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RESEARCH ARTICLE

Dual-task performance during a climbing traverse

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Abstract High-angle climbing is a physically and cognitively challenging activity. Whilst researchers have examined the physiological demands of climbing, the cognitive demands have been relatively neglected. In this experiment, we examined the performance of climbers when required to perform a dual climbing and word memory task, relative to single-task performance (word memory or climbing alone). Whilst there was no significant decrease in climbing distance during the dual-task condition, climbing efficiency was impaired, as was word recall. Participants' Energetic Arousal, Tense Arousal and Task-unrelated Thoughts (TUTs) all changed dependent on the condition, with arousal increasing after the climbing conditions, and TUTs decreasing after the memory-load conditions. These results could be expanded on in future research to examine the physical and cognitive demands of high-angle climbing in greater detail.

Keywords Attention · Dual task · Climbing · Skill · Word recall

Introduction

Climbing is a physically and psychologically demanding sport that involves moving vertically upwards or horizontally across a climbing surface via a succession of static and dynamic phases (Bourdin et al. 1998; Morrison and Schöffl 2007). A climb can be made in a number of different styles, including: (a) lead climbing, where the climber clips a safety rope through a series of bolt anchors along the route; (b) top rope climbing, where the safety rope passes through a top anchor that returns to a belayer (a partner who stands at the base of the route and protects the climber in case of a fall); and (c) bouldering, where the route is climbed without a rope, but usually with a protective bouldering mat underneath the climber (Draper et al. 2010; Sheel 2004).

Research has focused primarily on climbers' physiological responses to the physical demands of the climb (Sheel 2004). On top of the significant physical demands, climbing is also psychologically challenging, often requiring the climber to manage the arousal of a difficult and sometimes unknown route, plan which holds to use and which moves to use to reach those holds, and overcome potential anxiety regarding falling or possible injury (Morrison and Schöffl 2007). More recently, research has started to examine the psychological factors involved in climbing and how these influence both a climber's physiological responses and overall performance (Draper et al. 2008). Given the exposure to falls in climbing, this research has focused on emotion and anxiety as psychological factors (Hardy and Hutchinson 2007; Hodgson et al. 2009; Nieuwenhuys et al. 2008; Pijpers et al. 2003, 2005). Despite the growing focus on the role of psychological factors in climbing, there has been little research examining cognitive processes during climbing, for example, the costs of dual-tasking. This gap is troubling as there are a number of applied settings where individuals may need to climb whilst under additional cognitive load. These settings include not only recreational climbing, where for example the climber needs to also communicate with their belayer, but also high-angle search and rescue and some military-law enforcement operations.

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There have been many studies that have examined changes in cognition, both during and post-exercise (for a review, see Tomporowski 2003). Whilst the cognitive tasks used to assess the influence of exercise on cognition vary greatly, making it more difficult to generalize any effects, the physical activities used tended to be cyclic exercises, such as walking, running or cycling (Brisswalter et al. 2002; Tomporowski 2003). Well-rehearsed skills such as these are generally considered to be 'automated', requiring minimal online attention and control and operating mainly outside of working memory (Beilock et al. 2002a, b). The results of Bourdin et al. (1998) indicate that maintaining a static climbing position requires greater attention than standing upright on the ground and that the attention demands of a reaching movement in a climbing position nearly double compared with remaining static, even in expert climbers. It would appear that climbing demands greater online attention and control than many other physical activities would.

Research indicates that a simultaneous cognitive task interferes with the act of walking. Gait speed has been shown to reduce when having to perform an additional cognitive task (Lindenberger et al. 2000; Yogev-Seligmann et al. 2010). Yogev-Seligmann et al. (2010) showed that not only do participants reduce gait speed during a dual-task condition, but they also recall less words in the simultaneous memory task compared with when they are sitting or standing. Most dual-task studies show greater detriments to the secondary cognitive task than to the primary movement task during dual-task studies. The participants prioritize postural stability, the posture-first hypothesis (Shumway-Cook et al. 1997). Not every study, however, demonstrates secondary cognitive task costs from engaging in cyclic exercise activity. Researchers have suggested in some cases that a net boost in resources (cortical arousal) due to exercise enhances cognitive activity (see Schaefer et al. 2010). Nevertheless, the beneficial results of exercise-induced arousal should be outweighed when the exercise activity places high demands on cognitive resources. Indeed, researchers have found that making a walking task more challenging by elevating the walking platform, restricting movements, or adding obstacles, substantially increases the dual-task costs of constrained walking (Gage et al. 2003; Sparrow et al. 2002; Siu et al. 2008). If a simultaneous cognitive task causes interference in an activity that is cyclic and fairly automatic, like walking, we should expect it to cause significant interference in a physical activity that demands greater attention, like climbing, where the climber is constantly at risk of postural instability (e.g. falling).

In order to investigate how much interference occurs when a climber is required to perform a simultaneous cognitive task, we examined the performance of climbers when they were required to perform a dual climbing and auditory word recall task, compared with performing each task individually. Whilst a number of secondary tasks could be used, free recall of auditory words has high ecological relevance. There are a number of settings in which a climber may need to recall information told to the climber whilst climbing at a later time. Not only is this the case potentially in recreational climbing, where the climber is in verbal communication with the belayer, but may also occur in search and rescue operations. Multiple resource theory would suggest less interference between an audio task, such as free recall for audio words, and a visual task, presumably route finding in climbing, than for example two visual tasks (see Wickens 2008). Nevertheless, given the demanding nature of climbing, we suspected climbing would consume many cognitive resources including central attention resources. In a previous study, we found a demanding spatial working memory task interfered with a demanding verbal target detection task (Helton and Russell 2011). Demanding tasks are likely to demand more cognitive resources overall (see Helton et al. 2010).

We hypothesized that participants would either climb less distance or climb less efficiently (or both) in the dual-task condition as the memory task should have an attention cost for climbing efficiency. We expected, however, greater interference of the climbing task on memory performance as the climbing task should be prioritized even without instructions. Previous research involving walking and maintaining balance has demonstrated that people prioritize these tasks over secondary cognitive tasks due to the need to prevent personal injury (Shumway-Cook et al. 1997). This should be even more of a priority above the ground during climbing.

Participants also completed four scales of the Dundee Stress State Questionnaire (DSSQ; Matthews et al. 1999; Matthews et al. 2002), which assesses arousal and thoughts occurring during the tasks. We hypothesized elevated arousal (tense and energetic) following the climbing conditions, as climbing puts the climber at relative risk. We also hypothesized decreases in Task-related and Unrelated Thoughts in the memory-load conditions, as the cognitive load should suppress cognitive intrusions (both Task-related and Task-unrelated). All of these changes should be relative to the initial pre-task baseline levels.

Method

Participants

Participants were twelve (9 men, 3 women) climbers. The mean age of participants was 22.67 years (SD = 4.31 years). In order to participate, participants needed to have enough climbing experience to successfully climb at least an Australia/New Zealand grade 17 indoor climbing route top-roped. New Zealand and Australia use the Ewbank grading system, which is an open-ended system based on the technical difficulty of the climb. There is neither a unanimous consensus regarding the categorization of climbing grades, nor how grades on differing international grading systems compare across one another. However, using participants who could successfully climb grade 17 walls (and were now working on at least grade 18 walls) meant that participants were climbing at an intermediate level or higher (Brent et al. 2009). Although participants were bouldering, rather than performing a top-roped route climb, participants' climbing ability was assessed based on a top-roped grade as participants tended to be a lot more familiar with this grading system than the bouldering grading system. All participants were fluent speakers of English.

Materials

The experiment was run using the indoor climbing wall at the University of Canterbury Recreation Center. The area of the wall used for the experiment was 8.25 m in length. As participants were not harnessed, the height of the wall was restricted to a black-taped line set at a height of approximately 3.3 m. No free climbing done above this height was allowed. The wall contained numerous and differing holds, including larger jug holds and smaller jib holds. Some sections of the surface of the wall were also slightly raised, allowing for additional climbing support. The base of the climbing wall area was surrounded with a bouldering mat to cushion any fall. See Fig. 1 for a picture of the climbing wall.

The words used for the memory tasks were generated from the Paivio et al. (1968) Word Pool. The word pool contains 925 nouns. Three word lists, each containing 20 words, were generated. The generated words were randomly allocated to one of the three word lists. In order to ensure that each word list contained words that were equally memorable, the range of each of the variable parameters was restricted as follows: Number of syllables: 2; Number of letters: 5–7; Kucera-Francis word frequency: 0–30; Concreteness rating: 6–7; Imagery rating: 5–7; and Meaningfulness: 6–8. The word lists were recorded onto a computer using a Behringer C-1 studio condenser microphone and the recording program Ableton Live. The words were recorded using a New Zealand male speaker. In order to create the scrambled word lists, the recorded sound track of each word was cut into segments and rearranged using the Ableton Live program to create words that were no longer recognizable as English speech. The recorded word lists were played to participants using Altec Lansing 121I dual speakers.

The study employed four scales of the Dundee Stress State Questionnaire (DSSQ; Matthews et al. 1999; Matthews et al. 2002). The four scales were Energetic Arousal (EA), Tense Arousal (TA), Task-related Thoughts (TRT) and Task-unrelated Thoughts (TUT) and were used to measure self-reported subjective states. DSSQ instructions emphasize immediate reporting by the participant to ensure reporting of task-related state experiences, rather than traits.

Procedure

Upon arrival at the climbing wall, participants were provided with an information sheet outlining the purpose of the experiment. Participants were informed that they would be required to complete three separate conditions: a seated memory task; a traverse climbing task; and a dual traverse climbing task and combined memory task.

Before completing any of the conditions, participants first warmed up by traversing back and forth along the climbing wall, giving participants experience with the layout and particular holds on the wall. Participants brought their own climbing shoes. Once participants stated

Fig. 1 Pictures of the climbing traverse route

that they were sufficiently warmed up and familiar with the climbing wall, participants came down off the wall and completed the pre-task DSSQ. The pre-task DSSQ was administered prior to the participant commencing the first condition and asked the participant to report experienced thoughts and feelings of the last 10 min.

For the memory task, participants were instructed to sit on the bouldering mat at the base of the wall, facing the wall. Participants were informed that they would be played 20 words over a 3-min period and that they would be asked to recall as many of the words as they could at the end of the 3 min. The start of the task was indicated to participants by a high-pitched tone, preceded by three lower pitched tones. The words were played over the speakers set up at the back wall of the climbing room, approximately 5 m from the main climbing wall. The first word of the word list was played to participants 14 s into the task, with subsequent words played every 8 s. After the final word was played, there was an additional 14 s of silence before another high-pitched tone signalled the end of the 3 min. Following the final tone, participants were instructed to write down as many of the 20 words as they could recall on the paper that was provided to them. Participants were given 90 s to recall as many of the words as they could.

For the climbing task, participants were instructed to take position on the left side of the wall where the main climbing wall met the adjoining side wall (see Fig. 1). Participants were instructed to have their left hand and left foot on separate holds on the adjoining wall, and their right foot and right hand on separate holds on the main climbing wall. The task would begin once the participant stated that they were set and ready. The start of the climbing task was signalled by a higher pitched tone, preceded by three lower pitched tones. Upon hearing the higher pitched tone, participants began traversing right towards the other end of the main climbing wall. Participants were instructed that they were able to make use of any hold, and that they were told to ascend as high as the 3.3 m height black tape line that indicated the maximum safe free-climbing height. Participants traversed across the climbing wall until they reached the final major panel on the right side of the wall. Once the participant had both hands and feet on separate holds in the far right panel, they were instructed to traverse back towards the left side of the wall. Once the participant had made it back across to the far left side of the wall, they were instructed to ensure that they had both hands and feet on separate holds within the far left panel of the wall, before once again traversing back towards the right side of the climbing wall. If, at any stage, the participant came off the wall, they were instructed to climb back to the location where they had come off and then continue with the traverse. Participants performed the continual traverse climb for 3 min. During the climb, participants were played 20 scrambled words from one of the scrambled word lists. The scrambled words were the same words from the original word lists; however, the sound file of the recorded spoken words had been cut and spliced so that the original words were no longer recognizable. The scrambled words were played to participants across the same speakers located at the back wall. The scrambled words were used, so that participants were receiving auditory input during the task. However, as this auditory input lacked meaning, it was expected that these words would be less likely to interfere with participants' climbing than meaningful words. Participants were instructed that they would not be required to recall anything they heard during the climb. As in the memory task, the first scrambled word was played 14 s into the task, with subsequent scrambled words being played every 8 s. After the final scrambled word was played, there was another 14 s of silence before a high-pitched tone signalled the end of the task. Upon hearing the tone signalling the end of the task, participants were instructed to come off the climbing wall. Participants were filmed during the climbing task in order to count the total number of hand and foot holds that participants used during the climb. The total horizontal distance climbed was measured based on the number of climbing wall panels each participant crossed during the climb. The wall consisted of six 1,200-mm panels and one 1,050-mm panel. At the end of the 3 min, the final location of the participant was measured by taking the average distance between the two holds on which the participant had their feet located when the final tone sounded. The measurement between the holds was taken from the point on the hold where the bolt anchored it to the wall.

The dual-task condition involved a combination of the memory task and the climbing task. Participants received the same instructions as they did in the climbing task. However, instead of scrambled words, participants were played 20 regular words during the 3 min they were climbing (as in the memory task, there was a 14-s silence before the first word was played, with subsequent words played every 8 s, and a 14-s pause after the final word). Before the task, participants were told to remember as many words as they could because they would be asked to recall them at the completion of the climb. Upon hearing the tone signalling the end of the 3 min, participants came down off the wall and immediately wrote down as many of the words as they could recall on the paper provided. As in the memory task, participants were given 90 s for recall. As in the climbing task, participants were filmed during the dual task to assess the total number of holds each participant used during the climb. The total horizontal distance climbed was also measured.

Upon completing each condition, participants completed the post-task DSSQ. The post-task DSSQ asked participants to self-report thoughts and feelings they experienced during the task. The order in which participants completed the conditions was counterbalanced, as were the word lists used for each condition. Participants were given at least 5 min between climbing tasks to minimize the effect of fatigue on the second climb, with the option of taking longer if needed. However, due to the relative ease of the climb and the level of climbing ability of the participants, no participant reported any significant fatigue before starting the second climb.

Results

Performance

For performance comparisons between the three conditions, we employed one-tailed directional *t* tests, as we had a priori directional hypotheses. We examined differences in memory performance (total number of words recalled correctly), climbing efficiency (number of holds per metre climbed) and total climbing distance (metres). As expected, free recall memory performance was significantly better in the memory-only condition ($M = 11.83$, $SD = 2.73$) than in the dual-task condition ($M = 6.00$, $SD = 2.30$), $t_{11} = 10.14$, $P < 0.001$, Cohen's $d = 2.31$. As expected, climbing efficiency was better in the climbing-only condition ($M = 5.80$, $SD = 2.50$) than in the dual-task condition ($M = 6.28$, $SD = 2.34$), $t_{11} = 1.94$, $P = 0.040$, Cohen's $d = 0.20$. Total climbing distance was not, however, significantly different between the climbing-only ($M = 27.60$, $SD = 11.11$) and the dual-task conditions ($M = 25.79$, $SD = 11.40$), $t_{11} = 1.49$, $P = 0.082$.

Subjective state

Each DSSQ scale was analysed for differences across the four time points (pre-task baseline, post-climb, post-memory and post-dual-task) with a repeated measures analysis of variance. These analyses were significant for Energetic Arousal, $F_{3,30} = 3.52$, $P = 0.027$, Tense Arousal, $F_{3,30} = 4.44$, $P = 0.011$, and Task-unrelated Thoughts, $F_{3,27} = 4.67$, $P = 0.009$. The analysis for Task-related Thoughts was not significant, $F_{3,27} = 0.28$, $P = 0.842$. We calculated individual change scores for each scale for each participant for each task condition using the formula, *d = (individual post-score − individual baseline-score)*, as has been performed in the previous studies (Helton et al. 2000; Helton and Warm 2008; Stevenson et al. (in press); Szalma et al. 2006). Since all the self-report items were measured on the same response scale (e.g. 1–5), the raw (unstandardized) change scores were used as recommended (Rogosa 1995). The summary results of this data are presented in Fig. 2. In the figure, zero represents no change from pre-task baseline and the error bars are 95% confidence intervals. This enables a clear perspective on how the DSSQ scales changed relative to the pre-task baseline measures for each task.

In addition, for descriptive purposes, we calculated the Pearson correlation coefficients between the post-task subjective state measures and the relevant performance metrics from the task performed. These results are presented in Table 1. As can be seen in Table 1, there was a significant relationship between Task-related Thoughts and climbing performance in the single-task condition. Those who reported more Task-related Thoughts climbed less distance and climbed less efficiently (more holds per metre climbed).

Discussion

The main finding of this study is that when performing the dual climbing and memory task, participants' climbing efficiency and free memory recall significantly decreased compared with performing the climbing and memory tasks alone. The decrease in free memory recall was particularly large. Relative to the single memory task condition, there was a 50% decrease in recall performance during the dual-task condition. Anecdotally, participants reported finding memory recall in the dual-task condition more difficult than they had expected, even for the most experienced climbers in the study. This decrease in recall indicates that it is difficult to remember information provided whilst climbing, consistent with the results of Yogev-Seligmann et al. (2010). The increased memory load also impairs climbing performance, with participants using more holds per metre climbed in the dual-task condition. These findings are consistent with those of Nieuwenhuys et al. (2008) and Pijpers et al. (2005) who found that climbing efficiency

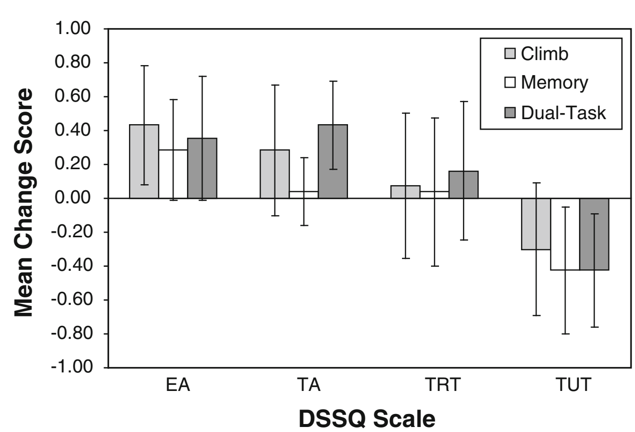

Fig. 2 The mean post–pre DSSQ change scores for the three task conditions (*error bars* are 95% confidence intervals)

Table 1 Correlations of post-task state and performance metrics ($N = 11$)

	$Memory_{single}$	$Distance_{single}$	$Holds/m_{single}$	$Memory_{dual}$	$Distance_{dual}$	$Holds/m_{dual}$
Energetic Arousal	0.16	0.58	−0.36	−0.07	−0.01	0.02
Tense Arousal	−0.34	−0.38	0.39	−0.08	−0.24	0.15
Task-related Thoughts	−0.55	**−0.82**	**0.71**	−0.34	−0.57	0.49
Task-unrelated Thoughts	−0.22	0.07	−0.27	−0.18	−0.27	−0.03

Note: Bold $P < 0.05$

decreased when climbers had to process higher levels of anxiety.

Whilst the increased memory load of the dual task decreased climbing efficiency, a significant decrease in climbing distance did not occur, as was hypothesized. A plausible explanation for this is that participants gave priority to the climbing task. Whilst participants were not instructed to prioritize either task in the dual-task condition, not climbing well would put the climber at the risk of falling. Climbing would naturally be prioritized, and this finding is inline with previous results indicating walking and standing are also given priority when combined with cognitive tasks (Shumway-Cook et al. 1997). We also note that the direction of difference in climbing distance was in the expected direction. Perhaps, the climbers took more conservative positions on the wall during the dual-task condition to enhance their detection of the auditory words themselves. Researchers should in the future more carefully investigate the changes in climbing kinematics during dual-task cognitive load.

Despite not finding a significant difference in climbing distance between the dual-task and climbing-only conditions, it could be expected that a difference would occur over a greater climbing distance. Elite climbers have reported that jerky movements, such as may occur when reaching for closer holds, hinder overall performance (Ferrand et al. 2006). A decrease in climbing efficiency, as a result of the dual task, would likely result in greater physical fatigue as the climber makes more frequent movements to cover the same distance. Had participants climbed for a greater period than 3 min, then the effects of decreased climbing efficiency may have resulted in significantly less total distance climbed in the dual-task condition.

Results from the DSSQ indicate that climbing increased Energetic Arousal relative to pre-task baseline. The dual-task condition elevated Tense Arousal relative to baseline. The memory load that occurred in both the memory and dual-task conditions appeared to suppress Task-unrelated Thoughts. No significant change was found in Task-related Thoughts between conditions. Intriguingly, elevated self-reports of Task-related Thoughts were related to climbing less distance and climbing less efficiently (more holds per metre climbed). This only was significant in the single climbing task condition. However, the correlations were in the same direction in the dual climbing task condition. This may provide support for the proposal that skill-directed attention may actually be counterproductive for experienced performers (Beilock et al. 2002a, b). There is evidence that skill-directed attention can result in performance choking in more skilled performers. The climbers employed in the present experiment were experienced climbers. The approach employed in the present experiment of looking at relationships between subjective states and performance may be useful in resolving this and related issues in future studies. This approach has begun to be used in laboratory studies of cognitive tasks and has provided informative results (Helton et al. 2009).

From a practical perspective, the results of this study are not only of importance to recreational climbers but may also have implications for military and high-angle search and rescue operations. The nature of search and rescue work is extremely varied. However, some operations will require the search and rescue worker to navigate terrain in a manner that will make similar physical demands as recreational climbing. Search and rescue workers will also be in remote contact during such operations and will be receiving auditory information that may need to be remembered. The results from this study lead us to suspect that the performance of a task that makes both physical demands (such as climbing down a rock face or into a collapsed building to retrieve a person) and psychological demands (such as planning the best route to take) is going to suffer when the person must also attend to auditory information. Similar situations would also occur in some military or law enforcement operations. If an auditory task is disrupted so greatly by a climbing task (e.g. a 50% loss of information), we suspect given multiple resource theory (Wickens 2008) even more substantial interference from a secondary visual task during climbing. Given the potential use of heads-up displays in search and rescue, military and law enforcement operations, this possibility should be explored in future studies.

This study did have limitations. Due to the need for a consistent measure of climbing distance, only the total horizontal distance climbed by participants was measured (as this was aligned with task instructions to maximize horizontal distance). As participants also climbed some vertical distance, this may have had an impact on the total distance climbed. Any similar future research may wish to measure vertical distance climbed, as well as horizontal distance.

Future research should examine climbing performance by manipulations of the qualitative content of the secondary memory load. For example, a secondary task that elicited negative emotional processing (anxiety) may be more interfering than a task that was emotionally neutral. This also may alter self-reported subjective states, and this might be a useful means to dissect the role of conscious attention during task performance.

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