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Reduced motor cortex inhibition and a 'cognitive-first' prioritisation strategy for older adults during dual-tasking

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ABSTRACT

It is well established that older adults are less able to perform attentionally demanding motor tasks, placing them at greater risk of accident-related injury. The primary purpose of this study was to investigate whether the interplay between prefrontal and motor cortex activity could predict such age-related performance deficits. Using a dual-task (DT) paradigm, 15 younger and 15 older adults participated in experiment 1, where brain activity was simultaneously measured using functional near infrared spectroscopy (fNIRS) and transcranial magnetic stimulation (TMS). Experiment 1 demonstrated poorer performance for the older group across a range of DTs combining visuomotor arm tracking with a secondary cognitive or motor task. Interestingly however, older adults' DT performance error was isolated to the motor component of DTs. TMS data revealed reduced motor cortex (M1) inhibition during DTs for older adults, and a trend for this correlating with poorer performance. In contrast, poorer performing younger adults showed significantly higher M1 inhibition. Experiment 2 was conducted given a high amount of movement artifact in experiment 1 fNIRS data. Using fNIRS to measure prefrontal, premotor, and motor cortex activity in an additional 15 older adults, we found no evidence of an interplay between these regions predicting DT performance. Nevertheless, performance data replicated experiment 1 in showing that DT error was isolated to motor tasks in older adults, with no significant cognitive task error. Overall, this study shows that older adults seemed to adopt a 'cognitive-first' prioritisation strategy during the DTs involved in our study, and that deficits in DT performance may be related to the modulation of M1 inhibitory mechanisms. We propose that clinicians advise older adults to allocate greater attention to motor tasks during activities where they may be at risk of accident-related injury.

1. Introduction

Many studies have demonstrated that additional cognitive load is detrimental to our ability to perform a wide range of motor tasks, including walking (Al-Yahya et al., 2011), balancing (Li et al., 2010), and driving a motor vehicle (Blanco et al., 2006). Dual-task (DT) experiments, where participants are asked to perform two tasks simultaneously, have shown that these deficits in motor performance increase with advancing age (Verhaeghen et al., 2003), and demonstrated that DT performance can predict the future incidence of falls in older adults (Beauchet et al., 2007).

Prominent DT theories suggest that such deficits in motor performance are caused by spatial (Schumacher et al., 2003) and temporal interference (Pashler, 1992) in prefrontal cortex (PFC) information processing, leading to compromised motor response selection and execution. Age-related decreases in cortical volume are more pronounced in the PFC than other brain regions (Head et al., 2002; Salat et al., 2004), thus it has been suggested that motor performance deficits in

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Abbreviations

ST	single-task
DT	dual-task
nb	n-back task
Ftap	foot-tapping task
vfl	verbal fluency task
HbO	oxygentated haemoglobin
HbR	deoxygentated haemoglobin
HbDiff	(HbO − HbR)
DT_{change}	(DT/ST) × 100 (performance and TMS data); or DT-ST (fNIRS data)
PFC	prefrontal cortex
PM	premotor cortex
M1	primary motor cortex
BB	biceps brachii

older adults may be magnified because of a reduced capacity of PFC networks to activate the primary motor cortex (M1) structures required for task execution (Corp et al., 2013; Fujiyama et al., 2016).

In support of this hypothesis, DT experiments have shown reduced task-related brain activity in older adults in both the PFC (Heuninckx et al., 2008), and M1 (Fujiyama et al., 2012), and reduced disinhibition of PFC-M1 pathways during movement preparation (Fujiyama et al., 2016), that was related to poorer DT performance. In addition, better performing older adults have been shown to upregulate PFC activity during a motor DT (Goble et al., 2010), in line with prominent theories of age-related compensatory PFC activity to maintain task performance (Cabeza et al., 2002; Reuter-Lorenz and Cappell, 2008). These findings suggest a functional interplay between PFC and motor regions that is required for the successful performance of attentionally demanding motor tasks.

However, while DT experiments in older adults have shown task-related changes in PFC and M1 activity separately, to the authors' knowledge, it has yet to be demonstrated empirically whether changes in the functional interplay between these two brain regions during a DT can explain performance deficits in older adults. Thus, the primary aim of this study was to test the theory that DT performance in older adults was dependent on the concurrent upregulation of PFC and M1 activity (Corp et al., 2013). We hypothesised that multiple regression would show that a reduced ability to activate the PFC and M1 concurrently would predict poorer DT performance in older adults. While most studies involve only one DT condition, we included five different DT conditions to ascertain whether our findings were generalisable across tasks. Our initial experiment (experiment 1) used functional near-infrared spectroscopy (fNIRS) and TMS to concurrently measure PFC and M1 activity in 15 younger and 15 older adults. Unfortunately, much of the fNIRS data contained motion artifact, and we were thus unable to answer our primary question. Therefore we conducted a second experiment involving an additional 15 older adults (none of whom participated in experiment 1), to again address this aim.

2. Experiment 1 materials and methods

2.1. Participants

Fifteen younger (9 males; M = 27.7; SD = 3.1; range 21–35 years) and 15 older adults (9 males; M = 65.2; SD = 3.9; range 58–73 years) adults participated in experiment 1. Sample size was based on prior DT publications using TMS (Fujiyama et al., 2009; Fujiyama et al., 2012) and fNIRS (Beurskens et al., 2014; Holtzer et al., 2011), demonstrating significant group differences between younger and older adults. All participants were considered right handed as measured by the Edinburgh handedness questionnaire (Oldfield, 1971). All participants were above the Mini Mental State Examination (MMSE) cut-off for cognitive impairment (24) (Crum et al., 1993). There was no group difference in estimated IQ, based on the Weschler Test of Adult Reading (Wechsler, 2008) (younger mean = 109.8; SD = 8.2; older mean = 110.6; SD = 8.3; $p > 0.05$). All participants provided informed consent and completed a health-screening questionnaire prior to participation. Exclusion criteria were: self-reported hearing or vision impairments; history of traumatic brain injury; a previous neurological condition; or other motor impairment affecting task performance. All forms and procedures were approved by the Deakin University Human Research Ethics Committee.

2.2. Tasks

Videos of the tasks can be viewed at https://doi.org/10.1016/j.exger.2018.09.018.

2.2.1. Arm tracking

Participants were seated in a custom-built chair seated approximately 1 m from a computer screen (Fig. 1C). An adjustable handle was held from below to ensure comfortable and consistent arm position (arm supination) for all participants. An electronic goniometer (Biometrics, Ltd., UK) measured the angle of the elbow joint, and communicated with a custom-built computer program (LabVIEW, National Instruments, U.S.A.), which showed the arm tracking task on the computer screen. Elbow angles were normalised for each participant, with full comfortable extension for each participant calibrated to be 0° in the computer program, and 90° being a true 90° angle as measured by a hand-held goniometer. Two markers were presented on the computer screen: one 'target' marker that moved at a sinusoidal rate of 0.08 Hz, with an upper speed of 30° per second at the middle of the movement, and a lower speed of 0° at the top and bottom of the movement (where participants transitioned from flexion to extension, or vice versa); and a 'participant' marker, which moved with the elbow (elbow flexion = marker moved upward; elbow extension = downward). This variable arm tracking rate was used to ensure sustained vigilance. Participants were tasked with keeping their marker as close as possible to the 'target' marker throughout the one-minute trials.

2.2.2. n-back task (nb)

Three levels of nb difficulty were included: nb1, nb2, and nb3, each performed separately for one-minute (Kirchner, 1958). The task was exclusively auditory (Inquisit, v4, Millisecond Software, USA). A separate laptop played the sequence of letters through earphones worn by participants (Fig. 1C). Eight letters (c, h, k, l, q, r, s, t) were used. Twenty letter repetitions were read per trial with an inter-letter interval of 3 s. Thirty percent of letters were targets, which prompted participants to respond by clicking a wireless mouse held in their left hand (Fig. 1C). Non-targets required no response; therefore responses to non-targets constituted an error.

2.2.3. Foot tapping task (Ftap)

Participants were instructed to tap their left foot for one-minute in time with a 0.5 Hz metronome played through earbuds, while keeping their heel in contact with the ground (Video 2).

2.2.4. Verbal fluency task (vfl)

Participants were asked to recite as many words as possible starting with a target letter within the one-minute trial (Benton et al., 1994). Three target letters (either C, F, L or P, R, W - assigned randomly) were given consecutively (20 s each letter).