×) is the mean. Error bars represent standard errors. The dots beside box-and-whisker plots show the data of all participants. The (*) indicates $p < 0.05$ and the ns indicates non-significance.

Fig. 4 Comparisons of joint angles and angle speed velocity between single task and dual task.

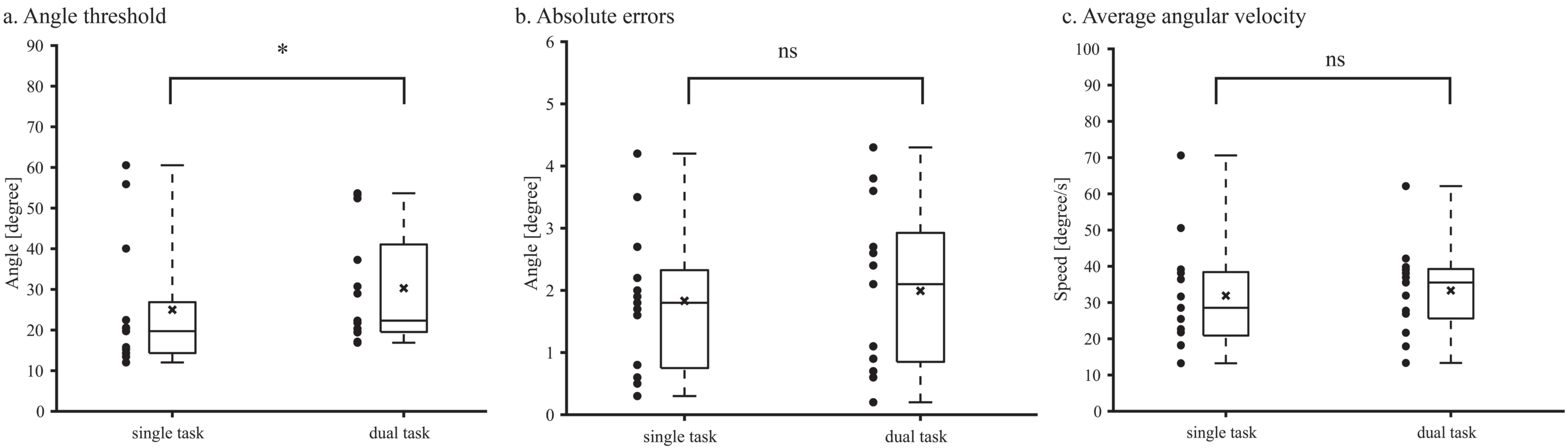
(a) Angle threshold, (b) Absolute errors, (c) Average angular velocity. The line in the middle of the box-and-whisker is the median, and the (×) is the mean. Error bars represent standard errors. The dots beside box-and-whisker plots show the data of all participants. The (*) indicates $p < 0.05$ and "ns" indicates non-significance.


spring
electromagnet
switch
Sponge pad for fixing shank
PowerLab


a. Electromagnet signal
Release onset
Voltage [V]
15
10
5
0
−5
−10
−15
0
500
1000
1500
2000
2500
Time [msec]
b. Knee angle
D1
D2
D3
D4
Release onset
Angle [Degree]
50
45
40
35
30
25
20
0
500
1000
1500
2000
2500
Time [msec]



a. Reaction time
b. Return time
c. Total durtion
*
ns
*
Time [msec]
single task
dual task



a. Angle threshold
Angle [degree]
*
single task
dual task
b. Absolute errors
Angle [degree]
ns
single task
dual task
c. Average angular velocity
Speed [degree/s]
ns
single task
dual task