Memory Impairment during a Climbing Traverse: Implications for Search and Rescue Climbing

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Abstract

Cognitive resource limitations can impair one's ability to multitask. Previous research has shown that climbing is a particularly demanding task, and does not neatly fit into existing cognitive resource models. Climbing is a task relevant to firefighting and search and rescue, and operators often must also handle communication and navigation tasks in tandem. We present the results of a study where a naturalistic narrative memory task was paired with a climbing traverse. As hypothesized, both climbing and memory performance significantly declined in the dual- compared to each single-task condition. The specific cognitive demands of climbing should be explored further using non-verbal secondary tasks, to determine whether an executive resource bottleneck, verbal resource demand, or something else entirely can better explain the dual-task interference. A more thorough understanding of the mental demand in concurrent operational tasks can be used to tailor the modality and timing or diversion of certain tasks for minimal interference.

***Keywords*: Dual-Task - Resource Theory – Working Memory – Climbing**

Introduction

The ability to efficiently perform several tasks at once is essential in a variety of situations. Researchers have explored the effects of many task combinations on performance outcomes, and have created models for computing which cognitive tasks should or should not be performed together (Wickens 2008). However, many daily tasks require strenuous physical activity as well as cognitive activity. For example, emergency responders make rapid and complex decisions regarding emergency medical triage and treatment, while at the same time helping with injured personnel evacuation (Fischer et al. 2015). Search and rescue climbers have to negotiate treacherous conditions while navigating and communicating with teammates (Helton et al. 2013). Unfortunately, these physical tasks are less well understood from the cognitive interference perspective proposed by cognitive psychologists (Wickens 2008). This omission is odd given the evolutionary significance of physically demanding tasks such as hunting and gathering. Presumably much of cognition itself evolved to occur while people engaged in physically demanding tasks, for example, tracking while engaging in pursuit predation (Carrier et al. 1984; Bramble and Lieberman 2004).

Though interference between physical and cognitive tasks has been explored (Etnier et al. 1997; Dietrich and Audiffren 2011; Labelle et al. 2013), much of this literature lacks realism. This is due to the cyclical, laboratory-based physical tasks that have been most commonly used. For example, running on a treadmill and stationary cycling require little to no executive processing or decision making (Whelan 1996). These studies therefore may not be appropriate for understanding more realistic settings where the physical tasks are more cognitively demanding, like traversing over complex terrain. Such artificial laboratory tasks may require fitness and physical effort, but they do not require navigation, planning, obstacle avoidance, or situation awareness. Therefore, it is important for cognitively demanding physical tasks to be studied in this context.

Epling and colleagues (2017) compared several dual-task experiments in which a verbal free recall task was paired with a variety of secondary tasks, including both computer tasks and physical tasks. While several outcomes were as expected (e.g., a verbal discrimination task significantly interfered with the verbal free recall task; Epling et al. 2016b), the climbing task stood out as uniquely demanding. Word recall declined from single- to dual-task by as much or more in the climbing tasks (Green and Helton 2011; Darling and Helton 2014; Green et al. 2014; Woodham et al. 2016) as it did in the verbally demanding discrimination task, even though the climbing task did not involve any overt verbal processing demands. The recall decline with climbing was also approximately twice as great as that produced by physically strenuous but simple running (Epling et al. 2016a).

Perhaps the interference seen between climbing and verbal free recall was driven by the free recall task. Memorizing a list of unrelated words through rote rehearsal, without any context or deeper meaning, lacks ecological validity; climbing needs to be studied in conjunction with a more realistic cognitive task. Unlike a free recall task, understanding verbal cues from an individual's surroundings, or remembering the gist of a verbal narrative such as a conversation, could be very important in real world situations. This is because poor comprehension or failed memory of a situation or conversation can lead to accidents or mistakes (Edgar and Edgar 2007). Can climbing and memory performance be maintained at a higher level when the memory task becomes more contextual, realistic, and subjectively interesting (Abbott 2008)? A more realistic verbal task, where participants must listen to a narrative and remember operationally relevant details for a true/false assessment, was chosen to replace the free recall task in the present dual-task experiment.

The new memory task may not prove as difficult to perform while climbing as verbal free recall. The new task has a mere recognition or gist memory requirement (recognizing whether simple statements about the scenario are true or false) of contextual and subjectively interesting information, more similar to real world verbal memory demands. The prior free recall task was devoid of context and required constant rehearsal to enable free recall memory. Regardless of these task alterations, dual-task interference was expected. The new memory task requires constant attention, updating, and processing of the scenarios, loading working memory (Endsley and Garland 2000). This may interfere with the process of planning a climbing traverse. It has also been suggested, in addition to a general executive or planning demand, that climbing may utilize verbal resources for planning the traverse via an internal monologue (Epling et al. 2017). Because the narrative memory task requires listening to and remembering a verbal scenario, this may also be a cause of interference. Therefore, we predicted dual-task performance impairment on both tasks compared to individual task performance, even though the narrative memory task should be less interfering than the previous free recall task. More specifically, we expected a dual-task decline in both the number of correct probes and the sensitivity to true probes on the true/false memory assessment, as well as a dual-task decline in both the distance climbed and climbing efficiency (number of climbing holds used per meter traversed; Green and Helton 2011), compared to both single-task conditions. Additionally, we examined the differential effects in performance over time in the single- versus dual-task conditions. Due to the additional cognitive load in the dual-task, dual-task performance (correct probes, distance climbed) should get worse over time relative to the single-task performance.

Method

Participants

Twelve athletes (4 women) recruited from the general Christchurch region participated in this research. Participants were required to be physically fit (exercising a minimum of three days a week), healthy, fluent English speakers, and to have normal vision and hearing. All participants were required to have climbing experience (New Zealand grade 17 for indoor top-rope was the minimum level reported). Participants were 19 to 30 years old (M = 24 years, SD = 3.8). The study was approved by the University of Canterbury Human Ethics Committee, and informed consent was gained from each participant. All participants received a $10 voucher to a local shopping mall as compensation for their time. Participant demographics are presented in Table 1.

Materials

Participants wore their own climbing gear. On-ear headphones (Manhattan) were attached to an IPod (A1367) and were worn for the duration of the task. A digital scale was used to obtain participants' weight (Tanita BC-532 Inner Scan Body Composition Monitor), and a measuring tape (with participant standing against a wall) to obtain height. Participants wore a heart rate monitor (Polar RC3 GPS), and the researcher used a stopwatch to determine when five-minute climbs were complete.

Narrative memory task. Two detail-rich scenarios were written to represent a conversation held by people involved in a building fire. The scenarios were designed to be audio analogues of visually presented scenarios previously used in fireground situation awareness research (Catherwood et al. 2012). The scenarios were read aloud and recorded, each being four minutes and thirty four seconds in duration and containing enough information for 24 true/false probe statements about events in each. Every probe statement was unambiguously true or false, and related to events spaced as evenly as possible throughout the scenarios. Probes included statements that would be operationally relevant to emergency responder communication and situation awareness (e.g. 'The people were on the 5th floor when the fire broke out.') rather than inconsequential details. Silence was added to each scenario such that the audio tracks lasted exactly five minutes. A response grid (Fig. 1) accompanied each set of probe statements, given to participants at the end of the five minute audio track as an assessment of narrative memory.

Climbing task. This experiment was conducted at the University of Canterbury Recreation Centre indoor climbing wall. The area of the wall used for the traverse was 8.25m in horizontal distance. Participants were not roped, and were required to stay below the 3.3m tape line marked as the maximum safe height for un-roped climbers. The wall was configured with varying sizes, shapes, and colors of holds. The floor around the wall was heavily padded to prevent injury. Participants were run through the experiment one at a time. A high resolution, widescreen webcam (Logitech C930e) was used to film the climbing components for later analysis. During the climbing tasks, the IPod was secured in a lightweight, unobtrusive runner's belt (Spibelt) around the waist. Attached to the belt was also a yellow plastic ball, used as a distinct target for later analysis of the video recordings. The belt was worn such that the yellow ball appeared in the center of participants' mid-back. This task was performed while listening to a scrambled audio scenario (incomprehensible noise; no memory imperative), created with Audacity sound editing software by splicing the two audio scenarios into small segments and randomly arranging them to create a nonsensical scenario.

Dual-task. Participants listened to one of the audio scenarios while climbing. The narrative memory assessment was given immediately following the task. The particular scenario participants heard in the single- versus dual-task condition was counterbalanced.

Subjective Stress State Questionnaire. A paper and pencil version of a modified NASA-TLX workload scale (Hart and Staveland 1988; Blakely et al. 2016) was used after each task in this study. This includes a subset of the TLX subscales as well as physical fatigue, mental fatigue, tension, unhappiness, motivation, task interest, self-related thoughts, concentration, confidence, task related thoughts, and task unrelated thoughts, derived from the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 2002). Participants completed the questionnaire after each task. The ratings went from 0 (very low) to 100 (very high) and participants circled their ratings on the given 5 point intervals.

Procedure

Participants met the researcher at the entrance of the Recreation Centre and were led to the climbing room. They were given an information packet outlining the purpose and instructions for the task, an informed consent document, a biographical questionnaire, and an exercise rating questionnaire. Participants were given the opportunity to ask questions. Once consent was given, participants were asked to remove their shoes and any heavy outer garments to take height and weight measurements.

Participants were instructed how to put the chest strap heart rate monitor on themselves, along with the accompanying watch. Participants were asked to take a seat while the researcher gave a brief demonstration on the climbing task. They were told that the researcher would queue the IPod, and secure it into the belt. Participants would then place their left hand and left foot on the left wall. Upon hearing the audio track commence, they were to mount the main wall and begin their traverse, at which point the researcher would start the stopwatch and the video recording, as well as manually make notes on how many full traverses (and number of panels for partial traverses) the participant made. They were to move across the wall, covering as much horizontal distance as possible in the five minutes given. They were shown the 8.25m turn around point and were told that they needed to fully cross that line with their right hand and foot before heading back in the other direction. They were to keep going until told that five minutes was up and they could dismount the wall. They were told that should they come off the wall at any point, to immediately remount the wall in the same location.

After the demonstration, participants were told that they would be doing three different tasks: a five minute seated memory task, a five minute climb (with the scrambled scenario), and a five minute climb with memory task (dual-task condition). Participants were told they were allowed water and as much rest time as they needed between each task. This was a within-subjects design, and participants were assigned to one of six possible orders for the three tasks based on the counterbalance. If participants had no questions, their resting heart rate was recorded and they were told how to begin the first task.

For the climb-alone task, participants were instructed to partially mount the wall, and commence the climb with the beginning of the scrambled audio track and to traverse as far as possible horizontally in the given time. For the memory task, participants were instructed to sit on the padded floor and to listen and remember as much about the scenario as possible in preparation for a true/false memory assessment. At the end of five minutes, participants were given the memory assessment to complete. For the dual-task, both of the above tasks were performed simultaneously. At the end of five minutes, participants were given the memory assessment. At the end of each of the three tasks, participants filled out the modified workload scale.

Results

For performance comparisons between single- and dual-task conditions for both the climbing and memory tasks, one-tailed directional within-subjects t-tests were employed due to a priori directional hypotheses (superior performance was expected in the single- compared to dual-task condition).

Narrative Memory

Participants had significantly more correct responses in the single- (M = 17.81, SD = 2.47) compared to dual-task (M = 14.33, SD = 3.20) condition, $t(11) = 2.70$, $p = .010$, $M_{\text{difference}} = 3.58$ (95% CI [.66,6.51]). Signal detection theory (SDT) metrics were applied to the true/false responses, such that a true statement marked as true was considered a hit, and a false statement marked as true was considered a false alarm (Edgar et al. 2017). A´, an SDT measure of ability to discriminate signal from noise (sensitivity), was calculated in the traditional manner from the proportion of hits and false alarms (Stanislaw and Todorov 1999). For A´ participants had significantly greater sensitivity to true probes in the single-task (M = .829, SD = .086) than the dual-task (M = .648, SD = .145), $t(11) = 3.31$, $p = .003$, $M_{\text{difference}} = .181$ (95% CI [.061,.301]), Cohen's $d_z = .956$ (95% CI [.174,1.739]) (d_z is reported for the primary performance metric in each task to facilitate comparisons to prior research). Participants were also significantly less confident about their memory performance in the dual- (M = 2.36, SD = 0.37) compared to single-task (M = 3.02, SD = 0.44), $t(11) = 4.76$, $p < .001$, $M_{\text{difference}} = .66$ (95% CI [.35,.96]).

In addition to simple single- and dual-task memory differences, memory trends over time (periods) were also examined. Because each probe referred to events spaced as evenly as possible throughout the scenario, we will refer to probe one through eight as Period 1, nine through sixteen as Period 2, and seventeen through twenty-four as Period 3. A repeated measures analysis of variance revealed a statistically significant linear trend for the condition (single- versus dual-task) by period interaction, $F(1,11) = 5.077$, $p = .046$. This interaction can be seen in Fig. 2.

Climbing

Participants climbed farther in single- (M = 44.47 m, SD = 20.05) compared to dual-task (M = 39.35 m, SD = 16.47) condition, $t(11) = 1.86$, $p = .045$, $M_{\text{difference}} = 5.12$ m (95% CI [-.94,11.18]), Cohen's $d_z = .537$ (95% CI [.182,.892]). This difference is not likely due to a difference in physical effort as there is no difference in max HR reached in the single-task climb (M = 141.5 bpm, SD = 16.84) compared to the dual-task climb (M = 142.5 bpm, SD = 18.54), $t(11) = .399$, $p = .697$, $M_{\text{difference}} = 1.0$ (95% CI [-4.5,6.5]). Participants used significantly more holds per horizontal meter traversed, a measure of climbing efficiency, in the dual- (M = 5.59, SD = 1.14) compared to single-task (M = 4.78, SD = 1.15) condition, $t(11) = 5.35$, $p < .001$, $M_{\text{difference}} = .81$m (95% CI [.48,1.14]), Cohen's $d_z = 1.544$ (95% CI [.849,2.239]).

Climbing distance over time was also examined. Each five-minute climb was split into three, 100-second periods. The linear trend for the condition by period interaction failed to reach statistical significance, $F(1,11) = 2.406$, $p = .149$.

The percent performance change from single- to dual- task ([(single-task performance – dual-task performance) / single-task performance] * 100) in each period for both memory performance and climbing distance were also compared. The significant linear trend for period, $F(1,11) = 6.808$, $p = .024$, can be seen in Fig. 3.

Subjective Stress State

The average ratings on the self-report scale are shown in Table 2. The components of workload (mean of mental demand, physical demand, temporal demand, emotional demand, performance monitoring demand, effort), spent (how burnt out or exhausted participants felt; mean of physical fatigue, mental fatigue, tense, unhappy, confidence (reverse scored)), and task focus (mean of motivation, self-related thoughts (reverse scored), concentration, task-related thoughts, task-unrelated thoughts (reverse scored)), were calculated according to prior research (Epling et al. 2016a; Blakely et al. 2016). An analysis of variance showed significant within subjects effects of task on workload, $F(2,22) = 7.56$, $p = .003$, $\eta_p^2 = .407$, and on the spent component, $F(2,22) = 3.47$, $p = .049$, $\eta_p^2 = .240$ but no significant within subjects effects of task on task focus, $F(2,22) = .91$, $p = .417$, $\eta_p^2 = .076$. The sphericity assumption was not violated.

Because we were interested in the difference between single- and dual-task performance, pre-planned contrasts were conducted. Dual-task workload ($M = 56.39$, $SD = 17.56$) was significantly greater than memory task-alone workload ($M = 31.53$, $SD = 17.07$), $t(11) = 3.97$, $p = .001$, $M_{\text{difference}} = 24.86$ (95% CI [11.07,38.65]). The climb-alone workload ($M = 46.39$, $SD = 15.51$) was greater than the memory-alone workload, $t(11) = 2.13$, $p = .028$, $M_{\text{difference}} = 14.86$ (95% CI [-.48,30.21]). The spent component was significantly greater in the dual-task ($M = 38.83$, $SD = 18.22$) than the memory-alone task ($M = 23.42$, $SD = 15.84$), $t(11) = 2.91$, $p = .007$, $M_{\text{difference}} = 15.41$ (95% CI [.367,27.07]).

Discussion

Narrative Memory

Participant's narrative memory (A´) declined when performing a concurrent climbing task compared to the single-task condition. Climbing requires executive effort to maintain attention, actively plan a route, and constantly monitor body orientation, and may also require not only spatial but verbal resources, making it particularly interfering with the memory task. A strong link exists between language and gesture, both neuro-anatomically and in practice, so the use of climbers' hands and arms may impair their ability to adequately process and remember the verbal narrative (Frick-Horbury & Guttentag, 1998; Wagner, Nusbaum, & Goldin-Meadow, 2004; Xu, Gannon, Emmorey, Smith, & Braun, 2009). In addition, climbers may actually plan their route using an internal verbal monologue, even if the climbing itself is considered a spatial activity (e.g., climbers traverse space, as do walkers, swimmers, etc.). Verbal mediation (i.e., talking to one-self) may be used when considering where to place hands/fingers and feet for maximum efficiency and grip, particularly in relation to the required muscle strength to position one-self in such a way, and which holds are available for the next move.

The difference in dual-task performance impairments can be related to prior studies using standardized effect sizes (Cohen's d_z). In this experiment, narrative memory performance decline from single- to dual-task had an effect size of $d_z = 0.956$ (SE = .399), compared to the effect averaged from two prior climbing studies (Green and Helton 2011; Green et al. 2014) on dual-task word recall performance: $d_z = 2.292$ (SE = .369) (Epling 2017). According to conventional benchmarks (Nakagawa and Cuthill 2007), the dual-task performance decline is considered a large effect in both experiments, however it is more than twice as large in the recall experiments. This supports the idea that the word recall task may be exceptionally demanding. However, even when taking away the constant rehearsal requirement and providing the participants with a richer context for memory, the new memory task still proves difficult to perform under the strain of climbing.

In addition to the overarching single- and dual-task memory differences, a significant period by condition interaction was found. As seen in Fig. 2, memory performance in the single task tended to improve across periods (i.e., more probes were answered correctly towards the end of the task than the beginning) relative to memory performance in the dual-task where memory performance tended to decrease with time. As expected, in the single-task, the ubiquitous recency effect held true. On the contrary, because participants experienced greater cognitive load in the dual-task, it was more difficult to store additional information as time progressed. This is important to consider in real-world situations, as it is possible for dual-task performance to start out at a high level but performance deterioration over time may be accelerated (compared to the single-task) due to faster depletion of cognitive resources.

Climbing

The prediction that participants would not climb as far or as efficiently in the dual-task condition, similar to Green and colleagues' research (Green et al. 2014), was supported by the results. A clear difference in climbing efficiency (number of holds used per meter; Green and Helton 2011) in the single- compared to dual- task implies that performing the memory task utilizes cognitive resources that might otherwise be put towards planning the most efficient route across the wall. Though there is some evidence that people naturally prioritize physical demands (Green and Helton 2011; Darling and Helton 2014; Epling et al. 2016a), particularly when injury or falling is a possibility, participants did succumb to dual-tasking deficits in the climbing element of this experiment, in addition to the memory element. Anecdotally, some participants admitted to focusing on the climbing element of the dual-task more than they focused on the scenario (despite being told to do their best on both), yet the climbing deficits still occurred. The dual-task decline in climbing efficiency (d_z = 1.544) was actually greater than the dual-task decline in memory performance (d_z = 0.956).

The dual-task performance decline in climbing distance (d_z = .537) was only slightly less than that of the previous climbing plus free recall research (d_z = .652) (an averaged value from Green and Helton 2011; Green et al. 2014). These effect sizes, along with the dual-task memory decline effect sizes, can be visualized two-dimensionally in Fig. 4: the X-Axis represents the decline in the memory task performance, while the Y-Axis represents the decline in the climbing distance. It can be seen that the performance decline on both dimensions was comparatively greater in previous research, though not by much on the climbing dimension: though the act of climbing harmed free recall memory more than it did narrative memory, the narrative memory and free recall tasks harmed climbing distance by similar amounts.

The participants in this experiment were experienced recreational and competitive sport climbers. One participant noted that the dual-task condition is different to competitive climbing such as soloing and hard red-pointing as these activities require blocking out all other sensory inputs to focus on the task at hand. This participant found it hard to switch mindsets for the experimental task. If other participants had similar perspectives, though dual-task deficits did occur in the climb, perhaps the decline in performance on the memory task was still partially due to task shedding (i.e., neglecting the memory task in order to preserve performance on the climbing task). Future research should aim to use trained professionals as participants. Firefighters and search and rescue climbers would likely better understand the importance of remaining attentive to both the physical task and verbal communications. An additional study should look into differential dual-tasking effects with novice versus expert climbers. It is expected that there would be a greater dual-task memory impairment for more novice climbers, because climbing would be more automated and less cognitive resource demanding for the more experienced group. Therefore, the experienced group would have more processing resources available for the memory task.

Though no significant distance by period interaction was found in climbing, there was a significant linear trend for period in the percent performance change from single- to dual- task (Fig. 3). In both the memory task and climbing task, the difference between single- and dual-task performance becomes greater with time, consistent with cognitive resource theory, i.e., dual-task performance impairments increase over time as more cognitive resources are depleted.

Subjective Stress State Questionnaire

As expected, workload, task focus, and being “spent” tended to be greater in the dual-task than single-tasks. Workload was significantly greater in the dual-task than the seated narrative memory task. Participants were also more “spent” in the dual-task than the seated narrative memory task. No significant difference in task focus was found among the three different conditions, implying that both single tasks were engaging and demanding enough to require a great deal of focus, but performing them at the same time did not elicit *extra* focus. The lack of increase in focus, particularly from the single memory task to the dual-task, demonstrates that listening to the scenario is very engaging in and of itself, allowing little room for mind wandering. Yet, it is somewhat surprising that participants do not “dig deeper” for the dual-task condition. Perhaps participants are not using the entire range of the subjective scale, and are already truly focused at max capacity in the memory-alone task (hence no increase in task focus for the dual-task).

In general, the results of this experiment are consistent with past dual-task climbing research, indicating that climbing is a particularly cognitively demanding task. Several possible explanations for the task interference found in the present experiment exist: First, and foremost, climbing may be a globally demanding task, i.e. planning or other components of climbing may cause an executive processing bottleneck, preventing maximal performance on any secondary cognitive task regardless of the specific task resource requirement. Second, there is a strong link between language and gesture (Frick-Horbury & Guttentag, 1998; Wagner et al., 2004; Xu et al., 2009). Because climbers’ hands and arms are occupied, their ability to process the verbal memory task may be impaired. Third, though climbing is an activity that is spatial in nature, the traverse may actually be planned using verbal resources (i.e., an internal monologue). Finally, the memory task may require more spatial resources than evident on the surface, due to an attempt to visualize what is happening in the scene. Regardless of specific demands of the memory task, the fact that climbers essentially are attempting to remain aware of two independent situations (the traverse and the scenario) makes it unsurprising but all the more important that such significant dual-tasking performance impairment was found.

The use of a new narrative memory task paired with climbing, and the resulting dual-task impairments found, indicate that it was not the free recall task alone driving the significant and unique performance impairments in prior research. Rather, climbing truly is a demanding task that could interfere with something as practiced and seemingly automatic as remembering the gist of a conversation. If the planning component of climbing is the primary driver of interference, was that due to an executive bottleneck, or the fact that planning is an inherently verbal activity and thus competed for the verbal resources needed in the free recall and narrative memory tasks? Climbing requires further exploration in the dual-task paradigm with non-verbal tasks of varying levels of executive requirements. It is also possible that neither planning nor specific resource overlap is the main driver of high levels of interference. Anxiety (i.e., the fear of falling) and/or resulting neurochemicals may alter the way the memory task is processed (Nieuwenhuys et al. 2008). This can be manipulated by varying the height at which climbers perform the experiment, and whether or not they are roped.

Because climbing interfered with free recall and narrative memory to different degrees, it is important to consider more specifically how two ostensibly verbal tasks (free recall and narrative understanding/gist memory) differ in terms of their component processes and resource requirements. The better the understanding of specific task qualities and how those interfere with other tasks, the better the task interference could be mitigated. Climbing should be explored in a wider variety of dual-task situations, as a better understanding of the factors that produce reduced climbing performance in dual-task situations should help with the safety, efficiency, and performance of search and rescue climbers. It would also enhance the understanding of processes underlying both climbing and dual-tasking in general, and help with the reverse engineering of the brain and human cognitive system. At present, multi-tasking demands may be unavoidable – but advances in cognitive ergonomics can and should inform ways of minimizing task interference, as well as inform the types of assistive technologies to provide when the task interference itself cannot be minimized.

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Approval: All procedures performed involving human participants were in accordance with the ethical standards of the University of Canterbury Human Ethics Committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent: Informed consent was obtained from all participants included in the study.

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Figures

Fig. 1

The probe response grid, which appeared below the list of 24 probe statements on participant response sheets.

Probe #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	P#
True																									**T**
False																									**F**
Guess																									**G**
Fairly uncertain																									**F un**
Fairly certain																									**F cer**
Certain																									**cer**

Fig. 2

Average number of correct probe responses in single- compared to dual-task condition over time. Each period included eight probes. Error bars are standard error.

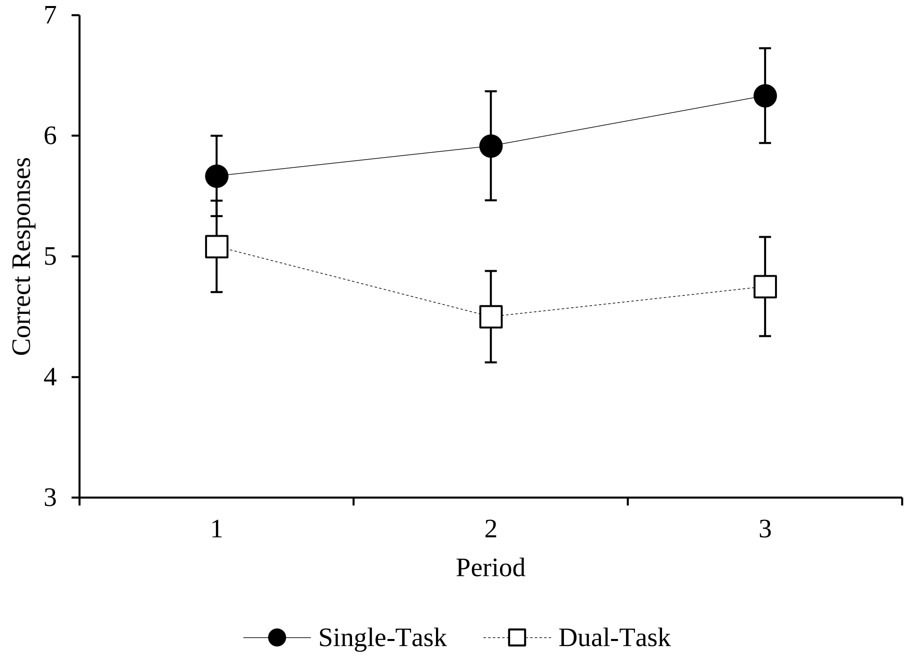


Fig. 3

The percent performance change from single- to dual- task ([(single-task performance – dual-task performance) / single-task performance] * 100) in each period for both memory performance and climbing distance. Error bars are standard error.

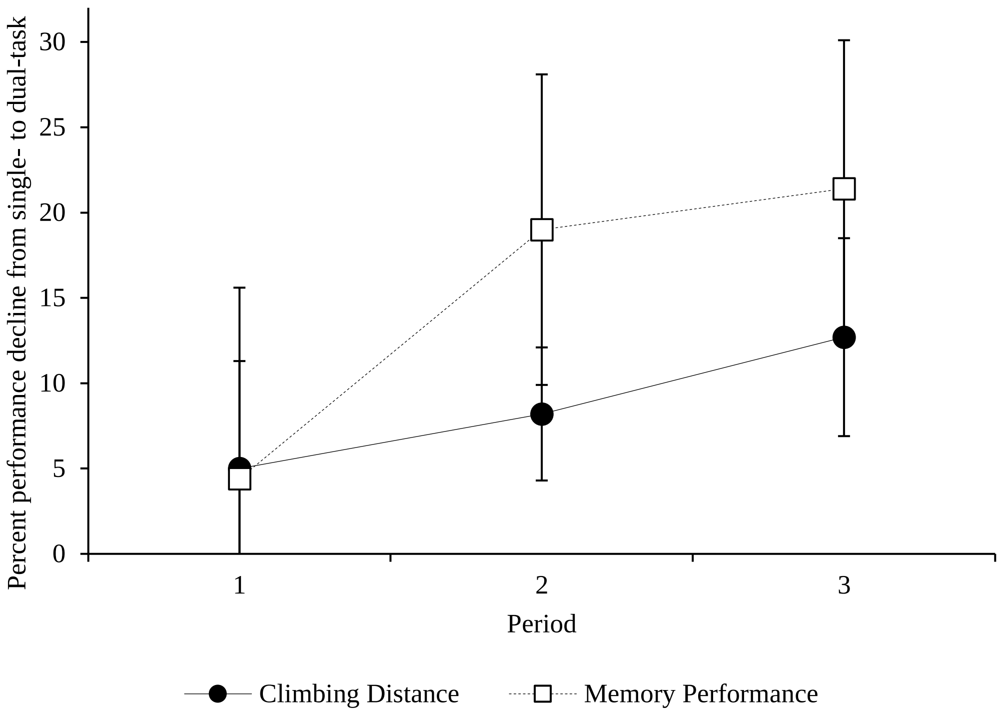
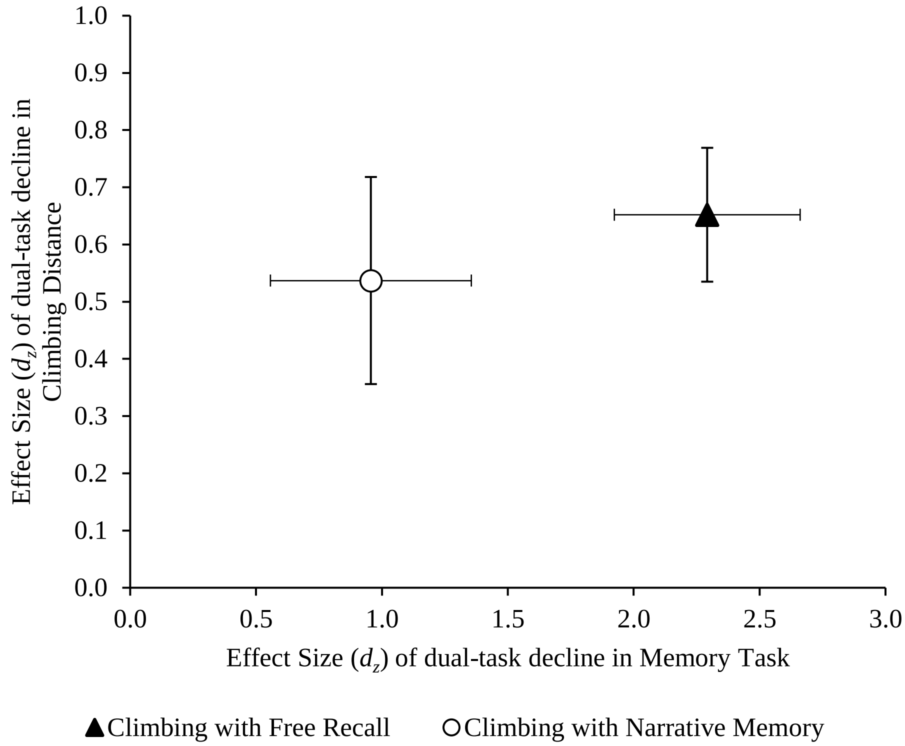


Fig. 4

Effect sizes of dual-task performance decline on both the memory task and climbing tasks in the present, and in prior, research. Values are Cohen's d_z, and error bars are standard error.



Tables

Table 1

Participant Demographics and Fitness Information

Participant	Gender	Age	Weight(kg)	Height(m)	BMI	PA-R	VO_2max
1	Female	24	59.0	1.53	25.2	6	39.7
2	Male	26	75.4	1.78	23.8	7	53.0
3	Male	29	74.2	1.81	22.7	6	50.8
4	Female	25	57.3	1.67	20.6	7	44.8
5	Male	20	69.8	1.79	21.8	6	54.8
6	Male	27	65.3	1.63	24.6	7	52.0
7	Male	20	91.3	1.85	26.7	7	53.1
8	Male	20	73.0	1.76	23.6	7	55.4
9	Male	29	57.0	1.71	19.5	3	47.4
10	Male	30	84.1	1.84	24.8	7	50.6
11	Female	19	60.9	1.65	22.4	6	43.8
12	Female	23	60.1	1.68	21.3	7	45.0

Notes. BMI is given by weight (in kilograms) divided by squared height (in meters). PA-R comes from the physical activity questionnaire used with the Jackson Non-Exercise Test. VO_2max was calculated from the Jackson Non-Exercise Test, see appendix.

Table 2

Self-Report Averages

	Memory Alone	Dual-Task	Climbing Alone
Mental Demand	59.6(7.6)	73.3(7.5)	49.6(6.4)
Physical Demand	1.3(0.7)	61.3(6.7)	68.8(5.4)
Temporal Demand	19.2(6.4)	55.0(8.0)	41.7(9.1)
Emotional Demand	22.1(6.9)	27.9(5.6)	13.3(4.0)
Performance Monitoring Demand	37.1(7.3)	52.5(7.3)	46.3(8.4)
Effort	50.0(8.3)	68.3(6.9)	58.8(7.0)
Physical Fatigue	3.8(1.6)	42.9(7.9)	65.0(5.1)
Mental Fatigue	33.8(7.8)	53.3(7.5)	26.3(6.9)
Tense	25.0(8.7)	37.5(8.1)	22.1(6.4)
Unhappy	15.8(6.4)	16.7(7.1)	8.3(3.2)
Motivation	74.2(5.9)	79.6(4.7)	78.3(4.0)
Task Interest	55.8(6.7)	75.8(5.9)	71.3(7.4)
Self Related Thoughts	17.9(5.9)	23.3(7.3)	25.0(6.4)
Concentration	82.1(4.2)	82.5(6.1)	74.6(6.2)
Confidence	61.3(4.9)	56.3(7.3)	70.0(4.8)
Task Related Thoughts	74.6(7.7)	77.5(5.0)	69.6(7.4)
Task Unrelated Thoughts	14.2(4.2)	15.0(4.6)	18.3(6.4)
Workload	31.5(4.9)	56.4(5.1)	46.4(4.5)
Spent	23.4(4.6)	38.8(5.3)	30.3(3.0)
Task-Focus	79.8(3.4)	80.3(3.2)	75.8(3.6)

Notes. Each value is the mean (standard error of the mean) self-report rating on the subjective stress state questionnaire across all participants for that measure, on a scale of 0-100.

Appendix

Participants' VO_2max was estimated using the following model:

The Jackson Non-Exercise Test (Jackson et al. 1990):

Test procedure: The biographical details collected from the participant, along with their self-ranking on the activity scale below, was plugged into the formula $VO_2max = 56.363 + (1.921*PA\text{-}R) – (0.381*age) – (0.754*BMI) + (10.987*gender)$, where gender is coded 1 for male, 0 for female, and BMI is weight (in kilograms) divided by height (in meters) squared.

Participant Activity Rating (PA-R):
CIRCLE the appropriate number (0 to 7) which best describes your general activity level for the previous month.
Category 1. Do not participate regularly in programmed recreational sport or heavy physical activity.

0 – Avoid walking or exertion, e.g., always use elevator, drive whenever possible instead of walking.

1 – Walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration.

Category 2. Participated regularly in recreation or work requiring modest physical activity, such as golf, horseback riding, calisthenics, gymnastics, table tennis, bowling, weight lifting, yard work.

2 – 10-60 minutes per week.

3 – Over one hour per week.

Category 3. Participate regularly in heavy physical exercise such as running or jogging, swimming, cycling, rowing, skipping rope, running in place or engaging in vigorous aerobic activity-type exercise such as tennis, basketball, or handball.

4 – Run less than one mile per week or spend less than 30 minutes per week in comparable physical activity.

5 – Run 1 – 5 miles per week or spend 30 – 60 minutes per week in comparable physical activity.

6 – Run 5 – 10 miles per week or spend 1 to 3 hours per week in comparable physical activity.

7 – Run over 10 miles per week or spend over 3 hours per week in comparable physical activity.