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Item Type	Article
Authors	Vaportzis, Ria;Georgiou-Karistianis, N.;Stout, J.C.
Citation	Vaportzis E, Georgious-Karistianis N and Stout JC (2014) Age and task difficulty differences in dual tasking using circle tracing and serial subtraction tasks. Aging Clinical and Experimental Research. 26(2): 201-211.
DOI	https://doi.org/10.1007/s40520-013-0151-5
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Download date	2025-04-18 23:57:23
Link to Item	http://hdl.handle.net/10454/16813

Age and task difficulty differences on dual tasking using circle tracing and serial subtraction tasks

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Manuscript word count: 5,651

Abstract word count: 178

Abstract

The aim of this study was to investigate age-related differences in dual task performance by using an upper limb prioprioceptive task. Twenty-eight younger (18-30 years) and 28 older (> 60 years) healthy adults performed circle tracing and serial subtraction tasks separately and concurrently. Tasks had two levels of difficulty: easy and hard. The circle tracing task included direct (easy) and indirect (hard) visual feedback conditions, and it was paired with serial subtraction by twos (easy) or by threes (hard). We found that older adults were significantly slower than younger adults across all conditions, and had significantly greater dual task costs when they performed circle tracing with easy serial subtraction. Higher levels of task difficulty were associated with slower speed in both groups. We found no age differences in accuracy. Participants either traded speed for accuracy or accuracy for speed regardless of age group. Overall, the findings suggest that speed and accuracy may be affected differently during dual tasking. In addition, older adults may rely more extensively on proprioceptive feedback to guide upper limb movement compared with younger adults.

Keywords. Divided attention, Proprioception, Attention allocation, Speed-accuracy trade-off, Visuomotor integration.

Introduction

Dual tasking refers to the performance of two tasks simultaneously, such as cooking while talking. Although the effect of aging on dual tasking is well-documented [1, 2], in the aging literature there has been a clear bias towards research of the *lower* limbs [3-5]. Few studies have investigated *upper* limb performance [e.g., 6, 7], an essential function for everyday functioning that can influence the independence and well-being of the elderly [8]. Furthermore, despite evidence indicating deterioration of proprioception (awareness of one's body position) with age, few studies have investigated proprioception in the upper limbs [for a review see 9]. To date, research on aging and dual tasking using upper limb tasks has yielded inconsistent results. For example, Crossley and Hiscock [6] required 30 younger (20-40 years), 30 middle-aged (41-65 years) and 32 older (66-90 years) adults to perform a speeded finger tapping task with and without a concurrent cognitive task that was examined at two levels of difficulty. The decrement in tapping rate increased linearly with age from single to dual tasks, and tapping was slowed more by hard than by easy cognitive tasks. In addition, older adults' dual task performance was disproportionately affected by hard tasks, suggesting that age differences may emerge under more challenging conditions. This later finding was further supported by Kemper, Herman and Lian [10], who examined speaking while performing several concurrent tasks (separately), including simple and complex finger tapping. Results showed that older (70-80 years) adults manifested *greater dual task costs* in the complex finger tapping task compared with younger (18-28 years) adults.

Kemper, Schmalzried, Herman, Leedahl and Mohankumar [11] further assessed language production in 40 younger (18-34 years) and 40 older (65-85 years) adults who simultaneously performed a tracking task. Contrary to past research that has typically found *older* adults to incur greater dual task costs [12], in this study it was the *younger* adults who showed increased dual task costs in measures of tracking and language production. Kemper et al. [11]

suggested that slower, less complex speech protected older adults from dual task costs, whereas younger adults, who had faster, more complex speech, were more susceptible to dual task demands. These results were explained in terms of possible differential executive control strategies between different age groups.

A recent imaging study with 20 younger (20.7-32.6 years) and 20 older (62.3-76.5 years) adults found no dual task interference during circle drawing and serial addition in threes [7]. Age-related increased brain activation was evident in the fronto-parietal network only during circle drawing, suggesting that compared to younger adults, older adults may rely more extensively on proprioceptive information to guide upper limb movement. Moreover, Van Impe et al. [7] suggested that the fronto-parietal network may be involved in goal-directed attention. The authors also suggested that either overlearned tasks are not affected by aging or that serial addition may not have been challenging enough in terms of attentional loading to elicit significant age differences. Another imaging study used color and letter identification dual tasks, and found that neural substrates responsible for dual task performance were similar between younger (19-25 years) and older (65-77 years) adults , involving the medial prefrontal and lateral fronto-parietal networks [13]. Hartley et al. [13] concluded that concurrent tasks elicit executive functions, such as working memory, instead of only passive, stimulus-driven functions. However, this study also found that older adults had higher brain activation levels in occipital and polar prefrontal cortex during dual task performance. Thus, brains of older adults may work differently in order to perform at accuracy levels similar to younger adults', possibly demonstrating that neural compensation is needed with aging to successfully maintain low levels of dual task interference. This later finding has often been interpreted in terms of additional attentional resources recruitment [14].

Previous dual task studies report measures of speed and/or accuracy of performance [2, 15, 16]. Older adults are typically slower than younger adults when performing dual tasks, even after age-related slowing is controlled for by using the performance of the single tasks as a baseline for calculating interference in the dual task conditions; thus, controlling for age-related differences in the performance of each task on its own [6, 17]. However, Salthouse [18, 19] conducted a number of studies demonstrating that a large proportion of age-related differences in cognitive tasks can be accounted for by a slowing of information processing, and suggested that speed of processing is a cognitive primitive, or a basic building block of cognition. Compared to speed, the effect of aging on *accuracy* of dual task performance is less clear, with previous studies indicating no differences between younger and older adults [18], older adults making more errors [19-22], and older adults making fewer errors [11, 23].

In our view, an important drawback is that most previous studies have *either* provided measures of speed *or* accuracy. A meta-analysis of studies on age differences in dual tasking that carried out separate analyses on speed and accuracy data found the greatest effects on the studies that used speed as their dependent variable [24]. In addition, we know that people may experience speed-accuracy trade-offs when performing tasks [25], and therefore, faster reaction times may be associated with increased error rates or vice versa [26]. Although some studies reported no speed-accuracy trade-offs in dual tasking in younger and older adults [15], results of other studies suggested that older adults adopted a more conservative speed-accuracy criterion while performing cognitive tasks [4]. In addition, a meta-analysis that investigated the relationship between aging and dual task performance concluded that older adults showed speed-accuracy trade-offs less often than younger adults [12]. Therefore, an investigation of both speed and accuracy may be more informative than either speed or accuracy alone.

With regard to theoretical frameworks, a number of theories have attempted to explain dual tasking. One of the most prominent theories is the Multiple Resources Theory, which proposes that there are *separate* resource pools (e.g., a visual resource pool, an auditory resource pool), each of which can be divided among concurrent tasks. This theory proposes that multiple resources account for information processing depending on four dichotomous dimensions: (1) processing stages, including perception-cognition and response, (2) perceptual modalities, including visual and auditory, (3) processing codes, including spatial and verbal, and (4) responses, including manual and vocal. According to this theory, interference occurs when tasks make concurrent demands on the same resources [27, 28]. For example, the Multiple Resources Theory predicts minimal interference between a task that is presented visually (and requires manual response), and a concurrent task that is presented auditorily (and requires vocal response). Our study was designed to test the Multiple Resources Theory, and to investigate the influence of cognitive demands on manual motor outputs in aging. Thus, we examined dual task performance in younger and older adults by using a task that was presented visually and required a manual motor response (i.e., circle tracing), and a concurrent task that was presented auditorily and required a vocal response (i.e., serial subtraction).

An important question is how upper limb proprioception is affected by age and by the demands of a concurrent task. Proprioceptive ability is crucial in allowing people to move and interact with their environment [29]. Past research has demonstrated age-related changes in upper limb proprioception wherein aging was associated with difficulty in detecting finger-joint position [30], and positioning of the elbow joint relying only on proprioceptive feedback [31]. Therefore, the aim of the current study was to investigate age-related differences in dual task performance by using an upper limb prioprioceptive task. We instructed our participants to consider both tasks as primary, that is, to try to maintain optimal performance in both circle tracing and serial subtraction. Both tasks had two difficulty levels: easy and hard. The easy and hard tasks within the circle tracing and serial subtraction tasks involved the same stimuli and responses; however, the hard tasks presumably required more attentional loading and deeper cognitive processing than the easy tasks. In accordance with past research [32] that found age-related differences to be exacerbated with increased task difficulty, processing of the hard tasks was expected to show greater interference in older adults.

We combined circle tracing with serial subtraction so that we could examine the influence of cognitive demands (from the subtraction task) on manual motor output and proprioceptive ability. In addition, we wanted to investigate dual tasking under different levels of performance, and the difficulty levels of these tasks could be easily manipulated. Circle tracing engages visuomotor processes [33], whereas serial subtraction tasks engage working memory [34]. We selected circle tracing to specifically tax *upper limb* proprioceptive ability. This task has been previously used to investigate visuomotor integration under direct (easy) and indirect (hard) conditions in participants with Huntington's disease [33, 35]. In particular, the circle tracing task required participants to trace an annulus using a tablet and a stylus. In the direct condition, participants could view their arm and tracing path whilst tracing the circle. In the indirect circle tracing condition, however, their arm was covered, and the annulus and their tracing path were displayed on a separate monitor. Therefore, performance on the indirect condition required the use of proprioceptive feedback. Evidence suggests changes in upper limb proprioception with age, as reflected by greater errors and prolonged, irregular movements [31, 36]. Therefore, we expected that circle tracing performance of older adults would be more compromised compared with younger adults. We selected serial subtraction because it has been previously used as an attention demanding task [37], and is an effective distractor task of attention [38].

In support of the Multiple Resources Theory, interference between circle tracing and serial subtraction should be minimal, because these tasks are likely to be processed by separate modalities-responses (visual-manual for circle tracing and auditory-vocal for serial subtraction). In view of previous findings, we expected older adults to be slower across all task conditions compared with younger adults, and speed of both groups to decrease with greater task difficulty. We also expected error rates of both groups to increase with greater task difficulty, and older adults to incur greater dual task costs than younger adults.

Method

Participants

Sixty younger (18-30 years) and older (61-90 years) healthy adults participated in our study. Participants were recruited via advertisements around Monash University, and online advertisements on the Monash University website. In addition, some older participants were recruited through retirement villages and senior citizens clubs around the Melbourne region. Four older adults were excluded due to either low scores on the Montreal Cognitive Assessment [MoCA; 39] or inability to perform some of the tasks. The final sample consisted of 28 younger (15 females, *M* = 22.21, *SD* = 3.14) and 28 older (15 females, *M* = 71.96, *SD* = 7.84) participants. The MoCA is a 30-point cognitive screening test designed to detect cognitive impairment, and the suggested cut-off point (also adopted in this study) was 26. Other screening tests included the Wechsler Test of Adult Reading [WTAR; 40], and the Inventory of Depressive Symptomatology – Self-report [IDS-SR; 41]. The WTAR is used to estimate verbal IQ, and is composed of 50 words that have irregular letter to sound translations. The IDS-SR is a 30-item questionnaire that assesses the severity of depression within the past 7 days for all symptom domains of major depression according to the Diagnostic and Statistical Manual-IV [42]. Scores can range between 0 (= no depressive symptoms) and 84 (= very severe depressive symptoms).

The young and old groups did not differ significantly on the MoCA ($M_{Y} = 28.07$, $SD_{Y} = 1.58$; $M_{O} = 27.04$, $SD_{O} = 1.87$), $t(54) = 1.79$, $p = .08$; WTAR ($M_{Y} = 107.50$, $SD_{Y} = 8.55$; $M_{O} = 110.32$, $SD_{O} = 5.89$), $t(54) = -.143$, $p = .16$; and IDS-SR ($M_{Y} = 11.96$, $SD_{Y} = 7.09$; M_{O}

$= 13.97$, $SD_O = 8.34$), $t(54) = -.435$, $p = .67$. Education level was also assessed based on the International Standard Classification of Education [ISCED; 43] system, according to which 0 indicates pre-primary education and 6 second stage tertiary education. Older adults had significantly fewer years of formal education than younger adults ($M_Y = 5.14$, $SD_Y = .35$; $M_O = 4.21$, $SD_O = .95$), $t(54) = 4.81$, $p < .001$. Education was used as a covariate in all statistical analyses.

All participants gave written informed consent, and self-reported that they were free of neurological disease, psychological disorders, and upper limb impairments. They had normal or corrected-to-normal vision and hearing, and they were fluent in English. Ethics approval was granted by the Monash University Human Research Ethics Committee.

Dual Task Description and Study Procedure

Participants were tested individually in a quiet room, and were advised to perform all tasks as quickly and as accurately as possible. For the dual task procedure, we combined circle tracing and serial subtraction tasks that both included an easy *and* a hard condition. The circle tracing task has been previously described by Say et al. [33], who adapted a task described in Lemay, Fimbel, Beuter and Chouinard [35]. It was administered on a Lenovo ThinkPad® X61 (Morrisville, NC, USA) tablet laptop, with the tablet positioned in front of the participants at comfortable reach. The tablet displayed a 90 mm diameter circle with a 5 mm thick white annulus on a gray background. For the hard circle tracing conditions, a desktop monitor, which was placed approximately 70 cm in front of the participants and displayed the same white annulus on a gray background, was also used. Participants traced the circle using a stylus that left a blue line indicating the circle tracing path trajectory. They started at the vertical apex of the circle, and traced it with their preferred hand in a clockwise direction. In the easy (direct) condition, participants could observe their arm and the circle tracing path on the tablet screen. In the hard (indirect) condition, participants' tracing arm and tablet were obscured by a box covering the tablet and a cloak covering the box and their arm. Thus, in contrast with the easy condition during which participants could *directly* observe their performance on the tablet, in the hard condition they could only monitor their progress *indirectly* on the desktop monitor.

For the serial subtraction task, participants were given 20 s and were instructed to count backward by twos (easy condition) or by threes (hard condition). Starting numbers ranged between 100 and 86 and half the trials commenced on an odd number.

Design and Statistical Analyses

Participants performed a practice circle tracing trial in the easy condition, and then, four single tasks separately and in the following order: (1) easy circle tracing, (2) hard circle tracing, (3) easy serial subtraction and (4) hard serial subtraction. Each circle tracing condition was repeated three times for 20 s each, and each serial subtraction condition was performed twice for 20 s each. Next, participants performed three trials of every possible combination of the circle tracing together with the serial subtraction tasks: (1) easy circle tracing with easy serial subtraction, (2) easy circle tracing with hard serial subtraction, (3) hard circle tracing with easy serial subtraction, and (4) hard circle tracing with hard serial subtraction. Each dual task trial lasted 20 s.

The circle tracing and serial subtraction dual task set was one of four sets of tasks that participants performed as part of a larger study, and the order of the four sets was counterbalanced across participants. In contrast, we did not counterbalance the eight conditions that make up the circle tracing and serial subtraction dual task set; all participants performed the eight task conditions *in the same order*. There were several reasons for this. First, with regard to the circle tracing and serial subtraction set, we wanted to ensure that hard tasks preceded by easy tasks as there is a learning component for each of these tasks. Secondly, because of the large number of conditions within each of the four sets of tasks, a task design containing all possible permutations of task order within and across sets would have required a much larger sample size. We also felt that within a task set, by presenting the easier tasks and task combinations first, we could maintain a level of control over the participants' previous experiences with the tasks, which could benefit them similarly as they reached the harder levels.

The dependent variables for circle tracing were speed (total number of rotations in 20 s), and accuracy (number of errors per rotation). Errors were defined as the stylus moving beyond either the inner or outer edge of the white annulus for > 100 ms. For serial subtraction, the dependent variable was accuracy (percentage of incorrect responses). We also calculated the rate of responses by dividing the time to complete the task (20 s) by the number of responses per participant.

For circle tracing, trials with values more than 3.5 standard deviations from the individual's mean were removed prior to computing overall means and standard deviations for *speed* and for *error rates* (see Table 1). We computed a 2 X 2 X 3 mixed-model ANCOVA with the between factor, age (young, old), and two within factors, circle tracing difficulty (easy, hard), and serial subtraction difficulty (none, easy, hard) for both speed and error rates of the circle tracing task. We report Greenhouse-Geisser corrected degrees of freedom due to violations of the sphericity assumption. Significant interactions of interest were followed with planned comparisons. Bonferroni post hoc tests were conducted for all post hoc pairwise comparisons. For serial subtraction, ANCOVA was inappropriate due to very low error rates. Therefore, we conducted non-parametric analyses using Wilcoxon signed rank tests to compare the easy and hard conditions for younger and older adults separately. For all analyses, alpha was set at 0.05.

Dual task costs were also computed to quantify participants’ ability to perform two tasks simultaneously. For the speed variable from circle tracing, we computed a 2 X 2 X 2 mixed-model ANCOVA with age (young, old) as the between subjects factor, and two within factors, circle tracing difficulty (easy, hard), and serial subtraction difficulty (easy, hard). We did not calculate dual task costs for error rates for the circle tracing task as both groups made fewer errors in the dual task conditions compared with the single task conditions. For the serial subtraction tasks, we added a value of one to each data point prior to computing dual task costs due to a large number of participants not committing any errors in the single tasks. Following de Ribaupierre and Ludwig [17] and Kemper et al. [10], *dual task costs* were computed by calculating the relative ratio of the single task to dual task performance using the following formula: dual task cost = (single task-dual task)/single task. Positive dual task costs in the circle tracing task denote a decrease from single to dual task conditions. Therefore, positive dual task costs suggest that participants performed fewer rotations on the circle tracing task in the dual task conditions compared with the single task conditions. Finally, to examine speed-accuracy trade-offs, we performed Pearson’s correlations between speed and error rates for each of the six circle tracing task separately for younger and older participants.

INSERT TABLE 1 HERE

Results

In the following section, we first describe the circle tracing task performance (single and dual tasks), followed by dual task costs and speed-accuracy trade-offs. Finally, we present serial subtraction performance.

As seen in Figure 1, older adults were slower than younger adults, and both groups were slower in the hard circle tracing conditions. Figure 2 shows that dual tasks were performed slower than single tasks. Indeed, a three way ANCOVA with speed as the dependent variable revealed significant main effects of age, $F(1,53) = 9.50$, $p = .003$, $\eta^2 = .15$, circle tracing, $F(1.00,53.00) = 9.39$, $p = .003$, $\eta^2 = .15$, and serial subtraction, $F(1.24,65.70) = 6.94$, $p < .001$, $\eta^2 = .11$. More importantly, we found a significant interaction between age and circle tracing, $F(1.00,53.00) = 7.19$, $p = .10$, $\eta^2 = .12$. Pairwise comparisons revealed that older adults were significantly slower when performing easy ($p < .001$) and hard ($p < .001$) circle tracing compared with younger adults. In addition, both groups were significantly ($p < .001$) faster in easy circle tracing compared with hard circle tracing. We also found a significant interaction between circle tracing and serial subtraction, $F(1.29,68.52) = 5.49$, $p < .015$, $\eta^2 = .09$. Pairwise comparisons revealed that performance on circle tracing (easy or hard) was significantly ($p < .001$) faster on its own than when combined with easy and hard serial subtraction (the latter two of which did not differ).

Both age groups maintained similar levels of accuracy across both levels of circle tracing task difficulty. We calculated a three way ANCOVA using error rates as the dependent variable. We found a significant main effect of serial subtraction, $F(1.36,72.34) = 2.36$, $p = .01$, $\eta^2 = .43$, but no other significant main effects or interactions. Pairwise comparisons revealed that participants made significantly ($p < .001$) more errors in the absence of serial subtraction than when they performed easy or hard serial subtraction concurrently. In addition, error rates were significantly ($p = .04$) higher when circle tracing was performed concurrently with easy than hard serial subtraction.

INSERT FIGURES 1 AND 2 HERE

Dual task costs for speed were greater in the easy circle tracing conditions compared with the hard circle tracing conditions, as suggested by a significant main effect of circle tracing, $F(1.00,53.00) = .29$, $p = .04$, $\eta^2 = .01$. We also found a significant two way interaction involving age and serial subtraction, $F(1.00,53.00) = 6.48$, $p = .01$, $\eta^2 = .10$ (see Figure 3). Pairwise comparisons revealed that older participants had marginally significantly ($p = .05$) greater dual task costs than younger participants when they performed circle tracing concurrently with easy serial subtraction compared with hard serial subtraction.

INSERT FIGURE 3 HERE

Regardless of age group, individual participants performed the tasks either more slowly and made fewer mistakes (compromised speed for accuracy) or faster and with more errors (compromised accuracy for speed). Figure 4 clearly shows significant ($p < .001$) positive correlations for both groups across all circle tracing conditions.

INSERT FIGURE 4 HERE

For error rates, on the serial subtraction task, Wilcoxon signed rank tests showed significant differences between the easy and hard single task conditions for younger (z = -2.45, $p = 0.1$) and older adults (z = -2.66, $p = 0.1$) suggesting that both groups made more errors when performing the hard serial subtraction task compared with the easy serial subtraction task. We found no other significant differences for error rates of serial subtraction. For response rates, on the serial subtraction task, we found significant differences between several conditions (see Table 2). Overall, response rates for both younger and older adults were slower in the harder conditions of the serial subtraction task.

INSERT TABLE 2 HERE

For dual task costs for error rates on the serial subtraction task, a 2 X 2 X 2 mixed-model ANCOVA showed no main effects or interactions ($p > .05$). However, we found a significant main effect of age for dual task costs for response rate, $F(1,53) = 6.99$, $p = .01$, $\eta^2 = .11$, suggesting that older adults generated fewer responses within 20 s than younger adults.

Discussion

The results of this study must be considered in light of three types of effects, including those associated with aging, those associated with task difficulty, and those associated with single versus dual tasks. In general, we found age-related differences in speed, but not in accuracy on circle tracing with serial subtraction tasks, highlighting the importance of investigating both speed and accuracy measures in dual task research. Circle tracing speed decreased with task difficulty and under the dual task conditions, whereas lower error rates were associated with higher levels of task difficulty and dual task performance.

Consistent with studies that have used other combinations of tasks [6], we found older age to be associated with slower performance in both easy and hard circle tracing, probably due to generalized psychomotor slowing, which is a characteristic of normal aging. Both groups were slower in circle tracing when they performed serial subtraction concurrently, corroborating that the addition of the serial subtraction task to the circle tracing task was associated with greater cognitive load than when the circle tracing task was performed on its own. Despite this, compared to the easy serial subtraction task, hard serial subtraction did not have differentially greater impact on circle tracing speed. This latter result may suggest that hard serial subtraction may not have been challenging enough to trigger greater decrease in speed than easy serial subtraction.

In line with past research [6, 10], higher levels of task difficulty were associated with slower circle tracing performance in both groups. That is, both younger and older adults performed more slowly hard circle tracing, which used visual occlusion of the arm with only indirect feedback of the tracing path, compared to the easy circle tracing, in which the arm and its tracing path could be freely seen. This finding is consistent with Say et al. [33] who also found slower performance in the indirect circle tracing condition. We and others have suggested that performance slowing in hard circle tracing may be explained by an additional sensorimotor transformation requirement that is necessary for integrating visual and proprioceptive information into a joint reference frame [33, 37, 44]. Additionally, this differential finding for the direct and indirect circle tracing conditions may imply that the demands of the visuospatial element of the task (which varied for easy versus hard conditions) were greater than the motor demands of the task (which were the same for easy versus hard conditions).

Interestingly, the easy circle tracing task speed appeared to be more susceptible to dual task interference than the hard circle tracing task speed, and this finding was consistent across both groups. Our interpretation of this is that the hard circle tracing task may be more robust to the interference of the second task because performance is already somewhat slow, thus allowing participants to incorporate the added demand of the second task without additional cost to their speed. With respect to the effect of aging, the dual task costs of performing circle tracing concurrently with easy serial subtraction was greater. However, with the hard serial subtraction task, performance of the two age groups was more similar. Overall, we interpret this pattern of effects as indicating that as tasks get more difficult, younger adults may adopt a more cautious approach, perhaps because they recognize the need of a slower performance speed to achieve reasonable accuracy. Alternatively, younger adults may be unable to perform the tasks more quickly due to their greater attentional requirements. In any case, the decrement in speed associated with task difficulty was greater for younger compared to older adults who were already performing the task more slowly.

Interestingly, the higher level of task difficulty was not associated with increased error rates on circle tracing. The greater proprioceptive demands of the hard circle tracing task seemed to only influence speed, but not errors for both groups. Therefore, the reduction in speed from easy to hard circle tracing seemed to engender sufficient control over performance, so that accuracy was maintained across both levels of difficulty for both younger and older adults.

Surprisingly, both groups performed the largest number of errors in circle tracing when it was performed as a single task (i.e., without serial subtraction), and the fewest errors when it was performed concurrently with hard serial subtraction. Consistent with this finding may be the explanation that because of the ease with which participants could perform the single tasks, perhaps they gave less effortful attention in single tasks compared to dual tasks, and therefore, performance was relatively more governed by automatic processes. In turn, under these more automatized performance conditions, errors may not have been as deliberately avoided, and thus occurred at higher rates. On the contrary, in dual task conditions, performance may have been necessarily more controlled due to the higher level of task difficulty, allowing participants to exercise better control over accuracy of performance, and in turn reducing error rates.

Overall, our results suggest that older adults may possibly rely more extensively on proprioceptive feedback to guide upper limb movement. Age-related deterioration in sensorimotor processing may affect upper limb position awareness, especially in harder task conditions [31, 36, 45]. Despite that, older adults were significantly slower than younger adults in the easy circle tracing conditions as well, when visual feedback was given directly. Past research reported differential brain activation in older and younger adults during performance of motor [14, 46, 47] and cognitive tasks [48, 49]. These findings are typically explained in terms of increased functional demands exerted on the aging brain. With advancing age cognitive functions may become inflexible, and automaticity may decline [50]. It is possible that the circle tracing task placed greater cognitive demands on older adults, even during the easy conditions, so that movement became less automated due to increased attentional resources required to maintain reasonable accuracy.

This study showed some resource sharing between two seemingly different tasks suggesting that the visual and auditory modalities *and* the manual and vocal responses are not utterly separate as the Multiple Resources Theory holds. Our results may be partially explained by the Unitary Resource Theory. This theory proposes that attention is a *single, limited capacity resource* that depends on several factors, including task difficulty, and it can be allocated to a single task or divided between different tasks [51]. According to the Unitary Resource Theory, in dual tasking, if one task is hard and requires a large proportion of this limited attentional resource, there will be little of this resource available to support the performance of the other task, and performance will deteriorate. This theory also postulates that compared to younger adults, older adults have reduced attentional resources, and therefore, some operations are more demanding for older adults [52]. In line with the Unitary Resource Theory [53], we found that with increased task difficulty, the speed of both groups was reduced and dual task interference was induced. In further support of this theory, we found that compared with younger adults, performance of older adults was slower possibly because they reached a point where available attentional resources were not sufficient to perform the tasks quicker than young adults [52, 53]. However, we found no age-related differences or dual task interference in accuracy of performance. Therefore, our study supports the Unitary Resource Theory only partially and demonstrates the importance of taking into account both measures in dual task research as each measure may yield different results.

We should point out certain limitations of our study. Firstly, most of the participants in the young group were university students, whereas only about half of the older participants had completed a higher education degree. Despite this, analyses suggested that there were no significant education effects on dual task performance. Secondly, although we asked participants to perform the tasks as quickly and as accurately as possible, there may have been an aging effect on the balance between the competing goals of speed and accuracy. That is, participants may have intentionally emphasized either speed or accuracy, and this tendency may have been associated with the age grouping to which the participant belonged. Whether the speed-accuracy trade-off effects that we observed were more a result of conscious than automatic processes is unknown and remains an important question. Finally, another limitation was that conditions were not counterbalanced for single and dual tasks and therefore, results can only be interpreted in the context of single tasks occurring first and dual tasks occurring after all single tasks had been performed. Despite this, participants were faster in the single task conditions, and their performance deteriorated with increased task difficulty in the dual task conditions. Thus, if anything, counterbalancing may have increased the magnitude of the observed differences.

In summary, this study has demonstrated that older adults are differentially affected compared with younger adults when circle tracing is performed concurrently with serial subtraction, a finding broadly consistent with other studies using different combinations of tasks to examine dual task effect. Older adults were slower than, but as accurate as younger adults, partially supporting the Unitary Resource Theory. Both groups showed speed-accuracy trade-offs sustaining our view that both speed and accuracy measures are imperative when examining dual task performance. We also found age differences in dual task costs for some, but not all conditions, suggesting that dual task interference may emerge under certain conditions, and possibly during certain tasks. Further studies investigating dual tasking using upper limb motor with cognitive tasks are warranted and represent a potentially strong research framework.

Acknowledgments

Financial support for this study was obtained from the School of Psychology and Psychiatry, Monash University. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Table 1

Means (and Standard Deviations) for Variables from the Circle Tracing and Serial Subtraction Tasks in Young and Old Participant Groups

	Tracing Speed		Tracing Errors		Tracing DTC (Speed)		Subtraction Errors		Subtraction Rates		Subtraction DTC (Errors)		Subtraction DTC (Rates)	
	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old
E single task	7.33	5.10	7.45	5.59			0.84	1.65	1.10	1.17				
	(3.42)	(2.59)	(6.83)	(5.92)			(1.73)	(2.51)	(.33)	(.27)				
H single task	3.42	2.21	7.46	4.97			3.23	5.25	1.91	2.08				
	(1.63)	(1.28)	(3.87)	(3.75)			(4.50)	(7.11)	(.90)	(.81)				
E Tracing with	5.27	3.11	4.86	2.96	.25	.37	1.10	1.66	1.38	1.66	-.62	-.59	-.26	-.43
E Subtraction	(2.48)	(1.71)	(4.50)	(3.32)	(.22)	(.21)	(2.10)	(2.81)	(.53)	(.45)	(1.97)	(1.91)	(.27)	(.31)
E Tracing with	4.85	3.21	4.05	2.70	.30	.35	0.52	1.19	1.29	1.65	-.21	-.38	-.19	-.42
H Subtraction	(2.37)	(1.79)	(3.43)	(3.22)	(.26)	(.25)	(1.29)	2.95)	(.47)	(.58)	(1.26)	(2.06)	(.25)	(.47)
H Tracing with	2.74	1.63	4.65	3.32	.16	.21	3.39	5.23	2.18	2.38	-.51	-1.75	-.17	-.18
E Subtraction	(1.16)	(.83)	(3.04)	(3.04)	(.20)	(.22)	(5.13)	(6.61)	(1.04)	(.82)	(1.70)	(4.06)	(.34)	(.33)
H Tracing with	2.53	1.65	3.90	3.14	.21	.21	2.59	4.28	2.18	2.46	-.51	-1.25	-.15	-.19

H Subtraction	(.97)	(.83)	(2.70)	(2.70)	(.21)	(.20)	(2.59)	(5.58)	(1.27)	(1.01)	(1.64)	(3.98)	(.30)	(.24)

Note. E: Easy; H: Hard. DTC: Dual task cost = (single task-dual task)/single task. Circle tracing speed = number of rotations in 20 s; circle tracing accuracy = number of errors per rotation; serial subtraction errors = percentage of incorrect responses; serial subtraction rate of response = time to complete the task (20 s)/number of responses.

Table 2

Comparison of Serial Subtraction Conditions for Young and Old Participants

	Young		Old	
	z	*p*	z	*p*
E Subtraction vs H Subtraction	-3.99	<.001	-4.62	<.001
E Subtraction vs E Subtraction with E Tracing	-3.66	<.001	-4.48	<.001
E Subtraction vs E Subtraction with H Tracing	-3.27	.001	-4.55	<.001
H Subtraction vs H Subtraction with E Tracing	-2.19	.028	-2.61	.009
H Subtraction vs H Subtraction with H Tracing	-2.40	.016	-3.17	<.001
E Subtraction with E Tracing vs E Subtraction with H Tracing	-2.51	.012	-0.55	.581
E Subtraction with E Tracing vs H Subtraction with E Tracing	-4.46	<.001	-4.42	<.001
E Subtraction with E Tracing vs H Subtraction with H Tracing	-4.54	<.001	-4.48	<.001
E Subtraction with H Tracing vs H Subtraction with E Tracing	-4.46	<.001	-4.25	<.001
E Subtraction with H Tracing vs H Subtraction with H Tracing	-4.60	<.001	-4.22	<.001
H Subtraction with E Tracing vs H Subtraction with H Tracing	-0.41	.682	-0.30	.764

Note. E: Easy; H: Hard.

Figure captions

Figure 1. Number of rotations on the circle tracing task (easy, hard) as a function of age (young, old). E: Easy; H: Hard. Standard error bars are included.

Figure 2. Number of rotations on the circle tracing task (easy, hard) as a function of serial subtraction difficulty (none, easy, hard). E: Easy; H: Hard. Standard error bars are included.

Figure 3. Dual task costs (speed) on the circle tracing task (easy, hard) as a function of age (young, old) and serial subtraction difficulty (none, easy, hard). E: Easy; H: Hard. Standard error bars are included.

Figure 4. Scatter plots of correlational analyses between speed and error rates for all circle tracing conditions for young and old participants. All correlations were significant ($p < .001$) suggesting speed-accuracy trade-offs for both groups.