Effects of Spatial and Nonspatial Memory Tasks on Choice Stepping Reaction Time in Older People

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Background. Studies comparing the effects of spatial and nonspatial secondary tasks on balance have produced conflicting results. However, in most of these studies the difficulty levels of the secondary tasks have not been matched. In this study, we compared the effects of carefully matched visuospatial (VS) and nonspatial (NS) secondary tasks on choice stepping reaction time (CSRT).

Methods. Forty-one older people (mean age 78.8 years) completed a CSRT test under five conditions: (i) no secondary task; (ii) an easy NS counting backward task; (iii) a difficult NS counting back task; (iv) an easy VS memory task; and (v) a difficult VS memory task. Response times and secondary task errors were measured for each condition. Participants also gave difficulty ratings for each secondary task.

Results. The difficult tasks were rated significantly more difficult than the easy tasks in both VS and NS conditions, and cognitive task errors were moderately correlated with perceived difficulty. A repeated-measure analysis of variance with planned contrasts revealed a significant effect of task type, with the VS condition slowing CSRT more than the NS condition. There was also a significant task difficulty effect with the more difficult tasks increasing CSRT.

Conclusions. The findings suggest that VS cognitive tasks affect CSRT more so than do NS tasks. The visuospatial sketchpad appears to be specifically utilized for carrying out motor tasks necessary for preserving balance. Practical implications are that tasks that require visuospatial attention and memory may adversely influence balance control in older people.

Key Words: Stepping—Reaction time—Attention—Balance control—Aged.
that are illuminated randomly, and thus body weight and balance transfers are similar to the step responses required to avoid many falls, particularly those as a result of late visual detection of hazards and unanticipated changes in the gait path. CSRT also has the advantage in that it lacks the variance of sway measures and is therefore useful for examining participant differences during different tasks (14). In this study, we examined whether VS and NS tasks, independently assessed for difficulty, differentially affect CSRT in older people.

**Methods**

**Participants**

Forty-one community-dwelling older participants (20 men, 21 women; mean age 78.8 years, standard deviation [SD] = 5.0) were recruited from a research database of participants held at the Prince of Wales Medical Research Institute. All participants were without cognitive impairment [i.e., a Mini-Mental State Examination (MMSE) (16) score of < 24]; a history of significant neurological, musculoskeletal, or cardiopulmonary disease; or uncorrected visual impairment. Participants were also, on average, at low to moderate risk of falls as indicated by Physiological Profile Assessment scores (17), and few reported a fear of falling. Demographic and health characteristics of the sample are presented in Table 1. The study was approved by the University of New South Wales Human Studies Ethics Committee, and all participants provided written informed consent prior to participation.

**CSRT**

The CSRT device consisted of a low platform (80 cm × 80 cm × 3 cm high) that contained six plates (32 × 13 cm): two base plates on which the participant stood and four stepping plates that could be illuminated in a random order (Figure 1). Participants were instructed to step as quickly as possible on to a plate when it became illuminated, to use the left foot only for the two left plates (front and side), and to use the right foot only for the two right plates. Participants stood with their feet 10 cm apart and in line with the two side plates. They stepped with their entire foot onto the illuminated plate to turn off the light, then moved their foot back to the standing plate at their own pace. There was no requirement to hold the landing posture for a minimum time interval.

The participants performed the CSRT task under five conditions: (i) with no secondary task; (ii) with an easy VS (VS-easy) task; (iii) with an easy NS (NS-easy) task; (iv) with a difficult VS (VS-diff) task; and (v) with a difficult NS (NS-diff) task. These conditions were administered in a random order with each comprising 20 trials with 5 randomly presented illuminations per plate. Sufficient time (usually between 5 and 10 seconds) was provided between trials for participants to re-establish their balance. Total testing time was approximately 30 minutes. All participants were routinely offered sitting breaks to reduce the possibility of fatigue; however, these offers were mostly declined.

Switches under the base plates were used to record CSRTs within 1-ms accuracy. Stepping errors (incorrect foot lift-off events) were also recorded by the base plate switches. Custom software developed using LabView 6.0 operated the device and acquired and processed the data (18). CSRT was measured in milliseconds from the time of panel illumination to the foot lift of the appropriate leg. A previous study investigating response time, movement time, and total reaction time demonstrated response time to be the only variable that differed significantly between old and young adult groups and between single- and dual-task conditions (15). The occurrence of incorrect foot lift-offs (i.e., when participants initially raised the incorrect stepping foot and then replaced it before initiating movement with the correct foot) was also recorded, and the increased time that resulted due to such errors in selecting the correct stepping foot was included in the response time. An assistant stood
near the participant to steady him or her in the event of a possible stumble. However, no participants stumbled or required additional steps to maintain stability after completing the stepping response.

Test–retest reliability for the CSRT test was determined in a separate sample of 27 older people who made up the control group in an exercise randomized controlled trial (19) that underwent the test on two occasions, 2 weeks apart. The intra-class correlation coefficient was 0.84 (95% confidence interval, 0.69–0.93).

Secondary Tasks

VS tasks.—The “visuospatial star movement” tasks were based on the Brook’s spatial memory task (9). These tests allowed participants to look directly at the stepping plates of the platform while performing the primary stepping task. The VS-easy task involved participants envisaging three boxes side by side labeled A, B, and C (as seen in Figure 2a). Participants were shown the empty boxes on a visual display during the explanation of the protocol and were asked to visualize a star located in one of the boxes making three movements. They then were allowed sufficient practice with and then without the visual display until they demonstrated that they understood the test requirements and scored five consecutive correct responses. The participants were told the starting position of the star and then the direction of the three movements, i.e., left or right. In the VS-diff task, participants were asked to visualize the star moving among four boxes arranged in a square (Figure 2b). The experimenter verbally delivered the starting position and four movements of the star, which comprised up, down, left, right, and diagonal moves. As with the VS-easy task, sufficient practice was provided, initially with and then without a visual display, until participants demonstrated that they understood the test requirements and scored five consecutive correct responses. Performance was recorded in terms of the number of trials in which the finishing position of the star was incorrectly reported.

NS tasks.—The NS memory tasks involved counting backwards. The NS-easy task involved counting backward by 3 starting from a random number between 20 and 50. The NS-diff task involved counting backward by 7 starting from a random number between 50 and 100. Sufficient practice was given in both tasks until participants demonstrated that they understood the test requirements and scored five consecutive correct responses. Performance was recorded in terms of the number of trials in which a counting error was made.

Perceived Difficulty Ratings

On completion of each VS and NS condition, participants were asked to provide an indication of how challenging they found the test to be, using a 10-point Likert scale (1 indicated very easy, and 10 indicated very difficult).

Test Protocol

The VS and NS tasks were performed concurrently with the CSRT task with participants looking down at the stepping plates. In the VS-easy task, a stepping plate was illuminated randomly after the experimenter delivered one, two, or three star movements. After the participant stepped, any remaining star movements were delivered and the participant was asked to report the finishing position of the star (i.e., box A, B, or C). In the NS-easy task, a stepping plate was illuminated randomly after the participant had counted backward one, two, or three numbers. After completing the step, he or she was asked to continue counting (if required) to complete four backward counts. In the NS-diff task, a stepping plate was illuminated randomly after the participant had counted backward one, two, three, or four numbers. Following the step, any remaining movements were delivered and the participant was asked to report the finishing position of the star (i.e., box A, B, C, or D). In the NS-diff task, a stepping plate was illuminated randomly after the participant had counted backward one, two, three, or four numbers. After the participant completed the step, he or she was asked to continue counting (if required) to complete four backward...
RESULTS

Task Type and Difficulty Effects

CSRTs (mean ± SD) for the five conditions were: Standard = 601 ± 97; VS-easy = 941 ± 274; VS-diff = 1162 ± 521; NS-easy = 807 ± 148; NS-diff = 930 ± 270. There was an overall condition effect (F\textsubscript{1,40} = 126.5, p < .001) with all dual-task conditions (VS-easy, VS-diff, NS-easy, NS-diff) producing significantly longer CSRTs than the standard condition (p < .05). The planned contrasts revealed a significant task difficulty effect (F\textsubscript{1,40} = 29.69, p < .001), with the more difficult tasks increasing response time. There was also a significant task type effect (F\textsubscript{1,40} = 17.33, p < .001), with the VS condition slowing response times more than the NS condition. There was no significant interaction effect between task type and task difficulty (F\textsubscript{1,40} = 1.08, p = .304).

Errors

The number of trials in which cognitive task errors were made (mean ± SD) were: VS-easy = 2.9 ± 2.8; VS-diff = 3.2 ± 2.7; NS-easy = 1.3 ± 1.7; NS-diff = 5.0 ± 4.6 (Kendall’s W = 0.30, p < .001). Post hoc tests revealed significant differences between the NS-easy and NS-diff conditions (p < .001), the NS-easy and the VS-easy conditions (p < .001), and the NS-diff and VS-diff conditions (p = .02). Cognitive task errors were moderately correlated with perceived difficulty: VS-easy (r = 0.43, p = .005), VS-diff (r = 0.24, p = .13), NS-easy (r = 0.47, p = .002), and NS-diff (r = 0.39, p = .12). Stepping errors (incorrect foot lift-off events) did not differ significantly across conditions (Kendall’s W = 0.18, p = .53).

Perceived Difficulty Ratings

Perceived secondary task difficulty ratings (mean ± SD) were: VS-easy = 3.1 ± 2.0; VS-diff = 5.0 ± 2.3; NS-easy = 3.4 ± 2.5; NS-diff = 6.4 ± 2.3 (Kendall’s W = 0.58, p < .001). As expected, the difficult tasks were rated significantly higher on the Likert difficulty scales than were the easy tasks in both VS and NS conditions (p < .001 in both cases). When comparisons were made across task types, there was no significant difference between the VS-easy and NS-easy conditions (p = .34), but a significant difference between the VS-diff and NS-diff conditions was observed (p = .001).

Figure 3 shows the mean (and standard error of the mean [SEM]) perceived secondary task difficulty ratings plotted against the mean (and SEM) response time on the CSRT task, in the five test conditions (Figure 3). The figure reveals that, although the NS tasks were perceived as being more difficult, the VS tasks had greater effects on CSRT.

DISCUSSION

The study findings support the hypothesis that VS secondary tasks interfere with postural tasks more than do nonspatial tasks and that it is not simply the degree of task difficulty that is responsible for compromised postural control. The differential effect of the VS task on CSRT found here is consistent with the working memory construct of Baddeley and Liebermann (21), which comprises a central executive system that coordinates and supervises two subsystems (the phonological loop and the VS sketchpad). Tasks requiring processing by the VS sketchpad, which is responsible for setting up and manipulating VS images, would interfere significantly with postural tasks, which also require VS processing. In contrast, tasks requiring processing by the phonological loop, which provides a store for speech-based information, would do so to a lesser extent.

Most previous studies have not matched difficulty levels well between differing secondary task types making conclusions with regard to differential effects of task type on postural control problematic. The results of one previous study that did achieve close matching of difficulty levels of
spatial and NS (verbal) tasks are in accord with our findings. That study, by Barra and colleagues (7), found that young participants had a higher frequency of falls from a narrow beam when undertaking spatial as opposed to verbal versions of the Stroop task. Support for the effect of VS interference tasks on CSRT also comes from cohort studies. In a large cross-sectional study of older people, we investigated neuropsychological, sensorimotor, speed, and balance contributions to CSRTs (14). We found that performances in four neuropsychological tests assessing cognitive processes relevant to spatial working memory and attention were significantly associated with CSRTs. These included motor persistence, sustained attention, response speed, and visuomotor coordination (Digit Symbol) (22); visual conceptual and visuomotor tracking (Trail Making Test parts A and B) (22); and ability to cope with response conflict and selective attention (STROOP Color Word) (23). Holtzer and colleagues (24) also found that a Speed/Executive Attention factor derived from the neuropsychological tests that are timed and visually mediated (Block Design, Digit Symbol, and Trail Making Test parts A and B) was uniquely related to gait velocity.

It is acknowledged that matching differing cognitive tasks with respect to test administration and difficulty levels is by nature problematic. In the current study, only the NS task involved verbalizing, which may differentially influence balance control (25). It can also not be ruled out that some participants used visualization to perform the serial subtraction task although it is highly probable that visualization was used to a lesser extent compared with the starmovement task. To avoid comparing tests of differing difficulties, we asked participants to rate each test, rather than assuming equivalence. We also recorded the number of errors in each task to provide an additional difficulty measure. As expected, the difficult tasks were rated significantly higher on the Likert difficulty scales than were the easy tasks in both VS and NS conditions. The VS-easy and NS-easy conditions were rated similarly, but the VS-diff condition was rated more difficult than the VS-diff condition. This pattern was mirrored with respect to cognitive task errors. The greater difficulty ratings and increased errors in the NS-diff condition, however, only strengthens the conclusions regarding the differential effects of spatial tasks on balance (i.e., if the converse were the case, it might simply mean that the more difficult secondary task had a proportionately greater effect on CSRTs).

A possible alternative interpretation is that the participants used different strategies in the NS and VS conditions, that is, prioritizing the primary response time task in the NS conditions and the secondary task in the VS conditions. Given the similar delivery of the secondary tasks presented both before and after onset of the stepping stimulus, it seems unlikely that this was the case.

It is also acknowledged that although the population studied was healthier older adults and the MMSE scores suggest that none of the participants had dementia, it is not possible to rule out preclinical dementia, which may have influenced the results. Further research is required to elucidate demographic, neuropsychological, health, and lifestyle factors that may differentially affect CSRT performance in the dual-task conditions.

Conclusion

Our results suggest that VS cognitive tasks affect CSRT performance more so than do nonspatial tasks. The VS sketchpad appears to be specifically used for planning and/or carrying out motor tasks that are necessary for preserving balance. Although these findings relate primarily to elucidating cognitive processes relating to balance control, they may also have practical implications in that they suggest that tasks requiring visual attention may disproportionately influence balance control in older people. This may be particularly relevant to older people with sensory deficits and/or neuropsychological impairments and to persons at increased risk of falls, as it has been shown that these groups require higher attention levels for balance control (1.3–5,10,14,26).

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