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Age-Differential Effects of Proactive Control in Dual Tasking: The Moderating Effect of Task Difficulty

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Abstract

Dual tasking refers to the ability to perform two concurrent tasks. Using the psychological refractory period (PRP) paradigm, two experiments examined whether providing a prompt that facilitated proactive control could benefit dual-task performance among younger and older adults. In Experiment 1, difficulty-related prompt words ("difficult," "easy," or null) were presented before easier dual tasks with a longer stimulus onset asynchrony (SOA) of 800 ms or harder tasks with a shorter SOA of 100 ms. Experiment 2 extended the investigation by presenting these prompts ("difficult" or "easy") before dual tasks with a fixed SOA of 150 ms. It also examined the moderating effects of actual task difficulty by manipulating task congruency. Both experiments suggested that proactive control triggered by difficulty-related prompts facilitated dual-task performance in both age groups. Notably, prompts benefited younger adults' dual-task performance only when the actual task difficulty was relatively higher, but they benefited older adults' dual-task performance regardless of the actual task difficulty. These findings contribute to our understanding of proactive control and the different effects of prompts on cognitive performance among younger and older adults.

Keywords Dual Tasking · Proactive control · Task difficulty · Task congruency · Age differences

Introduction

Dual tasking is an umbrella term that refers to the ability to coordinate two concurrent tasks (Pashler, 1994; Baddeley et al., 1997). It is involved in many situations in daily life, such as walking while talking on the phone and attending to traffic lights while driving. Dual-task performance in general declines with age (Allen et al., 1998; Glass et al., 2000; Maquestiaux et al., 2004; Maquestiaux & Ruthruff, 2021). Poor dual-task performance is associated with the risks of falls (Beauchet et al., 2009), car accidents (Cuenen et al., 2015; Yang et al., 2020), and mild cognitive impairment (Yang et al., 2020) among older adults. Dual tasking is a complex executive control process that differs from shifting, updating, and inhibition (Logan & Gordon, 2001a; Meyer & Kieras, 1997a, b; Miyake et al., 2000), and it may be specifically related to a conflict-control neural circuit in the brain (e.g., Hu et al., 2022). It is posited that a single general pool of attentional resources is allocated between the two tasks during dual tasking, and thus participants' performance on one task can influence their performance on the other task (e.g., Broadbent, 2013; Naveh-Benjamin et al., 2014). Researchers often employ two-choice reaction time (RT) tasks, such as the psychological refractory period (PRP) paradigm (Pashler, 1994), to investigate allocation of attentional resources in dual tasking by varying the temporal overlap (i.e., the stimulus onset asynchrony, SOA) between Task 1 (T1) and Task 2 (T2). Given that dual tasking is related to conflict control, the present research aims to test whether providing a prompt to facilitate proactive control may improve dual-task performance among younger and older adults.

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Proactive Control and Dual Tasking

In PRP paradigms, the cost of performing dual tasks is reflected in the PRP effect, which refers to the increase in reaction time for T2 as the SOA decreases, while the reaction time for T1 remains unaffected (Pashler, 1994). The response-selection bottleneck model (Pashler, 1994) attributes the PRP effect to the bottleneck in the central processing stage, where only one response can be selected at a time. However, this model fails to explain the findings that dual tasking can be performed without significant costs under certain conditions (e.g. Halvorson et al., 2013; Halvorson & Hazeltine, 2015). In view of these findings, alternative models such as the central capacity-sharing model (Tombu & Jolicoeur, 2003) and executive control of the theory of visual attention (ECVTA) model (Logan & Gordon, 2001a) suggest that dual tasks can be performed in parallel without a processing bottleneck, and the PRP effect is caused by a limited central capacity.

Cognitive control processes play a crucial role in the management and allocation of the limited central capacity. Through these cognitive control processes, individuals can strategically distribute their limited central capacities across tasks. For example, they can switch between parallel and serial processing modes (Fischer et al., 2014; Meyer & Kieras, 1997a, b; Miller et al., 2009) and/or modify the processing order of events (Leonhard & Ulrich, 2011; Szameitat et al., 2006). As such, the PRP effect and dual-task performance are not static; they can be changed by strategies (Himi et al., 2019; Hu et al., 2022; Wen et al., 2018). The dual mechanisms of control theory (Braver, Gray, & Burgess, 2007; Braver et al., 2009) classifies these cognitive control mechanisms into two categories: proactive control and reactive control. The former is a form of 'early selection' that actively maintains goal-relevant information in preparation for a cognitively demanding upcoming task (Braver, 2012), while the latter refers to control processes recruited after a conflict is detected (Botvinick et al., 2001). According to the proactive control/task-conflict (PC-TC) model (Kalanthroff et al., 2015, 2018), individuals can use proactive control as a form of 'early selection' to optimize their cognitive systems and actively maintain goal-relevant information before engaging in dual tasking, enhancing their dual-task performance (Kalanthroff et al., 2013).

The Role of Difficulty-Level Related Prompts

Proactive control processes can be triggered by cues or information about an upcoming task, such as prompts indicating the difficulty level of the task before its occurrence (Braver, Gray, & Burgess, 2007; Braver , 2012). Such cues or information mobilizes individuals to get into a preparation state early, which is expected to enhance performance on subsequent dual tasks. For example, using the PRP paradigm, previous studies have shown that longer preparation time leads to decreased reaction time for both T1 and T2 during dual tasking (Bausenhart et al., 2006). Cues indicating task order have been shown to effectively prepare individuals for dual tasks and subsequently improve their dual-task performance by optimizing the central processing order (De Jong, 1995; Luria & Meiran, 2003). When word prompts are used, those signaling higher (vs. lower) difficulty of the upcoming tasks tend to elicit greater engagement of proactive control and preparation strategies, which may enhance subsequent task performance.

Supporting this speculation, a previous EEG study utilizing single mental calculation tasks showed a more pronounced slow-drift ERP component associated with proactive control when younger adults were prompted for a difficult upcoming task compared with an easy upcoming task (De Loof et al., 2019). As for dual tasks, based on the PC-TC model (Kalanthroff et al., 2015) reviewed above, one may expect individuals to have better dual-task performance when they are prompted for a difficult upcoming task, due to the facilitative effect of proactive control. Yet, De Loof and colleagues (2019) found that younger participants responded more slowly when prompted with the word "difficult" compared to "easy" during dual tasking. This finding suggests that, in contrast to the PC-TC model, prompting "difficult" actually lowers task performance. Nevertheless, it is important to note that in that particular study, the effect of prompts was confounded by the effect of the actual difficulty level of the tasks, as the prompt words "difficult"/"easy" were invariably followed by dual tasks with certain difficulty levels. To address this confound, the present experiments directly examined the moderating role of actual difficulty level on the effect of the difficulty-related prompt on dual-task performance.

The Moderating Role of Actual Task Difficulty

As mentioned above, prior studies examining the effect of difficulty-related prompts might have confounded the difficulty expectation (and the corresponding recruitment of proactive control) with the actual task difficulty (De Loof et al., 2019). To address this issue, the present experiments directly examined the moderating role of actual task difficulty. Two experiments were conducted to assess dual-task performance using the classical PRP paradigm (Pashler, 1984, 1994; Pashler & Johnston, 1989). Actual task difficulty was manipulated by varying the SOA and task congruency between T1 and T2. Dual tasks with shorter SOAs are more difficult because of more overlap and stronger interference between T1 and T2. Task congruency refers to whether the correct responses to T1 and T2 are the same (high task congruency) or not (low congruency) (Meiran & Kessler, 2008). Higher task congruency attenuates the conflict between T1 and T2, making the dual task easier (Logan & Delheimer, 2001b; Logan & Schulkind, 2000).

Based on previous findings, shorter SOAs and lower task congruency increase the actual task difficulty in the PRP paradigm by intensifying the interference between T1 and T2. If providing prompts about the difficulty levels of upcoming tasks improves dual-task performance by motivating individuals to recruit proactive control, this effect may be weaker when proactive control is less necessary, for instance, when the actual difficulty of the task is lower. Therefore, a major objective of this study is to test whether the actual task difficulty might moderate the effect of difficult-related prompts on dual-task performance in the PRP paradigm.

Cognitive Control Mode Among Younger and Older Adults

Although proactive control may facilitate dual-task performance for everyone, some prior research suggests that younger adults tend to employ proactive control while older adults rely more on reactive control (Braver et al., 2001, 2005). Consistent with this finding, functional MRI studies have shown an age-related shift from proactive control to reactive control in brain activity among healthy older adults (Jimura & Braver, 2010; Lamichhane et al., 2018; Paxton et al., 2008). The decline in proactive control in aging may be attributed to decreases in goal maintenance abilities among older adults relative to younger adults (Staub et al., 2014). Nevertheless, some studies have shown that older adults can still effectively deploy proactive control in certain situations (Berger et al., 2019; Braver et al., 2009). For example, in an emotional Stroop study (Berger et al., 2019), older adults had better task performance when they expected a higher (vs. lower) level of task conflict, which might be because the expectation of a higher level of task conflict elicited greater engagement of proactive control.

Overall, while older adults typically rely less on proactive control compared to younger adults, they can employ it under certain conditions and with proper inducement. It is unclear whether older adults can effectively utilize proactive control to enhance their performance in dual tasking. A major objective of the present study is to address this gap. Building upon these findings, the present experiments manipulated the recruitment of proactive control by presenting younger and older adults with prompts ("difficult" vs. "easy") indicating the difficulty levels of upcoming dual tasks. We predicted that both younger and older adults would have better dual-task performance when they were prompted with "difficult" compared to "easy."

The Present Study

While convergent research has evidenced the vital role of cognitive control in dual tasking (Logan & Gordon, 2001a; Himi et al., 2019; Hu et al., 2022; Tombu & Jolicoeur, 2003; Wen et al., 2018), it remains elusive if proactive cognitive control differently affects dual tasking among younger and older adults. Using the classic PRP paradigm, the present study aims to examine (1) whether proactive control improves the dual-task performance of both younger and older adults, and (2) whether the effect of proactive control on dual-task performance was moderated by actual task difficulty. Proactive control was manipulated by providing difficulty prompts. Moreover, we manipulated the actual difficulty level of the dual task in two ways to examine whether it interacted with the provision of prompt to affect dual-task performance. In Experiment 1, we manipulated the actual difficulty by altering the stimulus onset asynchrony (SOA; i.e., the overlapping between T1 and T2) in the PRP paradigm, with a shorter SOA representing higher difficulty. In Experiment 2, we manipulated the actual difficulty by varying task congruency (i.e., T1 and T2 have the same correct response or not; Meiran & Kessler, 2008) in the PRP paradigm, with higher incongruency representing higher difficulty. As per the discussion above, we proposed the following hypotheses.

Hypothesis 1 The presence of difficulty-related prompts would improve the dual-task performance of both younger and older adults compared to the absence of such prompts, particularly when SOAs are shorter (i.e., when the dual tasks are more difficult) in Experiment 1.

Hypothesis 2 The presence of a "difficult" prompt would improve the dual-task performance of both younger and older adults to a larger extent compared to the presence of an "easy" prompt in Experiment 2.

Hypothesis 3 As proactive control may be less necessary for dual tasks with lower actual difficulty levels, we hypothesized that the effects of prompt words ("difficult" vs. "easy") would be smaller for tasks with higher task congruency (i.e., lower actual task difficulty) compared to tasks with lower task congruency (i.e., higher actual task difficulty).

Experiment 1

Experiment 1 aimed to explore whether prompt presence improved dual-task performance. Experiment 1a and Experiment 1b with the same PRP procedures were conducted. The former was conducted in the laboratory, while the latter was conducted online. In some trials, a prompt, "difficult" or "easy," which reliably indicated a shorter (100ms) or longer (800ms) SOA respectively, was displayed before T1. In other trials, no prompt (i.e., a blank screen) was displayed. The dependent variable of interest in Experiment 1 was reaction time on T1 (RT_1) and T2 (RT_2). As discussed above, we hypothesized that both younger and older adults would have better dual-task performance (i.e., shorter RT_2) under the prompt-presence conditions than under the prompt-absence condition.

Materials and Methods

Participants

To detect a medium effect size ($f=0.25$) for a 2×2×2 mixed-factor design with a statistical power of 0.95 at an alpha level of 0.05, a total sample size of 36 was required according to a power analysis conducted using G*Power (Faul et al., 2009). After 40 younger adults (YAs, aged from 18 to 24 years) from our university subject pool participated in Experiment 1a, the Hong Kong Government tightened up social distancing measures due to the COVID-19 pandemic, which prohibited face-to-face data collection in the laboratory. As a consequence, subsequent participant recruitment and experiment were carried out via the online platform Prolific (https://www.prolific.co/), which has been demonstrated to provide high data quality as compared with other online platforms (Peer et al., 2022). Experiment 1b recruited a total of 66 YAs (24 males, mean age 21.80 ± 1.99) and 111 cognitively healthy older adults (OAs, 50 males, mean age 65.08 ± 5.23, also see Table 1) via Prolific.

Table 1 Demographic information of the participants

	Participants	Age (Mean ± SD)	Percentage of males
Experiment 1	YA ($n=94$)	21.80 ± 1.99	46.8%
	OA ($n=102$)	65.08 ± 5.23	49%
Experiment 2	YA ($n=39$)	22.10 ± 2.02	43.5%
	OA ($n=44$)	65.29 ± 4.20	70%

Note: YA: younger adults; OA: older adults

Experimental Paradigm

The PRP paradigm was used to test our hypotheses. Figure 1 illustrates the flow of a trial in the PRP paradigm. In each trial, a fixation point was presented at the center of the screen for 200 ms. Then a cue (the word "difficult" or "easy") prompting the difficulty of the following task or a blank screen (no prompt) appeared on the screen for 200 ms. Afterward, two tasks (T1 and T2) showed up consecutively in a predetermined order with an SOA of 100 ms or 800 ms. T1 contained an upward or downward arrow stimulus 3.0° left to the screen center, and T2 contained an upward or downward arrow stimulus 3.0° right to the screen center. Each stimulus lasted for 200 ms. For each stimulus, participants needed to judge the orientation of each arrow by pressing certain keys on the keyboard ("d" for the upward arrow and "f" for the downward arrow in T1; "k" for the upward arrow and "l" for the downward arrow in T2). Participants were instructed to respond accurately and as fast as possible to each target to minimize the response grouping effect (Miller & Ulrich, 2008). A shorter SOA made the judgment and response toward T2 more challenging, as participants' attention might have not yet fully shifted from T1 to T2. No feedback on accuracy was given to participants. At the end of each trial, there was an inter-trial interval jittering between 2000 ms and 3600 ms before the next trial started. The PRP paradigm was run on a computer using E-prime (Experiment 1a) or E-prime Go (Experiment 1b) software (Psychology Software Tools Inc., USA). The arrows in the target stimuli were displayed in 60-point Microsoft YaHei font in white on a black background.

Design and Procedures

Experiment 1a employed a 2 (prompt: presence vs. absence) × 2 (SOA: shorter vs. longer) within-subject design for a sample of younger participants. Each participant completed an experiment consisting of two different blocks: a control block first and then a prompt block. The control block consisted of 12 difficult PRP trials (SOA = 100 ms) without prompt (i.e., the difficult-control condition) and 12 easy PRP trials (SOA = 800 ms) without prompt (i.e., easy-control condition). The prompt block consisted of 12 difficult PRP trials (SOA = 100 ms) with the "difficult" prompt (i.e., the difficult-prompt condition) and 12 easy PRP trials (SOA = 800 ms) with the "easy" prompt (i.e., the easy-prompt condition). Although the order of the two blocks was constant, the order among trials within each block was randomized. To familiarize participants with the task before the formal experiment, all participants did a practice session where error feedback was given. Loops of ten dual-task trials were performed till the participants reached an accuracy

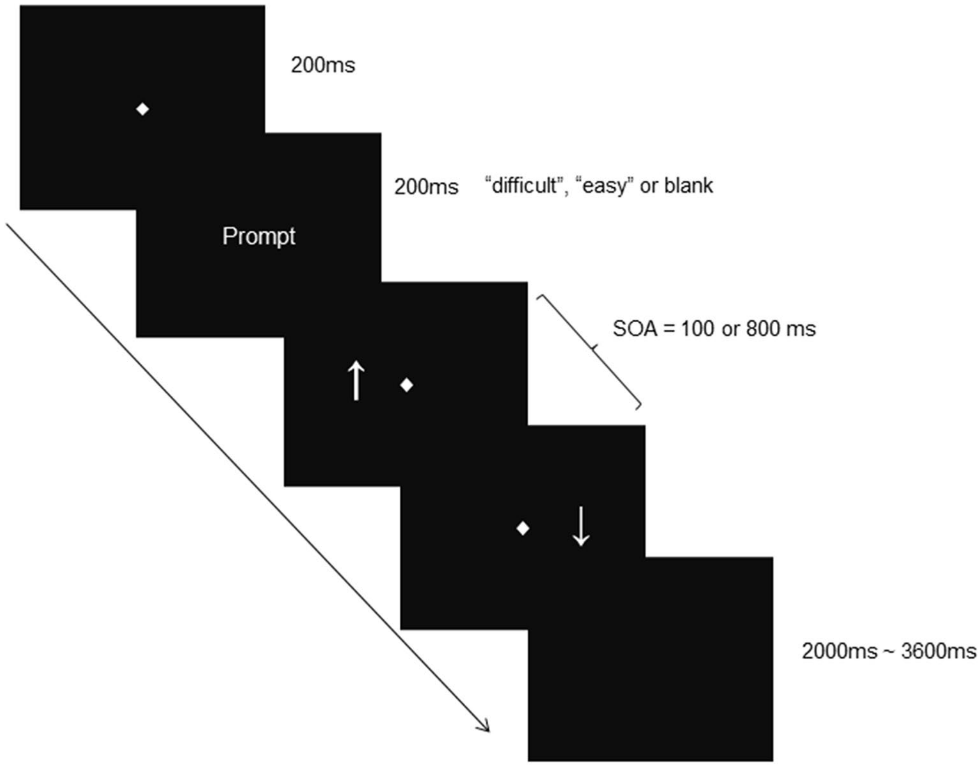

Fig. 1 Schematic of a trial in the Psychological Refractory Period (PRP) paradigm. *Note* Schematic of a trial in the PRP paradigm. Following the fixation point (lasting for 200 ms), a prompt word ("difficult" or "easy") was displayed at the center of the screen for 200 ms. Afterward, two target stimuli T1 and T2 (upward or downward arrows) showed up consecutively, each lasting for 200 ms. There was a 100 ms or 800 ms gap in the onset time between T1 and T2 (i.e., stimulus onset asynchrony, SOA = 100 ms or 800 ms). T1 was an upward or downward arrow displayed on the left side of the screen, and participants needed to judge the orientation of the arrow in T1 by pressing the key "d" (for an upward arrow) or "f" (for a downward arrow). T2 was an upward or downward arrow displayed on the right side of the screen, and participants needed to judge the orientation of the arrow in T2 by pressing the key "k" (for an upward arrow) or "l" (for a downward arrow). The inter-trial interval randomly jittered between 2000 ms and 3600 ms

rate of at least 85%. At the end of the experiment, participants were asked to rate their degrees of fatigue on a five-point Likert scale (from 1 representing "totally not tired" to 5 representing "very tired"). Experiment 1b employed the same experimental design for both younger and older adults, resulting in a 2 (age group: YA vs. OA; between-subject factor) × 2 (SOA: shorter vs. longer; within-subject factor) × 2 (prompt: presence vs. absence; within-subject factor) mixed-factor design. The procedure of Experiment 1b was the same as Experiment 1a, except that participants were required to complete the task in a quiet and distraction-free room, free of interruptions, on their own computers. The schematic of a trial is displayed in Fig. 1.

Data Analysis

Similar to previous studies (Halvorson et al., 2013; Pashler, 1994), we primarily focused on participants' reaction time rather than response accuracy, given that a consistent and robust pattern of the PRP effect is typically observed in reaction time. Moreover, probably because participants reached at least 85% accuracy in practice trials before the formal study began, no age main effect or age by SOA by prompt interaction on response accuracy was observed. Results of the analyses on response accuracy are presented in the supplementary materials. Medians of reaction time to T2 (RT_2) were computed separately for each participant in each experimental condition based on the correct trials. Participants with an accuracy rate of zero in any of the conditions were excluded from further data analysis. Participants whose reaction time (RT_1 and RT_2) was below or above 3 standard deviations from the median reaction time were also excluded. Eventually, 12 (46.8% males) out of 106 YAs and 9 (49% males) out of 111 OAs were excluded from further analysis. Given the skewed distributions of RT among both YAs and OAs, RT was log-transformed before being analyzed (e.g., Tun & Lachman, 2008).

To investigate whether data-collection methods in Experiments 1a and 1b made a difference in task performance, a 2 (methods: laboratory vs. online; between-subject factor) × 2 (SOA: shorter vs. longer; within-subject factor) × 2 (prompt: presence vs. absence; within-subject factor) repeated measures ANOVA was performed for the YAs from Experiment 1a and Experiment 1b. The three-way interaction effect, $F(1,100)=0.24$, $p=.62$, $\eta^2 < 0.001$, and the two-way interaction effect of data collection methods × prompt, $F(1,100)=3.12$, $p=.081$, $\eta^2 = 0.031$, on RT_2 were non-significant, which indicated that YAs recruited from the subject pool in Experiment 1a could be merged with those from Prolific in Experiment 1b for further analysis. Therefore, a 2 (age group) × 2 (prompt) × 2 (SOA) repeated-measures ANOVA was performed on both RT_1 and RT_2 for the whole sample (with the samples of Experiments 1a and 1b merged) of Experiment 1.

Results

The median and SD of RT_1 and RT_2 under different conditions among YA and OA were displayed in Table 2. A main effect of SOA, F (1, 184) = 123.11, $p<.001$, $\eta^2 = 0.40$, was found to be significant on RT_2 while nonsignificant on RT_1, $F(1, 184)=0.38$, $p=.84$, $\eta^2 = 0.00$, indicating that the performance of T2 was affected by SOA ($M_{SOA = 100}$ = 1251 ms, $SD=263$ ms; $M_{SOA = 800}$ = 824 ms, $SD=249$ ms) while the performance of T1 was unaffected by SOA, which supported the PRP effect. We also found a marginally significant main effect of prompt, $F_{(1, 184)}=3.58$, $p=.06$, $\eta^2 =$ 0.019 on RT_2 whilst not on RT_1, $F(1, 184)=0.71$, $p=.40$, η^2 = 0.004, indicating that participants tended to have overall shorter RT_2 under the prompt-presence condition ($M=1028$ ms, $SD=247$ ms) than under the prompt-absence condition ($M=1048$ ms, $SD=249$ ms). The two-way interaction effect between prompt and SOA was significant on RT_2, $F(1, 184)=7.20$, $p<.01$, $\eta^2 = 0.038$, but not on RT_1, F(1, 184) = 0.23, $p=.87$, $\eta^2 = 0.00$. The two-way prompt by age interaction effect was significant on RT_1, $F(1, 184)=4.06$, $p<.05$, $\eta^2 = 0.02$, but not on RT_2, $F(1, 184)=0.198$, $p=.65$, $\eta^2 = 0.001$. There was also a significant three-way interaction effect among prompt, SOA, and age on RT_2, F(1, 184) = 4.04, $p<.05$, $\eta^2 = 0.021$, but not significant on RT_1, $F(1, 184)=3.52$, $p=.06$, $\eta^2 = 0.017$. A simple-simple effect analysis following the three-way interaction effect on RT_2 found that the presence of prompts decreased RT_2 compared to the absence of prompts when SOA was shorter (F_{YA} = 7.35, $p<.01$; F_{OA} = 5.87, $p<.05$) but not when SOA was longer (F_{YA} = 0.74, $p=.39$; F_{OA} = 0.88, $p=.35$) among both age groups, supporting our **Hypothesis1**. In addition, the simple-simple effect analysis showed that the difference in the effect of prompt between the shorter SOA and longer SOA conditions (i.e., the interaction between prompt and SOA) was larger among younger adults than older adults (see Table 2; Fig. 2), indicating that younger adults benefited more from the presence of prompts in the shorter SOA condition compared with older adults.

Discussion

Experiment 1 examined the effect of prompt presence (vs. absence) on age-related dual tasks with shorter or longer SOA by a modified PRP paradigm. A reliable prompt "difficult" always preceded a difficult task (SOA = 100 ms) while the prompt "easy" always preceded an easy task (SOA = 800 ms). The main finding was that dual-task performance, mainly the performance on T2, was improved under the prompt-presence condition as compared with the prompt-absence condition, when SOA was shorter (i.e., actual task difficulty was higher). This prompt effect occurred for both age groups, although younger adults benefited more from it than did older adults. This demonstrated that prompt, at least the prompt "difficult", was effective in improving dual-task performance. It might be because prompting "difficult" more strongly motivated participants to recruit proactive control and thereby resulting in better dual-task performance compared to prompting "easy". In addition, participants might feel that it was less necessary to engage in proactive control when they expected the upcoming tasks to be easy. Note that the control blocks (without prompts) were administered before the experimental blocks (with prompts). This sequence was implemented to minimize carry over effects of the prompts. However, this arrangement might have confounded the effect of prompt presence (vs. absence) with the practice effect, due to the fixed order between the control and experimental blocks. In addition, it remained unclear whether the prompt effect occurred only in more difficult trials because they required more proactive control, or because proactive control only occurred in

Table 2 The median and *SD* of reaction time under different conditions in Experiment 1

		$SOA_{difficult\_prompt}$	$SOA_{difficult\_control}$	SOA_{easy_prompt}	$SOA_{easy\_control}$
YA	RT_1	914 ± 218	951 ± 220	1058 ± 399	1068 ± 403
(n = 94)	RT_2	974 ± 245	1016 ± 237	680 ± 200	666 ± 201
OA	RT_1	1272 ± 332	1243 ± 321	1232 ± 515	1227 ± 509
(n = 102)	RT_2	1488 ± 323	1525 ± 355	967 ± 368	982 ± 373

Note: RT1: reaction time for Task 1 in the dual tasks; RT2: reaction time for Task 2 in the dual tasks; YA: younger adults; OA: older adults; SOA: stimulus onset asynchrony. The SOA was constantly 100 ms under the difficult-prompt condition and the difficult-control conditions, and it was constantly 800 ms under the easy-prompt condition and the easy-control conditions

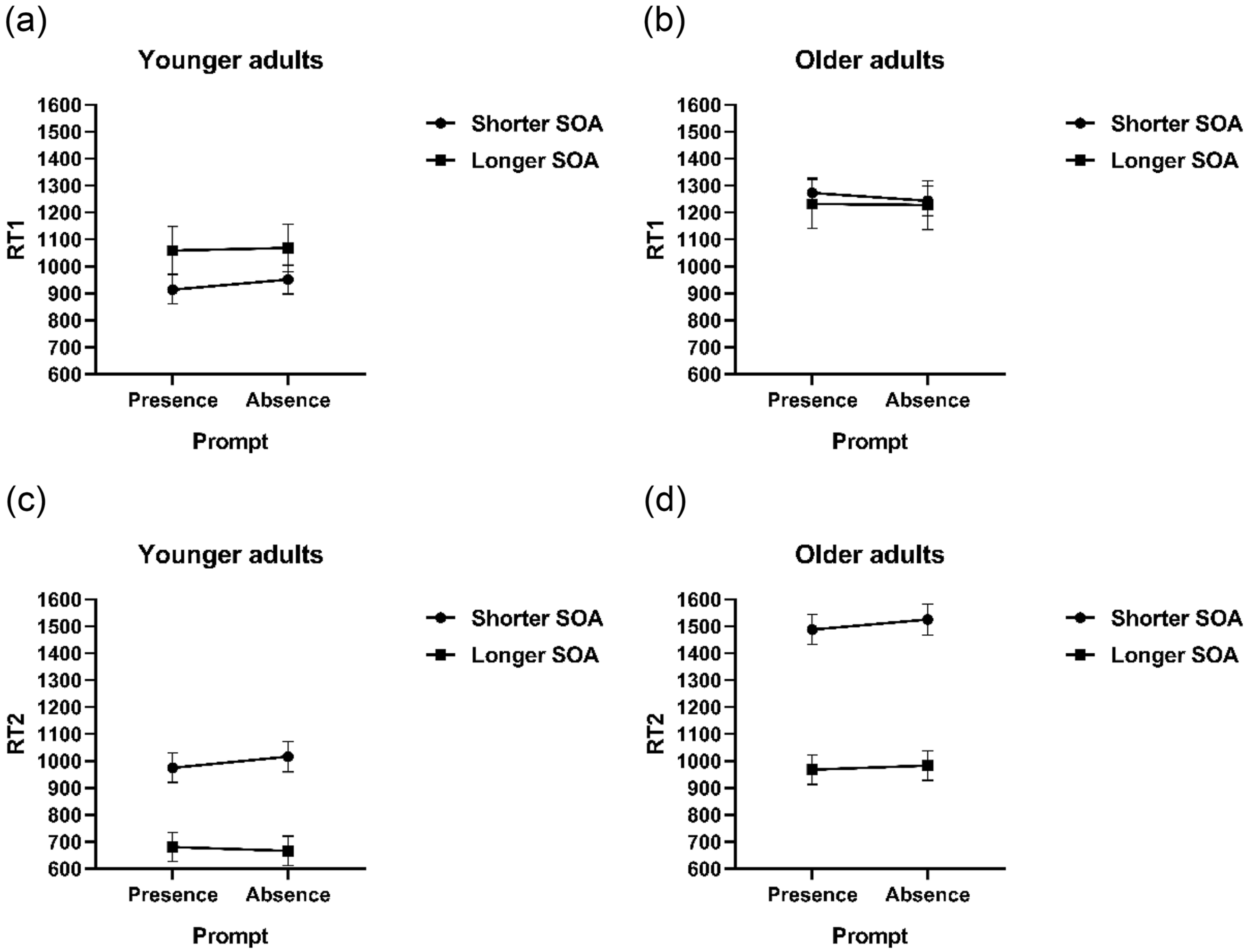

Fig. 2 The median reaction time under different conditions among younger (left panel) and older adults (right panel) in Experiment 1. (**a**)The median reaction time of Task 1 under different conditions in younger adults in Experiment 1. (**b**) The median reaction time of Task 1 under different conditions in older adults in Experiment 1. (**c**)The median reaction time of Task 2 under different conditions in younger adults in Experiment 1.(**d**) The median reaction time of Task 2 under different conditions in older adults in Experiment 1. *Note* RT1: reaction time for Task 1 in the dual tasks; RT2: reaction time for Task 2 in the dual tasks. Error bars indicate the 95% confidence intervals. The sample includes 94 younger adults and 92 older adults

the face of a "difficult" prompt (i.e., an expectation that the upcoming task was going to be difficult) but not an "easy" prompt. We addressed these limitations in Experiment 2.

Experiment 2

In Experiment 2, we controlled for the potential confound arising from the fixed order of control and experimental blocks by randomizing the presentation of experimental trials. We also attempted to disentangle difficulty expectation from the actual difficulty level of a task by applying the prompts "difficult" and "easy" to trials with the same SOA. We modified the PRP paradigm by displaying prompt words "difficult" vs. "easy" before the dual-task trials with the same SOA. Theoretically, the prompt words only manipulated the expectation of difficulty (and thus the recruitment of proactive control), but not the actual difficulty of the task. We predicted that both age groups would have better dual-task performance under the "difficult"-prompt condition in comparison to the "easy"-prompt condition, as per the PC-TC model (Kalanthroff et al., 2015). In addition, Experiment 2 further tested the moderating role of actual task difficulty by varying task congruency using full factorial design. In this design, a specific prompt (e.g., "difficult") was not exclusively bound with a fixed level of actual task difficulty (e.g., a higher level of actual task difficulty). Instead, there was an equal probability that a given prompt was followed by either a more difficult task (with lower congruency) or an easier task (with higher congruency). Given that there was crosstalk (i.e., the dependence of reaction time to one of the stimuli on the response that is required for the other stimulus, Townsend & Ashby, 1983) between T1 to T2, task difficulty was lower when T1 and T2 were congruent (e.g., arrows pointing to the same direction) than when they were incongruent (e.g., arrows pointing to different directions). We tested whether the effect of providing a "difficult" prompt improved dual-task performance to a greater extent for more difficult tasks (when T1 and T2 were incongruent) than less difficult tasks (when T1 and T2 were congruent).

Materials and Methods

Participants

Our Experiment 1 showed a medium size (f = 0.14; i.e., $\eta^2 = 0.02$) of prompt × age group × SOA interaction on RT_2. Assuming a similar effect size for Experiment 2, power analysis with G*Power (Faul et al., 2009) showed that a total sample size of 72 was required to detect the effect size ($f = 0.14$) at an alpha level of 0.05 and a statistical power level of 0.8 for a 2×2×2 mixed-factor design. A total of 81 participants, 38 YAs (mean age 22.10 ± 2.02; 17 males) and 43 cognitively healthy OAs (mean age 65.29 ± 4.20; 31 males, see Table 1) were recruited via Prolific to participate in this experiment.

Experimental Paradigm

An adapted PRP paradigm similar to Experiment 1 was employed in Experiment 2. The difference between the two experiments was that in Experiment 2, all target trials had the same SOA regardless of prompt words. Based on a previous study (Glass et al., 2000), although RT_2 of a dual task decreases with longer SOA, such decreases level off when SOA exceeds 200ms. Dual tasks with longer SOA are perceived as relatively easy. Previous research on attentional blink (Raymond et al., 1992) also demonstrated that 200 ms might be a critical value for the processing of T2. Given this, two pilot studies by titration methods were conducted among two independent older adult samples to examine if 200 ms was a proper SOA that could be used in the target trials. Then another pilot study was conducted among younger adults to replicate the findings found among older adults (see the supplementary materials). The results showed that a dual task with a SOA of 150 ms rather than 200 ms was more likely to be labeled as either "easy" or "difficult" without causing disparity between the prompt and participants' perception among both younger and older adults (see the supplementary materials). To further reduce potential prompt-perception disparity induced by varying the prompts to the same dual task, these target trials (SOA = 150 ms) were embedded in a random-ordered sequence of contextual trials with SOAs of 50 ms/100 ms/200 ms/250 ms. A 2 (age group: YA vs. OA) × 4 (SOA of the contextual trials: 50/100/200/250 ms) repeated measures ANOVA was conducted on participants' difficulty ratings for the context trials. The results showed a significant main effect of SOA, $F(3, 243) = 8.32$, $p < .001$, $\eta^2 = 0.180$, but no significant interaction effect between age group and SOA, $F(3, 243) = 1.27$, $p = .289$, $\eta^2 = 0.032$, indicating that dual tasks with shorter SOAs were rated to be more difficult than those with longer SOAs by both YAs and OAs.

Design and Procedures

We employed 2 (age group: YA vs. OA; as a between-subject factor) × 2 (prompt condition: "difficult" prompt condition vs. "easy" prompt condition; as a within-subject factor) × 2 (congruency: congruent vs. incongruent; as a within-subject factor) mixed design. Participants were instructed to respond accurately and as fast as possible to each target to minimize the response grouping effect (Miller & Ulrich, 2008). Before entering the formal session, participants were asked to acquire at least an 85% accuracy rate during the practice session. Participants completed one block of the PRP paradigm in the formal experiment. The block included 20 target trials (SOA = 150 ms), including 10 trials with the "easy" prompt and 10 trials with the "difficult" prompt. The block also included 10 contextual trials (SOA = 50 ms or 100 ms) with the "difficult" prompt and 10 contextual trials (SOA = 200 ms or 250 ms) with the "easy" prompt. Half of the target trials were incongruent (i.e., two arrows had opposite orientations) while the other half were congruent (i.e., two arrows had the same orientations). All target trials and context trials were intermixed and presented in random order. After the PRP paradigm, all participants rated the difficulty levels of the dual tasks with SOAs of 50/100/200/250 ms and their momentary level of fatigue on Likert scales from 1 to 5.

Data Analysis

Medians of reaction time to RT_1 and RT_2 of the correct target trials (SOA = 150 ms) were computed separately for each participant for each experimental condition. The criteria of data exclusion were the same as in Experiment 1. Eventually, 2 out of 39 YA and 2 out of 45 OA were excluded from further analysis. A 2 (age group) × 2 (prompt condition) × 2 (congruency) repeated-measures ANOVA was conducted separately for log-transformed RT_1 and RT_2. Log-transformation was performed due to the skewed distributions of RT_1 and RT_2 among both YAs and OAs.

Results

The median and SD of RT_1 and RT_2 under different conditions among YA and OA are displayed in Table 3. As expected, participants had significantly longer RT_2 than RT_1 (mean difference = 107 ms, $t = 4.85$, $p < .001$), once again confirming the PRP effect. The main effect of prompt was not significant on RT_1, $F(1, 79) = 3.57$, $p = .06$, $\eta^2 = 0.043$, but significant on RT_2, $F(1, 79) = 13.69$, $p < .001$, $\eta^2 = 0.149$. Participants had overall shorter RT_2 under the "difficult" prompt condition (M_{RT2} = 1019 ms, $SD = 269$ ms) than the "easy" prompt condition (M_{RT2} = 1071 ms, $SD = 297$ ms), supporting our **Hypothesis**2. The main effect of congruency was significant on both RT_1, $F(1, 79) = 60.80$, $p < .001$, $\eta^2 = 0.435$, and RT_2, $F(1, 79) = 96.53$, $p < .001$, $\eta^2 = 0.553$, with shorter RT_1 and RT_2 under the congruent trials (M_{RT1} = 865 ms, $SD = 196$ ms; M_{RT2} = 936, $SD = 268$ ms) than incongruent trials (M_{RT1} =1013 ms, $SD = 253$ ms; M_{RT2} =1155 ms, $SD = 320$ ms). The three-way interaction effect (prompt × congruency × age) was significant on RT_2, $F(1, 81) = 4.75$, $p < .05$, $\eta^2 = 0.055$, but not on RT_1, $F(1, 81) = 0.131$, $p = .718$, $\eta^2 = 0.002$. As shown in Fig. 3, a simple-simple effect analysis following the three-way interaction effect on RT_2 revealed that the "difficult" prompt decreased RT_2 compared to the "easy" prompt in the incongruent condition ($F = 10.73$, $p = .002$) but not in the congruent condition ($F = 0.26$, $p = .61$) among younger adults. This result is consistent with our **Hypothesis**3. In contrast, among older adults, the "difficult" prompt reduced RT_2 compared to the "easy" prompt in both the congruent condition ($F = 5.48$, $p = .02$) and the incongruent condition ($F = 3.68$, $p = .05$).

Discussion

Experiment 2 examined the effect of providing difficulty prompt words ("difficult" vs. "easy") on dual tasks of the same SOA among younger and older adults. We found that both younger and older adults had better dual-task performance under the "difficult" prompt condition in comparison to the "easy" prompt condition. This facilitation effect of prompt, presumably indicating the use of proactive control, was stronger on incongruent than congruent dual-task trials among younger adults but had relatively more comparable effects among older adults. Probably because congruent dual tasks are too easy for younger adults (see reaction time in Fig. 3), providing a "difficult" prompt (vs. "easy" prompt) benefits younger adults' dual tasking only when the dual task is incongruent. Yet, it benefits older adults' dual tasking regardless of task congruency.

General Discussion

Adopting the classic PRP paradigm, the two experiments presented therein aimed to investigate how difficulty prompt (which elicits proactive control) influenced the performance of younger and older adults on dual tasking. They also investigated the moderating role of task difficulty in the prompt effect by varying the SOA between T1 and T2 (Experiment 1) or the response congruency between T1 and T2 (Experiment 2).

Findings from the present experiments suggest that providing a prompt indicating the difficulty level (especially a high difficulty level) of an upcoming task facilitates the dual-task performance of both younger and older adults. However, this facilitation effect was moderated by the level of actual task difficulty. In Experiment 1, the presence of prompts improved dual-task performance (as indicated by shorter RT_2) to a greater extent on dual tasks with a shorter SOA than those with a longer SOA. This experiment showed that the performance-enhancement effect of the presence of prompts was stronger for more difficult dual tasks than for easier dual tasks, which suggests that prompting might be more effective when proactive control is more necessary (e.g., when the task is more difficult). However, it is notable that the effect of prompts might be confounded by actual task difficulty in Experiment 1, because the "easy" prompt was always followed by an easier task that had a longer SOA whereas the "difficult" prompt was always followed by a more difficult task that had a shorter SOA.

In Experiment 2, we disentangle the effects of difficulty prompts and actual task difficulty by (1) associating "difficult" and "easy" prompts with dual tasks of the same SOA and (2) presenting these two prompts before congruent dual

Table 3 The median and SD of reaction time under different conditions in Experiment 2

		Difficult_congruent	Difficult_incongruent	Easy_congruent	Easy_incongruent
YA ($n = 39$)	RT_1	743.34 ± 170.06	880.95 ± 226.99	713.18 ± 153.55	952.74 ± 255.81
	RT_2	731.03 ± 211.22	933.70 ± 287.66	711.22 ± 208.46	1033.09 ± 309.01
OA ($n = 43$)	RT_1	976.28 ± 197.97	1101.24 ± 305.16	1030.78 ± 288.60	1119.36 ± 303.40
	RT_2	1117.37 ± 276.03	1298.26 ± 354.30	1177.30 ± 366.89	1355.35 ± 357.68

Note: RT1: reaction time (ms) for Task 1 in the dual tasks; RT2: reaction time (ms) for Task 2 in the dual tasks; YA: younger adults; OA: older adults; SOA: stimulus onset asynchrony. The SOA was 150 ms under both the difficult-prompt condition and the easy-prompt condition. Difficult_congruent: congruent dual task prompted by "difficult"; Difficult_incongruent: incongruent dual task prompted by "difficult"; Easy_congruent: congruent dual task prompted by "easy"; Easy_incongruent: incongruent dual task prompted by "easy"

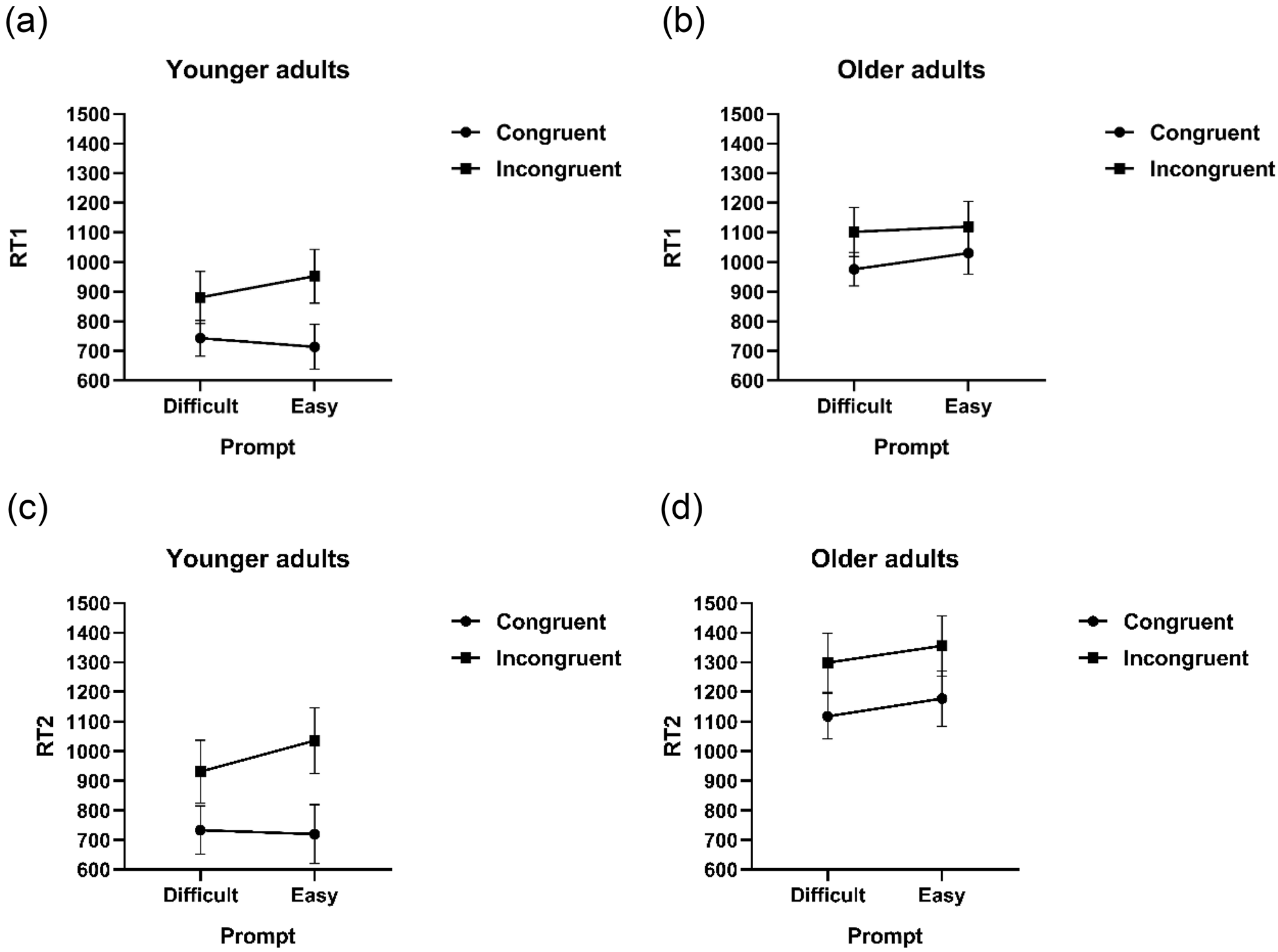

Fig. 3 The median reaction time under different conditions among younger (left panel) and older adults (right panel) in Experiment 2. (**a**) The median reaction time of Task 1 under different conditions in younger adults in Experiment 2. (**b**) The median reaction time of Task 1 under different conditions in older adults in Experiment 2. (**c**) The median reaction time of Task 2 under different conditions in younger adults in Experiment 2. (**d**) The median reaction time of Task 2 under different conditions in older adults in Experiment 2. *Note* RT1: reaction time for Task 1 in the dual tasks; RT2: reaction time for Task 2 in the dual tasks. Error bars indicate the 95% confidence intervals. The sample includes 38 younger adults and 43 older adults

tasks that were easier and incongruent dual tasks that were more difficult with equal probability. The results showed that participants' performance was better (as indicated by shorter RT_2) on tasks with a "difficult" prompt than on those with an "easy" prompt. This finding suggests that it was indeed difficulty prompts (and the proactive control they elicited) that contributed to the improved dual-task performance (i.e., shorter RT_2 but no significant change in RT_1) among younger and older adults. In addition, Experiment 2 found that task difficulty (manipulated by altering task congruency) moderated the performance-enhancement effect of prompts on dual-task performance for younger but not older adults. Younger adults displayed shorter RT_2 but no significant change in RT_1 in response to "difficult" prompts only when the stimuli in the dual tasks were incongruent. In contrast, older adults benefited from "difficult" prompts regardless of task congruency.

These findings enhance our understanding of age-related dual-task performance in the following ways. First, the two experiments consistently found that the "difficulty" prompt promoted dual-task performance (as indicated by shorter RT_2) in the PRP paradigm among both younger and older adults. This may be attributable to the fact that cues or information about upcoming tasks triggers proactive control to improve cognitive performance. When such cues or information is provided, participants could actively prepare and maintain goal-relevant information in a sustained manner before the dual tasks occur. This process optimizes the attention, perception, and action systems while minimizing interference from internal or external sources of distraction during the dual tasks, thereby facilitating task performance (Braver, 2012; Braver , Gray, & Burgess, 2007). The involvement of proactive control might enable flexible coordination of dual tasks by increasing the temporal overlap between the response-selection stages of the two tasks, resulting in faster reactions to the second task, which aligns with the adaptive executive-control model of dual tasking (Meyer & Kieras, 1997a, b). The promoting role of proactive control in cognitive tasks has been well documented in Stroop tasks among younger adults (Bugg & Smallwood, 2016; Goldfarb & Henik, 2007; Kalanthroff et al., 2013, 2015, 2018). The present experiments extend its use to non-Stroop dual tasks. More importantly, our findings suggest that older adults can also enjoy the promoting role of proactive control in dual-task performance despite well-established age-related declines in cognitive abilities that are essential for dual-task performance, such as speed of processing (Salthouse, 1991& 1996) and working memory (Park et al., 1996; Wingfield et al., 1988). Although overall, even with the help of prompts, the dual-task performance of older adults is lower than that of younger adults (see Figs. 2 and 3), the fact that older adults can benefit from the facilitation effect of proactive control suggests that it can be used to compensate for at least some age-related cognitive declines.

Second, actual task difficulty (manipulated by altering response congruency of dual tasks in Experiment 2) moderated the performance-facilitation effect of the “difficult” prompt on the dual-task performance of younger but not older adults. On the one hand, this may be attributable to a ceiling effect of dual-task performance for younger adults on congruent tasks. Task congruency facilitates the process of parallel response selection, which lowers the difficulty of T2 (Logan & Delheimer, 2001b; Logan & Schulkind, 2000). As shown in Fig. 3, younger adults on average only needed around 700 ms to respond to congruent dual tasks. Their high level of performance might have left little room for proactive control to further improve their performance. Such a ceiling effect did not occur for older adults, allowing the effect of proactive control to show up. On the other hand, it might be the case that the better motor execution of younger adults as compared to older adults (Sorond et al., 2015; Maes et al., 2017) allowed them to benefit more from the overlap between stimuli in congruent dual tasks, overriding the effect of proactive control. Older adults, however, might benefit less from the overlap between T1 and T2. They instead might reply more on proactive control to improve their dual-task performance under both the congruent and incongruent conditions. This higher level of reliance on proactive control among older adults is consistent with the hypothesis of over-reliance on central attention (ORCA) proposed by Maquestiaux and Ruthruff (2021). This hypothesis posits that older adults may apply extra central attention as a compensation strategy to cope with cognitive declines. In the case of our Experiment 2, older adults might continue to apply extra attention even in congruent dual tasks when such attention might not be necessary. Further studies should test this possibility.

Conclusions and Future Directions

The present work has demonstrated that enhancing proactive control through prompting that an upcoming task is going to be difficult can promote dual-task performance among both younger and older adults. Such an effect is particularly strong for tasks that are actually difficult. Yet, there are also some limitations in the present work, which should be addressed in future studies. First, the present experiments are all cross-sectional. Future studies should attempt to examine age-related dual-task performance and the role of proactive control in longitudinal studies. Secondly, only one kind of dual task was used in the present experiments. Future studies should test the generalizability of our findings to other dual tasks. Thirdly, the present experiments examined age-related dual-task performance in the laboratory, which is limited in ecological validity. Future studies should test whether our findings are generalizable to everyday life contexts where dual tasks are prevalent, such as the context of grandparenting.

Nevertheless, the present study has both theoretical and practical implications. Theoretically, the present study innovatively disentangles the effects of difficulty expectation and actual task difficulty, which provides a clearer view of the role of proactive control in dual-tasking. In terms of practical implications, the findings of the present study have direct relevance to everyday situations involving multitasking. By showing that both younger and older adults can benefit from difficulty prompts, despite age-related cognitive declines, the present study provides insights on how to develop intervention programs to improve dual-task performance in daily life among older adults. It suggests that proactive control (triggered by prompts) can be utilized to compensate for the age-related declines in dual-task performance.

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Data Availability The data is available at https://osf.io/phx9n/?view_only=*2a1440f43c9d4ce5 80d566c5e2734af3*.

Declarations

The authors have no conflicts of interest to declare.

Ethical Approval This study received ethics approval (SBRE-21-0065) from the Survey and Behavioral Research Ethics Committee at the Chinese University of Hong Kong. All participants gave informed consent before the study. Participants under the age of 18 obtained a signed consent form from their guardians.

Conflicts of interests The authors have no conflicts of interest to declare.

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