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The effects of Virtual Nature Exposure on Cognitive Fatigue Recovery and subsequent push-up performance

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Much research has examined the negative impacts of cognitive fatigue (CF) on subsequent physical performance, yet little research has explored potential interventions, such as virtual nature exposure (VNE), to disrupt these impacts and provide recovery effects. Fourteen healthy adults (78% male; aged 28±8.1 years) completed two online sessions, one week apart. Participants performed a Time-load Dual-back (TloadDback) for eight minutes before watching either a nature (intervention) or urban video (control). They then completed as many consecutive push-ups as possible and rated their perceived exertion (RPE). Participants reported more CF following the TloadDback, where this CF declined following the nature video but not the urban video. There was no difference in push-up performance or RPE between conditions. We showed that the TloadDback increased CF ratings, and CF recovery was greater following VNE. While this recovery did not translate into better push-up performance or lower RPE, it shows promise for continued investigation.

KEY WORDS: Mental fatigue; executive function; physical performance, endurance, Sport psychology.

Cognitive fatigue (CF) is the feeling that your thinking is slowed, ineffective, and simply not working properly. People report an inability to concentrate, where even the simplest daily tasks seem to take forever. Often described as 'brain fog', CF is a subjective state of exhaustion commonly characterised by increased tiredness (Badin et al, 2016), decreased attention (Boksem et al., 2005) and a decline in motivation (Barte et al., 2017). Performing a cognitively demanding task over a prolonged period induces CF due to the strain placed on several areas of the brain involved in executive functions such as attention, coordinated movement, decision making, plan-

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ning and self-monitoring (Boksem & Tops, 2008; Hockey, 2013). The effects of CF on performance have been observed in a variety of domains such as driving (Saxby et al., 2013) and academia (Sievertsen et al., 2016). Recently, work in athletic performance has shown that many aspects of physical performance, such as endurance running (e.g., pacing; MacMahon et al., 2014), push ups and sit ups to exhaustion (Dorris et al., 2012), technical and tactical sporting performance (Coutinho et al., 2017; Trecroci et al., 2020), sprint-start reaction time (Englert & Bertrams, 2014) and decision-making (Smith et al., 2016), can all be negatively affected by CF.

Given the potential for CF to impair an athlete's performance, it is important to determine techniques to minimise these effects. While recent research has made attempts to better identify the factors involved in the relationship between CF and physical performance (MacMahon et al., 2021), there are no current guidelines or best practices for the recovery of CF. Several recovery strategies have been examined over the years, with stronger evidence for some than others (see Proost et al., 2022, and Sun, Soh, Roslan, Wazir, Liu, et al., 2022, for reviews). Exposure to nature has been proposed as one such possibility to facilitate the recovery of CF (Kaplan, 1995; Sun, Soh, Roslan, Wazir, Mohammadi, et al., 2022), given the positive biophilic interaction that occurs between humans and their natural environments (Barbiero & Berto, 2021). According to the attention restoration theory (Kaplan, 1995), nature does not require the same level of directed attention as other environments, and thus these environments inherently allow for rest and recovery of cognitive processes, particularly our attentional capabilities.

The benefits of nature exposure for cognitive resources have been seen in several domains, and most promisingly, through various media of nature exposure. First-hand, in situ exposure to nature (like walking through an arboretum or park) after a taxing cognitive task can lead to improvements in mood (such as decreased anxiety and negative affect) and cognition (such as short-term memory span and working memory; Bratman et al., 2015; Berman et al., 2012). But less direct nature exposures have also shown similar effects. Simply viewing photographs of natural environments (compared to urban environments and geometric shapes) improved participant scores in a sustained-attention test after CF (Berto, 2005) and when not fatigued (Fu & Xue, 2023), and viewing nature images and videos led to greater mood and feelings of restoration and social belonging (Neale et al., 2021). Brief breaks (during a demanding sustained attention task) of watching nature videos also helped decrease physiological arousal, which can be an indicator of stress (Kimura et al., 2021). Nature exposure through virtual reality also appears to have similar restorative effects after CF (Ünal et al., 2022). The nature exposure does not even have to be visual: simply listening to an environmental soundscape facilitated greater recovery for sustained reaction time and short-term memory after CF (Shu & Ma, 2019), and natural smells, like that of green leaves (also known as a Hex-Hex Mix), can help reduce the impact of CF when completing multiple cognitive tasks (Saito et al., 2018). Taken together, these findings suggest that exposure to nature, in a variety of ways, can improve concentration, mood, perceptions, and our overall ability to perform cognitively, even after an initial cognitively fatiguing task.

While there is good evidence that nature exposure can help rejuvenate feelings of CF, there is less evidence about whether this leads to better subsequent physical performance as well. In one of the few studies to investigate physical performance following virtual nature exposure (VNE), Akers et al. (2012) examined maximal cycling performance in participants who were exposed to unaltered, greyscale, or red-hued nature images on a computer. Although there were no reported differences in peak power output between the conditions, the unaltered nature image condition produced lower perceived exertion and negative mood ratings (Akers et al., 2012). This finding highlights how nature exposure could aid in the relationship between CF and physical performance, as models describing this relationship specify perceived exertion/effort as a key mechanism. The psychobiological model (Marcora, 2008; Marcora et al., 2009) posits that the negative effects of CF on physical performance are primarily driven by motivational limitations and increased perceptions of effort, rather than any cognitive constraints. An increased perception of effort following a cognitively fatiguing task may negatively affect a performer's motivation for undertaking a subsequent physical task, and lead to the performer exerting less energy, resulting in poorer performance (Marcora, 2008; see also Hockey, 2013, and Pattyn et al., 2018). In line with this theory, nature exposure prior to sport or exercise may contribute to recovery from CF (through improvements of mood and perceptions of effort) and thus mitigate the negative impact of CF upon subsequent performance.

The aim of this study was to investigate the effects of VNE (using videos) on CF and subsequent push-up performance. The design of this study closely resembles that of Dorris et al. (2012), who had participants complete push ups in a repeated-measures design: once after a mentally demanding task, and once after a control task, one week apart. For our study, we used a similar design, but with the addition of recovery videos (nature vs urban scenes) in between the cognitive and physical tasks, to test whether there was a rejuvenating nature effect that helped protect push up performance. We hypothesised that the cognitively fatiguing task would cause an increase in CF (compared to baseline), while subsequent exposure to a nature video (but not the urban video) was expected to provide recovery from this increased CF. We also hypothesised that participants would complete a greater number of push-ups and report lower perceived exertion ratings following the nature video compared to the urban video.

Methods

Participants

Fourteen health participants (3 female, 11 male; M_{age} = 28.06 ± 8.08 years, range = 23-53 years) volunteered to participate in the study. All participants reported engaging in at least 30 minutes (M = 194.29 ± 123.08 minutes, range = 30-360 minutes) of exercise per week. Thirteen participants reported participating in resistance training (i.e., strength training, bodyweight training) at least once a week and 11 participants reporting participating in at least one type of sport. Of those participants, six reported participating at a non-competitive recreational level and five at a competitive level. The inclusion criteria were: 18-60 years old; fluent in written English; normal or corrected-to-normal vision; non-smoker; and the ability to complete a minimum of 5 push-ups in a row without stopping. All participants completed the ESSA adult pre-exercise screening tool (Exercise and Sport Science Australia, 2011) to ensure they were at lower risk of injury. Participants with a known history of psychiatric, neurological, or medical conditions were excluded. Additional exclusion criteria were colour-blindness and the occurrence of a concussion in the past three months. Participants were asked to refrain from consuming caffeine and alcohol within 12 and 24 hours of testing, respectively. Ethical approval was granted by the La Trobe University Human Ethics Committee (ethics number HEC20217) in compliance with the *National Statement on Ethical Conduct in Human Research* (The National Health and Medical Research Council, 2018). All subjects provided written and informed consent before volunteering to participate in the study.

Experimental Design

The study used a randomized, counter-balanced, repeated-measures design to investigate the effect of VNE on CF recovery and subsequent push-up performance. Two experimental sessions, involving exposure to nature or urban scenarios via videos, were completed one week apart to allow time for muscle recovery.

Materials

Video Intervention. During the two online testing sessions, participants were presented with one of two 5-minute videos. The first video was a nature walk, which mimicked a first-person walkthrough of green parkland and included the natural sounds of that area such as running water, bird sounds, and steps through a grassy footpath (Figure 1a). This nature video was chosen as it contained many elements identified as restorative in previous work, such as the visual elements of parkland (Laumann et al., 2001) and sounds of birdsong and streams (Shu & Ma, 2018). The second video was an urban walk, mimicking a first-person walkthrough of a populated city with little greenery, including sounds such as people talking, pedestrian crossing indications, and cars travelling (Figure 1b).

Measures

Cognitive task. The Time-load Dual-back (TloadDback; Borragán et al., 2017) requires participants to perform two components simultaneously. Alternating numbers and letters appear on a blank black screen (see Figure 2). When a number appears, participants indicate whether the number is odd or even. When a letter appears, participants indicate whether the letter is the same as the letter presented previously. This task has been used in previous work to induce CF in a similar way to classically used computer-based tasks, but over a shorter

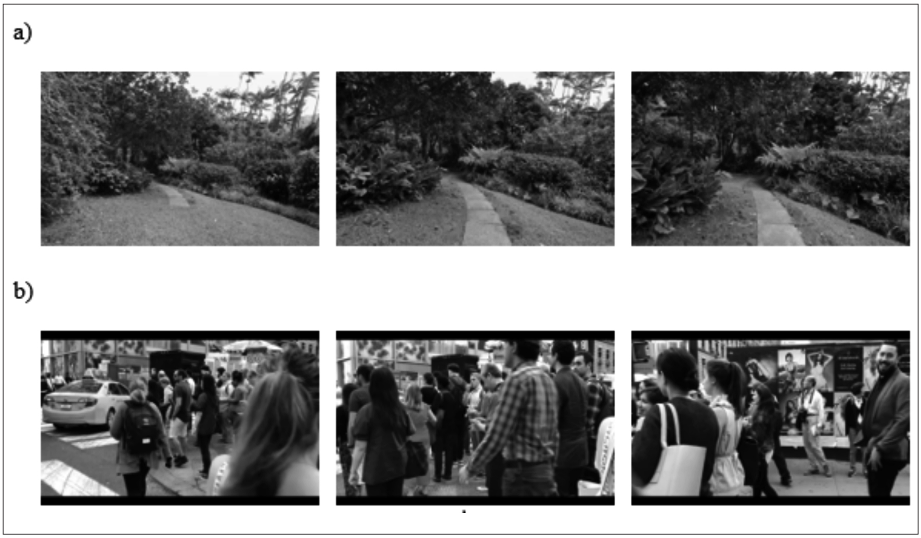


Fig. 1 - Still Images from the Nature (a) and Urban (b) Video Interventions.

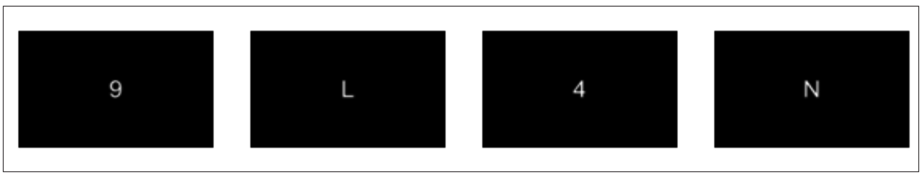


Fig. 2 - Example Sequence from the Time-load Dual-back (TloadDback) Task.

testing period that avoids an under-aroused state (O'Keeffe et al, 2020). Previous studies (e.g., Borragán et al., 2016, 2017) have individualised the speed of stimulus presentation for each participant in an initial separate session. Given the online nature of this study, however, this process was not feasible. Instead, a speed of 1000ms (where each number/letter stayed on screen for 1000ms before switching) was used for all participants. This speed is similar to what has been reported as the average individualised speed for this task (Borragán et al., 2017).

Push-up task. At the start of each session, participants were shown an exercise technique video describing the physical task (push-up maximum repetitions to exhaustion). The video included technical cues, an explanation of technical failure, and described the desired tempo, which was two seconds in the up position (i.e., eccentric) and one second in the down position (i.e., concentric). Prior to this push-up task, participants completed a short warm-up that consisted of 10 arm circles forward, 10 backward, and 10 arm swings, followed by one warm-up set of push ups using the prescribed technique (3-5 repetitions). Following the warm-up, participants were reminded of proper set-up for push ups, how to perform them at the required tempo, and how to recognise technical failure. They were also given demonstrations of incorrect technique as examples of what to avoid. To ensure consistency of performance between conditions, participants were instructed to be conscious of their form during testing and a metronome at 60 beats per minute was played to help maintain the required tempo.

Rating of cognitive fatigue (CF). Participants reported their subjective CF in response to the question: "How cognitively fatigued do you feel right now? (i.e., how mentally tired or drained do you feel?)" using a visual analog scale (VAS) from 0 ("Not at all") to 100 ("Extremely"). A VAS was deemed suitable to measure subjective CF as previous work has shown it to be a valid way of identifying changes in CF over time, while also being quick to administer and easy to interpret (e.g., Smith et al., 2019).

Rating of Perceived Exertion (RPE). RPE was measured on a 10-point scale (Borg, 1998). Participants rated how intense they found the set of push-ups following the physical task from 1 ("Very, very easy") to 10 ("Maximal").

Procedure

Participants completed this study online. Upon enrollment in the study, participants accessed the online experimentation software platform Inquisit Web (https://www.millisecond.com) on a computer or laptop. First, participants were shown the push-up technique video. Following this video, participants reported their current CF levels using a VAS (Baseline CF). Participants were then presented with instructions for the TloadDback. They completed a 2-minute practise of the TloadDback with immediate feedback indicating correct and incorrect responses for familiarisation, before completing the full 8-minute version of the task. Following the TloadDback, participants were asked to rate their CF levels for a second time (post-TloadDback CF). Participants were then presented with their assigned video intervention (i.e., nature or urban). This video occupied the entirety of their computer screen and included audio as well. They were instructed to pay attention during the video so that afterwards they could indicate the location they believed the video took place (Hawaii, Australia, Greenland, or Russia). Participants then reported their CF levels for a third time after viewing the video (post-video CF).

Participants then completed a warm-up task, followed by performing as many push-ups as they could without stopping, until they were no longer able to complete a full push-up. After completion of their push-ups, participants were asked to report their performance (repetitions to fatigue; RTF), along with their RPE. Upon completing these questionnaires, participants were thanked for their time and reminded to complete their second session the following week. Following their second testing session, participants were presented with a debriefing document which disclosed the true purpose of the study. This procedure is visualised in Figure 3.

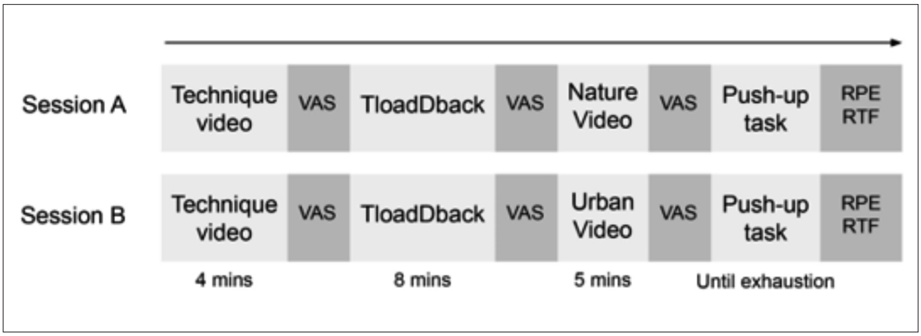
Statistical analysis

All data analyses were completed using SPSS 27.0. Data were examined initially for missing cases and the distribution checked for outliers and normality. No missing cases or outliers were identified, and all data were normally distributed, so parametric analyses were conducted. Subjective ratings of CF were analysed using a 3 (time: baseline, post-TloadDback, post-video) x 2 (condition: nature, urban) mixed model analysis of variance (ANOVA). Paired-sample *t*-tests were used to compare total push-ups completed and RPE scores between the nature and urban conditions.

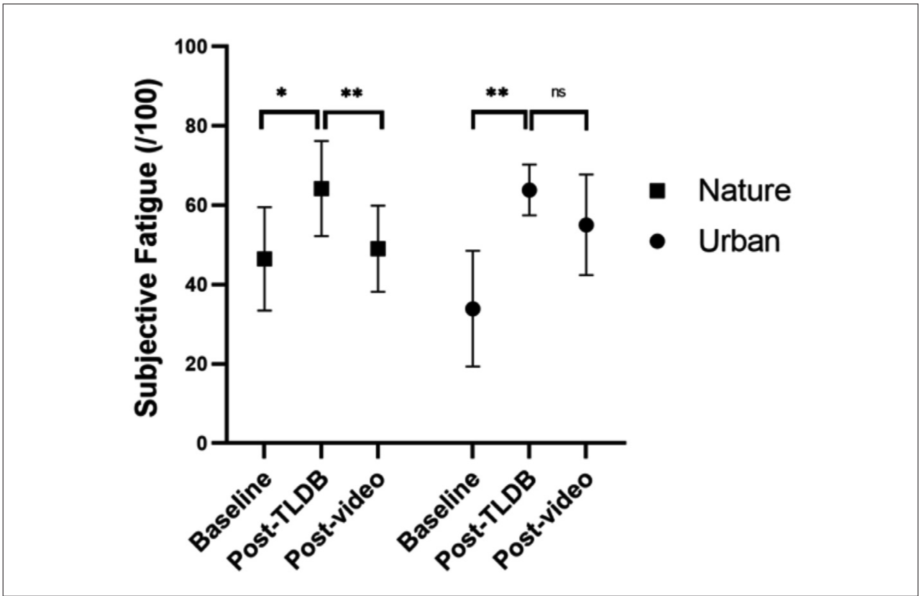
Results

CF ratings

To examine whether CF was successfully induced by the TloadDback, and then successfully reduced by watching the videos, CF ratings were compared at baseline, post-TloadDback, and post-video. This data is visualised in Figure 4.



Note. VAS = visual analog scale; TloadDback = Time-load Dual-back; RPE = rating of perceived exertion; RTF = repetitions to fatigue.
Fig. 3 - Experimental Procedure of the Study.



Note. Data presented here are *Mean ± 95% Confidence Intervals*; TLDB = TloadDback. *p < .05; **p < .01; ns = non-significant.
Fig. 4 - Subjective Cognitive Fatigue Ratings at Each Time Point for Both Conditions.

A 3 (time) by 2 (condition) mixed model ANOVA revealed a significant main effect of time, $F(2,26) = 15.40$, $p < .001$, $\eta^2_p = .54$, and no main effect of condition, $F(1,13) = 0.20$, $p = .661$, $\eta^2_p = .02$, but this was qualified by a significant interaction effect, $F(2,26) = 4.28$, $p = .025$, $\eta^2_p = .25$. Simple main effects of the interaction showed that was a significant change in scores over time for both the Nature condition, $F(2,12) = 5.73$, p = .018, $\eta^2_p = .49$, and the Urban condition, $F(2,12) = 10.97$, $p = .002$, $\eta^2_p = .65$. As shown in Figure 4, post-hoc analyses, with our α level adjusted using a Holm method for multiple comparisons (Holm, 1979), revealed a significant increase in CF from baseline to post-TloadDback for both conditions (nature: $p = .038$, Cohen's $d = 0.74$; urban: $p = .001$, $d = 1.00$). This was followed by a significant decrease in CF from post-TloadDback to post-video in the nature condition ($p = .008$, $d = 0.98$) but not in the urban condition ($p = .100$, $d = 0.42$). Additionally, in the nature condition, post-video CF ratings returned to baseline CF levels ($p = .568$, $d = 0.15$), while in the urban condition CF levels were still significantly higher at post-video than they were at baseline ($p = .002$, $d = 1.07$).

Push-Up Performance

Paired samples *t*-tests were conducted to examine the effect of CF on RTF and RPE between the nature and urban conditions. The mean and standard deviations of RTF and RPE for both conditions are presented in Table 1. There was no difference between conditions for RTF, $t(13) = 0.27$, $p = .792$, $d = 0.08$, or RPE scores, $t(13) = 1.83$, $p = .090$, $d = 0.47$.

Discussion

The aim of this study was to investigate whether exposure to a nature video (compared to an urban one) could aid in reducing CF. Exposure to nature was therefore expected to reduce the negative impact of CF on physical performance. Our findings partially supported our expectations: CF increased following the cognitive task, then dropped significantly after watching the nature video but not the urban video, suggesting that nature videos may facilitate recovery from CF. This reduced level of CF, however, did not translate to better push-up performance or RPE scores in the nature group compared to the urban group.

Previous work has highlighted the cognitive benefits of being exposed to nature, either through real exposure (e.g., Bratman et al., 2015) or exposure through videos, photos, or soundscapes (e.g., Kimura et al., 2021; Shu & Ma, 2019). Additionally, viewing nature photographs (Berto et al., 2005) and walking in nature (Berman et al., 2012) have both been shown to improve cognitive performance after being cognitively fatigued. Our results support this literature, finding that the nature condition (in which participants watched a first-person video of walking through nature) showed a greater reduction in subjective CF ratings after a cognitive fatiguing task than those in the urban condition (in which participants watched a first-person video of walking through busy city streets). As highlighted by the attention

Table I
Mean Repetitions to Fatigue and Ratings of Perceived Exertion for Both Conditions

Condition	RTF	RPE
Nature	25.43 ± 8.21	7.29 ± 1.94
Urban	25.79 ± 8.92	6.36 ± 2.10

Note. All values expressed as *Mean ± Standard Deviation*. RPE = rating of perceived exertion; RTF = repetitions to fatigue.

restoration theory (Kaplan, 1995), natural environments allow us to rest and recover our cognitive processes, as viewing nature does not require the same level of direct attention as other environments. Our findings thus support the idea that exposure to nature (even virtually) can aid in recovery from CF, and support the attention restoration theory in how nature exposure can recover our cognitive resources.

Even though our nature condition showed better recovery from CF, this did not translate to better physical performance on a subsequent push-up-to-exhaustion task. Existing literature shows that sub-maximal aerobic exercise, along with technical and tactical sporting performance, are susceptible to the negative effects of CF (Aitken & MacMahon, 2019). Bodyweight exercises, however, have been less extensively examined. While there is previous evidence of impaired push-up performance under the influence of CF (Dorris et al., 2012), this specific physical task is currently under examined.

The specific way in which the physical task was prescribed in this study may have influenced why no difference between conditions was seen. While we controlled the tempo of push-ups by having a 60 beats per minute metronome play during the push-up task (a similar approach to that used by Dorris et al., 2012), this study was self-administered by participants at home. As such, we could not verify that the prescribed tempo was followed. Dorris et al. (2012) carefully controlled the tempo, and thus a decline in performance was more likely to occur due to an inability to rest during the exercise. It may be that push-up performance is affected by CF but that there is a trade-off between RTF and time-on-task, where the freedom to complete the task at one's own pace will result in more repetitions. This could relate to motivational theories of CF (e.g., Inzlicht et al., 2014), where a prescribed tempo may lead to greater feelings of 'have to' motivation (rather than 'want to' motivation) and a greater impact on physical performance. To test whether this trade-off does occur, future research should test bodyweight exercise under CF and non-CF conditions, as well as performing the exercise with and without a controlled tempo.

In addition to there being no difference between the nature and urban conditions for push-up performance, there was also no difference between groups for RPE scores. RPE has been identified as one of the main mechanisms behind the effect of CF on physical performance (e.g., Marcora, 2008), with more cognitively fatigued individuals expected to report higher RPE scores. Previous work involving exposure to nature and physical performance, though, showed lower RPE scores (for similar peak power outputs) for participants exercising while exposed to imagery of natural, green environments (Akers et al., 2012). In this 'green exercise effect', however, Akers et al. (2012) did not test cognitively fatigued individuals. Sun, Soh, and Xu (2022) collected RPE after a cognitively fatiguing task and either nature or urban images, but they examined subsequent performance on a computerised decision-making task and found no change in RPE before and after this task. Indeed, to our knowledge, this study is the first to examine whether exposure to nature could limit the negative effect of CF on physical performance specifically. As such, while RPE scores may be lowered due to nature exposure in participants who have not engaged in demanding cognitive tasks before a physical task (as seen in Akers et al., 2012), there may be a more complicated effect in cognitively fatigued individuals. If RPE is often higher when one is cognitively fatigued, as per the psychobiological model (e.g., Marcora et al., 2009), then it may be that nature exposure is not enough to rejuvenate these feelings for a subsequent physical task. Additionally, the attention restoration theory highlights that nature exposure primarily restores attention specifically (Kaplan, 1995). A physical endurance task (like push ups to exhaustion) may not require as much attentional capacity to perform, so a nature exposure intervention would not be as beneficial for this type of physical exercise. Physical activities that incorporate more attention and cognitive demand, like decision-making in team sport, may benefit more from nature exposure (e.g., Sun, Soh, Roslan, Wazir, Mohammadi, et al., 2022). Further work in this area is needed.

This research has some limitations that should be considered when interpreting the results. This study was conducted online, which gave us less ability to control how participants completed the physical task (i.e., maintain proper push-up technique). It also gave us less control over when participants completed the study, although participants were told to complete the sessions one week apart, and to complete them both at roughly the same time of day. To reduce the demand of how many sessions participants had to complete online, we did not include a baseline measure of push up performance. Given our design was repeated measures, we instead relied on the two conditions eliciting different results, rather than comparing performance of both conditions to a baseline level. This was also similar to the design of Dorris et al. (2012). That being said, our sample consisted of recreationally active participants, with a variety of average exercise time per week (ranging from 30 mins to six hours), so future work could examine this effect with either a more homogenous sample, or by including a baseline measure of performance to better control for individual differences.

Another limitation may be the length of both the cognitive task and video interventions used. While the TloadDback effectively induced CF in participants, time-on-task may be a factor in the persistence of CF. Smith et al. (2019) reported that compared to a baseline rating, CF levels remained elevated for anywhere between 10 and 60 minutes depending on the specific cognitive task, but this was for tasks that were completed for 45 minutes. It may be the case that CF induced from only eight minutes of the TloadD-back, in comparison to the 16 minutes administered in previous studies (e.g., Borragán et al., 2017; O'Keeffe et al, 2020), did not persist for long enough to negatively influence subsequent push-up performance. A greater examination of CF recovery time following the administration of cognitive tasks in various lengths may help clarify our findings. Additionally, the length of nature interventions has not been consistent in previous work. Sun, Soh, and Xu (2022) had participants look at nature vs urban images for 4, 8, or 12 minutes, and found greater rejuvenating effects for the longer interventions, particularly the 12-minute nature condition. As such, our 5-minute videos, while appropriate for online testing in which potential distractions are not controlled, may not have been long enough to elicit a strong recovery effect, which may be why differences in push-up performance and RPE were not seen.

Conclusion

We demonstrated that a nature video was effective at reducing CF compared to an urban video, suggesting exposure to nature can improve recovery from CF. These findings, however, did not translate into better physical performance as expected. Regardless, this finding has possible applications in the fields of health, exercise, and sport. Studies comparing the differences between outdoor and indoor sport and exercise on mental wellbeing have shown promising results for outdoor physical activity (Thompson Coon et al., 2011). Indeed, the absence of restorative (natural) environments for individuals practicing sport indoors may serve as an inherent performance detriment, an area which has not yet been explored. Using nature as a restorative intervention may provide an edge for athletes competing in these environments. While we successfully conducted an online study in this space, the effects we induced may have been subtle in their impact on physical performance. More research is needed to determine the effects of exposure to nature on physical performance after CF, investigating different fatiguing tasks and lengths, and different physical outcome tasks. While there is evidence that research is progressing in this direction (e.g., MacMahon et al., 2021), it is clear that the specific underlying mechanisms implicated in the negative effects of CF on physical performance require further investigation. Our hope is that looking deep into nature, as Albert Einstein said, will help us understand everything better.

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