Tracking and Visuospatial Working Memory

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The present research examines the role of visuospatial working memory in supporting pursuit tracking. Participants completed a pursuit motor tracking task while simultaneously completing secondary tasks designed to separately place demands on either storage or processing in visuospatial working memory. The results show that simple pursuit tracking utilizes visuospatial processing in working memory without a strong requirement for visuospatial storage. These findings have implications for understanding time-sharing of tasks in the cockpit.

The ability to track moving objects is critical to supporting a number of tasks in the cockpit, including but not limited to, maintaining a flight path, pursuing other aircraft, as well as monitoring and maintaining flight parameters such as an aircraft's attitude. Research has demonstrated that object tracking requires substantial cognitive resources (Pylshyn & Storm, 1988) and a link has been made between tracking and visuospatial working memory (Baddeley & Logie, 1999). It has also been shown that performance on pursuit motor tracking tasks is sensitive to interference from other cognitive tasks (Mastoianni & Schopper, 1986). The objective of the present research was to examine what aspects of visuospatial working memory are involved in pursuit motor tracking.

Working memory is used to temporarily store and manipulate information and has been described in terms of a multicomponent model that includes a central executive, a phonological loop, and a visuospatial sketchpad (Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Baddeley, 2011). The central executive is a limited capacity system that controls the allocation of the attentional resources that support task performance. The phonological loop and visuospatial sketchpad are limited capacity storage and processing systems for verbal and visual information, respectively. A large body of research has examined the phonological loop. This research has shown that the phonological loop can be divided into two distinct subsystems: a phonological store and an articulatory rehearsal (processing) mechanism (Baddeley, 2001). It has been suggested that tracking is supported at the visuospatial sketchpad component of working memory (Baddeley & Logie, 1999) and that the sketchpad can also be subdivided into two subsystems: a visual cache for storage and an inner scribe for processing visuospatial information (Logie, 1995).

In pursuit motor tracking, participants are required to locate and monitor the changing position of a moving target while generating and executing a series of motor commands to maintain alignment with the moving target. This task requires constant online processing of the visual target and is therefore assumed to involve the visuospatial sketchpad's inner scribe subsystem. The inner scribe is thought to process information about spatial relationships and motion (Logie, 1995). Since tracking does not require participants to store information about a moving target's previous locations, pursuit tracking is viewed as a relatively pure processing task that places little, if any, demand on the visual cache (storage) subsystem.

In the present research, participants performed a pursuit motor tracking task in baseline and dual-task conditions. Two dual-task conditions were used. In one of the dual-task conditions tracking was combined with a visuospatial *storage* task. In the other dual-task condition, tracking was combined with a visuospatial *processing* task. It was hypothesized that relative to baseline performance, tracking performance would decrement more when combined with the visuospatial processing task than with the visuospatial storage task.

Method

Participants. Twenty-three undergraduate university students participated in the experiment. Participants had normal or corrected-to-normal vision. Three participants were dropped from the final analysis because their performance was found to be at or below chance for one or more of the experimental blocks, resulting in a final sample of 20 participants.

Materials. The target was a 5x5 moving grid (300x300 px) in which a single moving dot (processing task) or a pattern of dots (storage task) was presented. During pursuit tracking conditions a participant-controlled cursor consisting of a red-hashed outline of the grid was displayed (See Figure 1). Stimuli moved according to sinusoidal functions for X and Y motion such that the grid moved in a pseudorandom figure 8 pattern. The target grid moved at a maximum speed of 300 px /sec on the x- and y-axes while the participant-controlled cursor moved at a maximum of approximately 1360 px/sec on the x-axis and 650 px/sec on the y-axis. The cursor was purposefully programmed to move faster than the target to ensure that participants could catch up with the target.

Cursor inputs and storage/processing task responses were collected with an Xbox 360 controller connected to a Dell XPS computer. The experiment was coded in C++ using OpenGL and SDL libraries and was presented on an Asus V678H 120Hz 27-inch LCD monitor. Tracking performance was recorded as the Euclidian distance between the target grid and the cursor, sampled at 10 Hz. Performance on the visuospatial tasks was recorded as button-press responses on the direction pad of the game controller. Joystick sensitivity was set at a fine grain to ensure that the tracking task would be challenging - even for individuals with considerable experience using the controller.

Tasks. The experiment consisted of three baseline (single-task) conditions (tracking, visuospatial storage, visuospatial processing) and two dual-task conditions (tracking + visuospatial storage, tracking + visuospatial processing). Each condition consisted of forty 15-second trials, each of which were initiated at participants' press of the right joystick button. All blocks were preceded by practice trials.

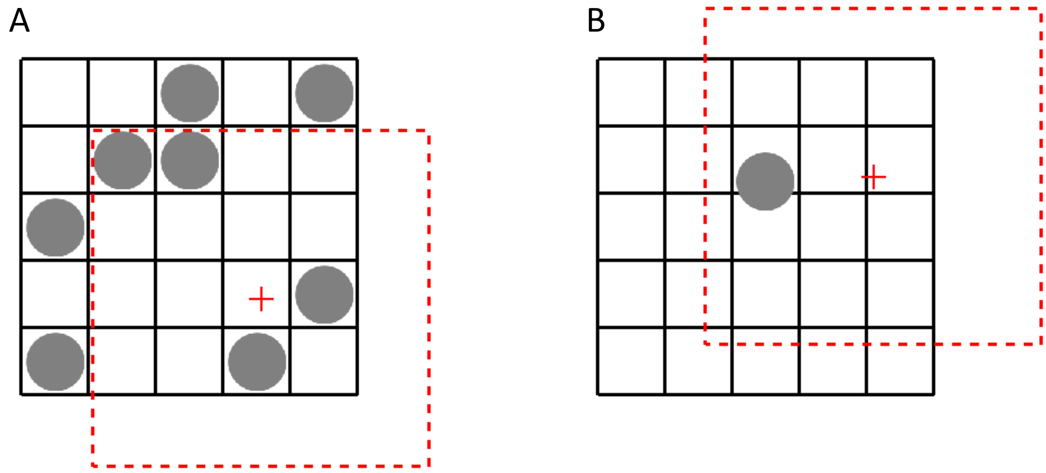

Figure 1. Depictions of the 5x5 target grid and the red participant-controlled cursor used in the dual-task conditions: Storage (A) and Processing (B). In the single-task tracking condition, no dots were displayed in the target grid (not depicted).

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For the tracking task, participants were instructed to use the controller's right joystick to position the cursor such that it overlapped the target grid. Each trial started with both the target and the cursor aligned at the center of the screen. After a 500ms delay the target would begin moving in one of four possible directions and participants would be attempt to follow it with the cursor. For the first 1000ms the target speed was increased exponentially from 0 to its maximum speed to allow participants to accommodate.

In the single-task visuospatial storage condition eight dots were presented for 1500ms in randomly selected cells of the 5 x 5 target grid and were then removed. Participants were instructed to maintain a visual image, or 'mental snapshot', of the dot pattern during a 7-second retention interval. Following the retention interval a second eight-dot pattern was presented for 1500ms and participants were to indicate via a button-press response whether this was the same or different from the first pattern. On half of the trials the second dot pattern was identical to the first pattern. On the other half, one dot had been moved by one cell. The dual-task visuospatial storage condition was identical to the single-task condition described above, except that participants had to track the target while simultaneously performing the storage task.

The processing task was specifically designed to index visuospatial processing without placing any demand on storage. In the single-task visuospatial condition, participants were required to monitor the up-down motion of a single dot located in the target and to make button-press responses each time the dot changed direction. The up and down keys of the controller direction pad were used. Participants were to quickly and accurately make up-down responses that followed the directional changes of the dot. At the start of each trial the dot was stationary for 1500-2000ms, after which it would begin moving either upwards or downwards. The dot would continue in one direction of motion for 1000-2000ms moving at a rate of 100 px/sec and changed direction 7-10 times per trial. To prevent participants from anticipating a directional change, the dot would either switch direction somewhere within the borders of the grid, or it could roll through the upper or lower border of the grid and wrap around to the opposite side to continue its direction of motion. The dual-task visuospatial processing condition was identical to the single-task condition described above, except that participants had to track the target while simultaneously performing the processing task

Procedure. Participants completed an informed consent form and were given detailed instructions and a practice block before each of the five experimental conditions. Participants repeated the practice trials prior to each condition until they attained at least 60% accuracy. Each participant began with the baseline tracking task, followed by one of the baseline (single-task) visuospatial tasks and then the corresponding dual-task condition. After completing the baseline and dual-task conditions for one of the visuospatial tasks, participants would complete the other baseline visuospatial task and its corresponding dual-task condition. The order of the visuospatial task conditions was counterbalanced such that half of the participants received the storage condition before the processing condition, with the other half receiving the reverse order.

Results

Tracking performance was measured as Root Mean Square Error (RMSE) of the Euclidean distance between the moving target and the participant-controlled cursor. The lines of data from the start of each trial to the point where the target attained maximum speed were discarded. A one-way ANOVA with 3 levels (Condition: baseline tracking, dual-task tracking + visuospatial storage, and dual-task tracking + visuospatial processing) was used to analyze the tracking data. There was an overall effect of Condition, $F(2,38) = 12.92$, $MSE = 108.01$, $p < .001$, $\eta_p^2 = .41$, (see Figure 2). Paired samples *t*-tests showed that tracking error was greater in the dual-task visuospatial processing condition than in both the baseline tracking, $t(19) = 4.23$, $p < .001$, and the dual-task visuospatial storage conditions, $t(19) = -3.70$, $p = .002$. Tracking error did not differ between baseline tracking and dual-task visuospatial storage conditions, $t(19) = 1.02$, p= .320.

A full analysis of the visuospatial task performance is not included here. However, performance on the visuospatial tasks did not compromise the interpretation of the tracking results. In brief, performance on the visuospatial storage task did not differ between the baseline (single-task) and dual-task conditions. In contrast, performance on the visuospatial processing task was worse in the dual-task condition than in the baseline (single-task) condition.

Discussion

Tracking has long been used as an in-lab analog to investigate aircraft flight performance, where both tasks require constant attention and information updates about object motion in conjunction with online motor planning and correction. The present research examined the nature of the demands that pursuit motor tracking places on visuospatial working memory. Using the multicomponent model of Working Memory as a framework (Baddeley, 2001; Baddeley & Hitch, 1977), a tracking task was combined with working memory tasks designed to place

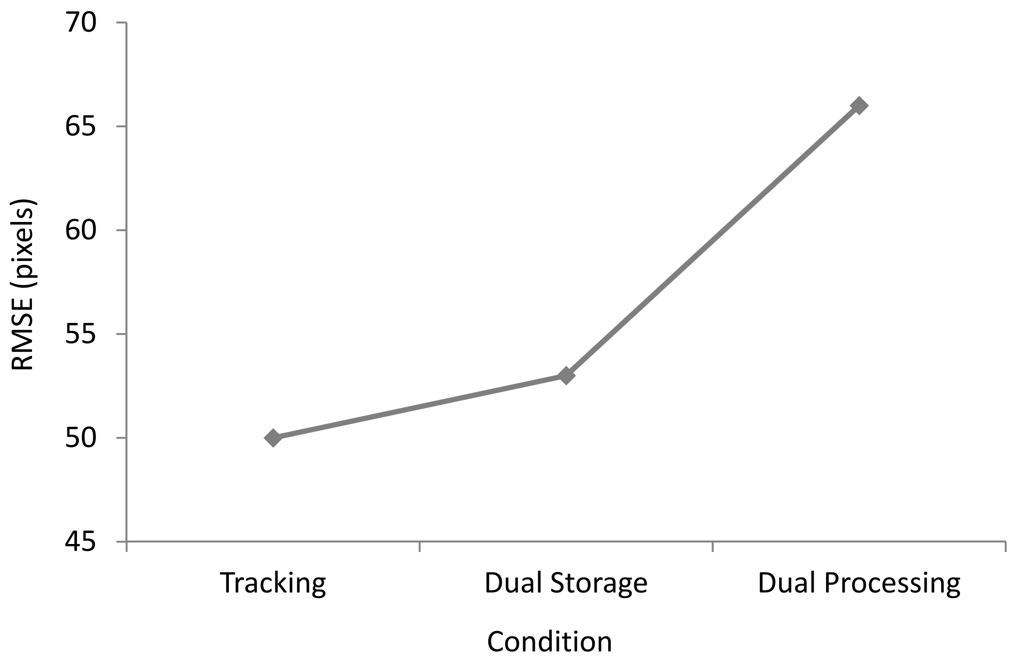

Figure 2. RMSE tracking performance (in pixels) between the target and the cursor as a function of Condition (baseline tracking, dual-task tracking + visuospatial storage, and dual-task tracking + visuospatial processing).

specific demands on either visuospatial storage (remembering a dot pattern) or visuospatial processing (detecting the directional change of a dot).

Participants were able to simultaneously perform the tracking task in combination with the visuospatial storage task without incurring any performance decrements relative to baseline performance levels. In contrast, tracking performance decremented significantly from baseline when combined with the visuospatial processing task. Because pursuit tracking is a continuous processing task, it can be considered as a visuospatial analog to articulatory suppression. Studies using articulatory suppression to specifically load the articulatory loop have provided evidence for a distinct and separable storage and processing subsystems in phonological working memory (see Baddeley & Hitch, 1994). By using pursuit tracking to continuously load the inner scribe, the present findings represent some of the strongest behvaioural evidence for Logie's (1995) suggestion of a delineation of storage and processing in the visuospatial sketchpad.

Following the assertion of distinct storage and processing subsystems, the present findings suggest that certain in-flight task that utilize the visuospatial processing component of the visuospatial sketchpad may interfere with a pilot's performance on tasks requiring pursuit tracking in the cockpit. Tasks that compete for resources in the inner scribe of the sketchpad will interfere with a pilot's ability to maintaining a flight path or flight formation, pursue other aircraft, as well as monitor and maintain flight parameters. In contrasts, tasks that utilize the visuospatial storage component of the visuospatial sketchpad are not likely to interfere with a pilot's performance on pursuit motor tracking in the cockpit.

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