

Title:

Effects of Working Memory on Naturally Occurring Cravings.

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Abstract

Elaborated Intrusion (EI) theory posits a key role for visuospatial working memory (WM) in craving. In line with the predictions of EI theory, several studies have found that WM and craving show mutually interfering effects - for example, performance of visuospatial WM tasks has been found to attenuate naturally occurring cravings. However, the extent to which these effects are driven specifically by visuospatial processing remains unclear. We conducted two experiments to investigate the effects of WM on naturally occurring cravings in more detail. In experiment 1, we examined whether such effects are driven specifically by visuospatial WM processes or can also be induced by a verbal WM task. Subjective craving ratings were attenuated equally by performance of visuospatial and verbal WM tasks, suggesting that craving is not dependent specifically on visuospatial processing. In experiment 2, we examined whether effects of visuospatial WM on craving could be driven by simple distraction. Naturally occurring cravings were attenuated in a control condition with minimal WM demands (watching a video). However, the magnitude of attenuation was significantly greater in a visuospatial WM condition. Taken together, these findings highlight a key role for WM in the attenuation of naturally occurring craving, but do not support the hypothesis that such effects are dependent specifically on visuospatial processing.

Key words: Craving; Working Memory; Addiction; Obesity

Introduction

Craving, the “strong desire or urge to engage in some consummatory behaviour” (Verheul et al., 1999) is widely recognised as a core feature of addiction and obesity; it is included as part of the diagnostic criteria for Substance Use Disorders in the DSM-V and ICD-10 (American Psychiatric Association, 2013; World Health Organisation, 2018) and plays a key role in the maintenance of addiction and relapse in abstinent individuals (Franken, 2003). There are also clear parallels between cravings for drugs and food (Pelchat, 2002); craving influences snacking behaviour and compliance with diet (Pelchat, 2002), and has been associated with binge-eating (Potenza & Grilo, 2014).

Elaborated Intrusion (EI) theory (Kavanagh, Andrade and May, 2005) suggests that visuospatial processing plays a key role in craving. According to EI theory, if a stimulus evokes a strong affective reaction or raises awareness of the unavailability of the relevant substance, intrusive thoughts about the item are elaborated in working memory (WM). This involves effortful cognitive processing, whereby relevant information from long term memory (e.g. sensory information, specific episodes of consumption) and the immediate environment is integrated to construct and maintain vivid sensory images of the target item (Kavanagh et al., 2005).

A key feature of this hypothesis is that craving depends on the same limited capacity storage buffers used to store modality-specific information in WM. WM is a limited resource system – task-relevant items compete for limited cognitive and neuronal processing resources (Desimone, 1996). Therefore, according to EI theory, the experience of craving should interfere with performance on a concurrent visuospatial WM task. One way to test this prediction is to artificially induce cravings and test the effects of such cravings on cognitive performance. Studies that have adopted this approach have generally found reduced cognitive performance during craving. For example, Tiggemann et al. (2010) induced artificial cravings by asking subjects to abstain from eating chocolate for 24 hours and found that subjects in the craving condition showed reduced performance on the Corsi Blocks task, a test of visuospatial WM, relative to subjects in the non-craving condition. Using the same chocolate abstinence method, Kemps et al. (2008) found reduced WM performance in the craving condition relative to the non-craving condition, albeit only in subjects who reported high levels of trait chocolate craving. Green et al. (2000) induced cravings by requiring subjects to imagine their favourite food (or holiday as a control) and found increased reaction times in the food group relative to the holiday group.

EI theory also makes the reverse prediction - that it should be possible to attenuate cravings by asking subjects to perform a concurrent visuospatial WM task. Kemps et al. (2004) tested this prediction using an artificially induced craving method, in which subjects were required to form images of food-related items, and found that performance of 3 different visuospatial tasks – an eye movement task, a dynamic visual noise task and a spatial tapping task – attenuated the vividness of such food-related imagery relative to a control task involving looking at a blank computer monitor. Kemps et al. (2005) used the same imagery method to induce cravings and found that vividness of food imagery was reduced significantly more strongly in a visuospatial condition involving passively watching random squares changing from black to white than in a verbal condition involving listening to Dutch speech. Skorka- Brown et al. (2014) also tested this prediction but using naturally occurring cravings – subjects were asked about the strength, vividness and intrusiveness of any cravings they were experiencing before and during performance of different computerised tasks - and found that playing the computer game Tetris reduced the strength and vividness of naturally occurring cravings for items such as food, caffeine and cigarettes to a greater extent than a control task.

Given the emphasis of EI theory on the role of visuospatial imagery in craving, the studies reviewed above have tended to focus on the impact of visuospatial processing on craving. Whilst these studies do indeed seem to demonstrate that WM and craving exert some mutually interfering effects on each other, the evidence for a *specific* role for visuospatial WM in this respect is far less clear-cut. Of the studies examining the effects of craving on cognitive performance (Green et al., 2000; Kemps, Tiggemann, & Grigg, 2008; Tiggemann et al., 2010) only one found an effect that was specific to a visuospatial WM task (Tiggemann et al., 2010) and in that study baseline (non-craving) performance of the visuospatial task was higher than in the verbal tasks. The fact that baseline cognitive performance was not accounted for in the analysis leaves open the possibility that the craving effect was due to task difficulty rather than a process-specific mechanism.

Of the studies that have tested the reverse prediction – effects of task performance on craving strength - only one used a non-visuospatial control condition (Kemps et al., 2005). That study found an attenuation of craving in both the visuospatial and verbal conditions, albeit of greater magnitude in the visuospatial condition. However, as participants passively viewed (or listened to) the stimuli, with no performance measure in any condition, it is difficult to assess whether the differences between the two experimental tasks in terms of

their effects on craving reflect differential processing requirements in the two conditions or some other confound, for example the extent to which participants found the stimuli engaging. Indeed, the use of a stream of Dutch language in the verbal condition in a study of non-Dutch speaking participants makes this latter explanation a distinct possibility.

Other studies that have demonstrated putative effects of visuospatial task performance on craving strength made no attempt to determine the specificity of such effects to visuospatial task performance. Kemps et al. (2004) found that 3 different visuospatial tasks reduced imagery vividness and craving intensity relative to a resting control condition in which participants sat and watched a blank computer monitor. Similarly, in the Skorka-Brown et al. (2014) study that examined effects of visuospatial task performance on naturally occurring cravings, the control task required participants to watch a screen where an error message appeared. The lack of any kind of active control condition in these studies makes it impossible to assess the extent to which the results are driven specifically by visuospatial WM processes, or whether the same results would be observed with performance of an equally demanding verbal WM task, or indeed even a sufficiently distracting task that places minimal demands on the WM system.

In the present study we adopted the broad methodology of Skorka-Brown et al. (2014) with the aim of replicating their findings – a reduction in subjective craving ratings driven by performance of a visuospatial WM task - whilst also attempting to provide stronger evidence that such an effect is due specifically to visuospatial WM. As outlined above, the emphasis of EI theory on the visuospatial nature of craving leads to the prediction that performance of a visuospatial WM task should have a stronger effect than performance of a verbal WM task on cravings. This is an important question for both theoretical and practical purposes – for understanding the mechanistic basis of craving and for optimising interventions to reduce its effects.

In experiment 1, subjects were first asked whether they were craving anything and if so to provide ratings of the strength, vividness and intrusiveness of such cravings. Subjects reported craving a variety of things including food, drink, caffeine, nicotine and alcohol. After providing subjective craving ratings, subjects performed one of three tasks – Tetris (for comparability with Skorka-Brown et al., (2014), Corsi Blocks (a visuospatial WM task) and Digit Span (a verbal WM task) and finally were asked again about the strength, vividness and intrusiveness of their cravings. To assess whether effects of task performance are specific to craving, we also included questions about mood alongside the questions about cravings. In

line with EI theory, we predicted that subjects would show a greater attenuation of craving ratings in the Tetris and Corsi Blocks conditions than in the Digit Span condition due to the relatively greater loading of these tasks on visuospatial processes.

Experiment 1

Method

Participants

The study was approved by the Exeter University Psychology Research Ethics Committee (eCLESPsy000931 v3.3). A total of 121 participants were recruited via opportunity sampling through advertising online and around Exeter University campus and Exeter City. Out of these participants 84 (69%) were included in further analysis. Participants were excluded if they had no cravings (i.e. when asked in the first craving question “Are you craving anything?” they responded negatively), or if their data were incomplete. Of the 84 analysed participants 28 were male, and 56 were female (33% and 67% respectively). The majority of participants were students currently enrolled on an undergraduate degree course at Exeter University. Age ranged from 18-42 years old ($M=22.17$; $SD= 3.87$). No compensation was offered for participation.

Materials

Computerised Tasks.

The Corsi Block task and Digit Span task were downloaded and run from millisecond.com and run on Inquisit version 4. The Millisecond version of the Corsi Block task implements the procedure described in Kessels et al. (2000). Following an instruction page, 9 blue square frames appeared on a black background. A sequence of blocks flashed in yellow and participants were asked to respond in forward order by clicking on the squares in the order they had just seen. Stimulus duration was set at 1000ms, with an inter-stimulus interval of 250ms. In order to keep the duration of the task approximately the same for each subject, the task was programmed to not adapt to the subject’s performance level – every subject completed 16 trials in total, with each block sequence (2-9 blocks) being shown twice.

Participants had an unlimited time to respond, and there was no feedback on performance for each trial.

The Millisecond version of the Digit Span task implements the procedure described in Woods et al. (2011). Following an information page, a red circle indicated the start of the auditory digit sequence. A sequence of digits was presented auditorily, and another red circle indicated the end of the sequence. A response box was then shown in which participants were required to type the digits in the same order in which they were presented. Each digit was read for 1000 ms, with an inter-stimulus interval of 250ms. In order to keep the duration of the task approximately the same for each subject, the task was programmed to not adapt to the subject's performance level – every subject completed 16 trials in total, with each digit sequence (2-9 digits) being read twice. Participants had an unlimited time to respond and there was no feedback on performance for each trial.

The Tetris task, which was run from <https://Tetris.com>, required the participant to stack blocks and remove rows in order to avoid reaching the 'finish' line. As rows are removed the falling blocks increase in speed making it harder to not reach the finish line. Tetris has previously been shown to depend on WM processing (Lau-Zhu et al., 2017).

Questionnaires

Demographics Questionnaire

The demographics questionnaire consisted of 3 questions asking for the subject's age, gender and handedness.

PANAS-SF: Participants rated their mood on the 20-item positive affect negative affect scale – short form (PANAS-SF; Watson et al., 1988). The PANAS-SF was adapted to ask participants about their current mood before (PANAS-SF_{now}) and what their mood was during (PANAS-SF_{then}) the computer task. The PANAS-SF positive has previously been reported to have Cronbach's alpha rating of .89 and the PANAS-SF negative has previously been reported to have Cronbach's alpha rating of .85. In the present study Cronbach's alpha was .82 for the PANAS-SF positive and .71 for the PANAS-SF negative.

The adapted PANAS-SF scores were summed across questions for positive and negative affect separately providing a score for each subscale. Higher scores indicated higher

ratings of positive, or negative affect. This was conducted for the PANAS-SF_{now} and the PANAS-SF_{then} to provide before and during scores.

Craving Scales: Craving was assessed by asking participants to report if they were craving anything, and if so to report what they were craving and to rate their current level of craving on a single-item scale from 1 (“not craving very strongly”) to 100 (“craving very strongly”).

Further measures of craving were obtained using the craving experience questionnaire (CEQ) which was adapted by Andrade et al. (2012) to include both current (CEQ_{now}) and retrospective (CEQ_{then}) assessment of craving and which was also used by Skorka-Brown et al. (2014). The CEQ-S_{now} consists of three subscales assessing different aspects of current craving which are strength, imagery vividness, and intrusiveness. Once participants had completed the computer task, they then completed the CEQ-S_{then} (May et al., 2014). The CEQ-S_{then} contained the same subscales as the CEQ-S_{now}. However, the tense of the question changed to assess craving experience during the computer task (Corsi Blocks, Tetris or Digit-Span). The CEQ-S_{now} and CEQ-S_{then} have previously been reported to have Cronbach’s alpha ratings of 0.93 and 0.97 respectively (Andrade et al., 2012). In the present study Cronbach’s alpha ratings for the CEQ-S_{now} was 0.90 and for the CEQ-S_{then} was 0.96.

The CEQ- now and CEQ-then contain 11 craving items: 3 about strength, 5 about vividness, and 3 about intrusiveness. For each participant we computed an average CEQ-now craving strength score by averaging scores on the 3 items relating to that measure. We did the same for the vividness and intrusiveness measures, and then repeated the process for the CEQ-then items.

Procedure

Upon arrival at the laboratory, participants were given an information sheet then signed a consent form to give their informed consent. First, the participant completed a demographic questionnaire asking about age, gender and handedness. Next participants completed a series of questionnaires asking about their experience now – first the craving rating scale (1-100), then the adapted PANAS-SF (PANAS-SF_{now}) (Watson et al., 1988), and then the CEQ-S_{now} (May et al., 2014). The suffix ‘now’ refers to the fact that the questions all asked about their current experience.

After these questionnaires had been completed, the participant completed the computer task that they had been randomly assigned to (Corsi Blocks, Tetris or Digit-Span). Each task lasted approximately 4.5 minutes.

Following the computer task, participants completed another series of questionnaires asking about their experience during the task. These consisted of the craving rating scale (1-100), the adapted PANAS-SF (PANAS-SF_{then}) to ask how the participant felt during the task (Watson et al., 1988), and the CEQ-S_{then} (May et al., 2014). The suffix ‘then’ refers to the fact that participants were being asked to retrospectively rate their experience in the past, during task performance. The second administration of the (1-100) craving rating scale also asked subjects to rate their craving during task performance i.e. “Now think about the thing that you previously reported craving and rate on a scale of 1 (not craving very strongly) to 100 (craving very strongly) how strongly you were craving it while performing the task on the computer”.

Results

121 participants were tested. Of these, 84 were analysed further. Of the 37 participants removed, all reported not craving anything, other than one who had not completed the CEQ-S_{then}. The 84 who were analysed further reported craving food (63%), drink (11%), caffeine (14%), nicotine (8%), alcohol (2%) and 2% did not specify a craving item. In total 30 participants completed the Corsi Block task, 27 completed the Tetris task, and 27 completed the Digit-Span task.

Baseline Demographics and Mood

3 one-way ANOVAs with task (Corsi Blocks, Digit Span, Tetris) as the factor were carried out to test whether there were baseline differences in mood and age between groups. These revealed no significant difference between groups for the PANAS-SF_{now} positive, $F(2,82) = 1.53$, $p = .22$, $\eta_p^2 = .04$, the PANAS-SF_{now} negative, $F(2,82) = 2.82$, $p = .07$, $\eta_p^2 = .06$, or for age, $F(2,82) = .90$, $p = .41$, $\eta_p^2 = .02$.

Craving Data

All analyses were conducted using SPSS v.25. Four 3 X 2 mixed ANOVA’s were run with time (pre-task and during-task) as the within-subjects factor and task (Corsi Blocks, Tetris and Digit-Span) as the between subjects factor, for each of the dependent variables; the

single-item craving scale and the 3 CEQ-S subscales. In order to control for task-induced changes in mood we included two covariates in each of these ANOVAs - a positive mood change score calculated by subtracting the positive subscale score of the PANAS-SF_{then} from the positive subscale score of the PANAS-SF_{now}, and a negative mood change score calculated by subtracting the negative subscale score of the PANAS-SF_{then} from the negative subscale score of the PANAS-SF_{now}.

Craving Scale

There was a significant main effect of time on the single item craving scale $F(1,81) = 48.17$, $p < .001$, $\eta_p^2 = .379$. However, there was no significant interaction between time and task $F(2,81) = .24$, $p = .789$, $\eta_p^2 = .006$. Paired samples t -tests revealed significant differences between pre- and during-task ratings for each task: Corsi Blocks $t(29) = 4.39$, $p < .001$; Digit-Span $t(26) = 4.92$, $p < .001$; Tetris $t(26) = 5.30$, $p < .001$. In all task conditions craving scale rating decreased significantly over time (see figure 1).

CEQ-Strength

There was a significant main effect of time $F(1,80) = 68.40$, $p < .001$, $\eta_p^2 = .467$ but no significant interaction between time and task $F(2,80) = .45$, $p = .637$, $\eta_p^2 = .011$. Paired samples t -tests revealed significantly higher strength rating at the 'pre' timepoint than at the 'during' timepoint for all tasks: Corsi Blocks $t(28)=4.91$, $p < .001$; Digit-Span $t(26)=5.62$, $p < .001$; Tetris $t(26)=6.02$, $p < .001$ (see Figure 1).

CEQ-Vividness

There was a significant main effect of time $F(1,77) = 101.69$, $p < .001$, $\eta_p^2 = .576$ but no significant interaction between time and task $F(2,77) = .68$, $p = .512$, $\eta_p^2 = .018$. Paired samples t -tests revealed significantly higher vividness rating at the 'pre' timepoint than at the 'during' timepoint for all tasks: Corsi Blocks $t(28)=7.97$, $p < .001$; Digit-Span $t(25)=5.74$, $p < .001$; Tetris $t(24) = 7.33$, $p < .001$ (see Figure 1).

CEQ-Intrusiveness

There was a significant main effect of time $F(1,80) = 23.23$, $p < .001$, $\eta_p^2 = .229$. but no significant interaction between time and task $F(2,80) = .18$, $p = .833$, $\eta_p^2 = .005$. Paired samples t -tests revealed significantly higher intrusiveness rating at the 'pre' timepoint than at the 'during' timepoint for all tasks: Corsi Blocks $t(29)=2.48$, $p < .05$; Digit-Span $t(25)=2.93$, $p < .01$; Tetris $t(26)=4.16$, $p < .001$ (see Figure 1).

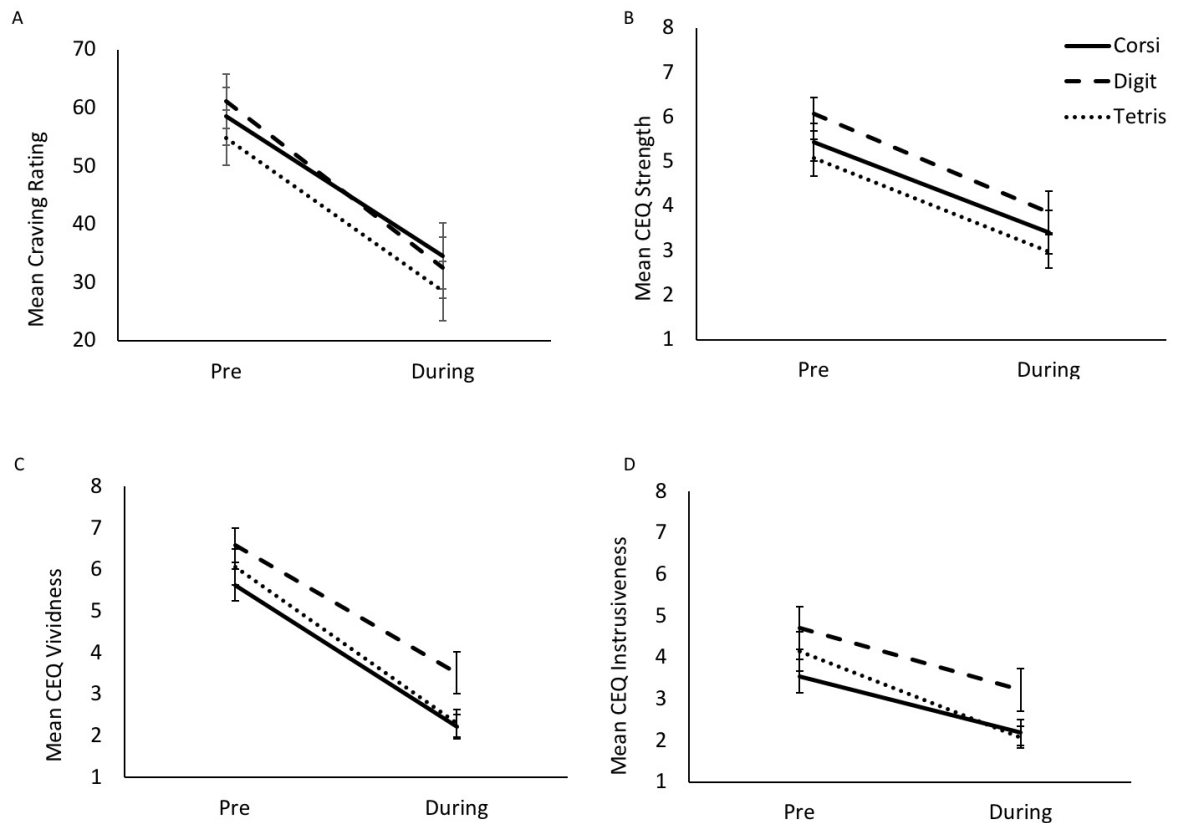


Figure 1: Mean subjective craving ratings at the two timepoints (pre- and during-task) in experiment 1 for the 3 task conditions, Corsi Blocks, Digit Span and Tetris. A – Overall (1-100) craving scale. B – CEQ strength subscale. C – CEQ vividness subscale. D – CEQ intrusiveness subscale. Error bars represent SEM.

Experiment 1 Discussion

The results of this experiment are broadly consistent with the hypothesis that craving involves WM processes as they clearly show attenuation of subjective craving ratings across all three task conditions, Corsi Blocks, Digit Span and Tetris. However, the finding that the attenuation of cravings was of equal magnitude in the Corsi Blocks and Digit Span conditions is inconsistent with the hypothesis that craving is specifically dependent on visuospatial processing; the results in fact demonstrate that performance of any WM task is sufficient to reduce cravings, regardless of the visuospatial content of the task.

An alternative explanation for the attenuation of craving seen in this study and in other similar studies, (e.g. Skorka-Brown et al., 2014) is that the effect is due to distraction rather than WM per se, in other words that the tasks reduced cravings because they simply

took subjects' minds off the target of their cravings. If that was the case, we should expect to see reductions of a similar magnitude in a condition that distracts subjects from the focus of their craving, but that places minimal demands on WM processes. In experiment 2, we investigated this possibility. Subjects provided subjective craving ratings before and after either performing the Corsi Blocks task or after a distraction control task (watching a video). We reasoned that if the attenuation of craving in experiment 1 was genuinely due to the concurrent WM load rather than simply distraction, there should be a stronger attenuation of cravings in the Corsi Blocks condition than in the video condition.

Experiment 2

Method

Participants

A total of 90 participants (39 male, 51 female) were recruited as a convenience sample from the University of Exeter undergraduate population. The majority of participants were students currently enrolled on an undergraduate degree course at Exeter University. Participants were aged between 19 and 25 ($M= 20.80$, $SD= 1.06$). There was no compensation for participation. The experiment was approved by the University of Exeter ethics committee (Ethics reference number: eCLESPsy000193).

Materials and Procedure

Subjective craving ratings were obtained using the same scales as in experiment 1. The procedure was exactly the same as that used in experiment 1, except for the following differences: Participants were randomly assigned to one of two groups – the experimental (Corsi Blocks) group or the control (video) group; The PANAS questions were not included in this experiment.

Results

In total 90 participants were tested. 14 participants reported not craving anything. Two participants reported being under the influence of marijuana. These participants were removed from subsequent analyses. The 74 who were analysed further (37 per condition) reported craving food and drink (70%), nicotine (9%), caffeine (18%), and other (3%).

Baseline Demographics

One way ANOVA with task as the factor (Corsi Blocks, Digit Span, Tetris) revealed no significant difference in age between the groups, $F(2,72) = .13$, $p = .72$, $\eta_p^2 = .002$.

Effects of WM on craving

In order to test the prediction that cravings reported before the experimental period would reduce to a greater extent whilst performing the Corsi blocks task compared to watching a video, we conducted a series of 2(condition) x 2(time) mixed ANOVAs on each dependent measure.

0-100 scale. The main effect of condition was significant $F(1,72) = 4.16$, $p < .05$, $\eta_p^2 = .06$, as was the main effect of time $F(1,72) = 102.45$, $p < .001$, $\eta_p^2 = .59$. There was also a significant interaction between condition and time $F(1,72) = 9.77$, $p < .01$, $\eta_p^2 = .12$. Paired samples t-tests revealed that craving strength significantly reduced from the pre to during time points in both the Corsi blocks task $t(36) = 8.74$, $p < .001$, and the video task $t(36) = 5.36$, $p < .001$. Independent samples t-tests revealed a significant difference between the Corsi Block and video conditions for during-task scores $t(72) = -3.11$, $p < .01$ but not for pre-task scores $t(72) = -0.38$, $p = .71$ (see figure 2).

CEQ- strength. The main effect of condition approached significance, $F(1,72) = 3.91$, $p = .052$, $\eta_p^2 = .05$. The main effect of time was significant $F(1,72) = 132.67$, $p < .001$, $\eta_p^2 = .65$, as well as the interaction between condition and time $F(1,72) = 4.09$, $p < .05$, $\eta_p^2 = .05$. Paired samples t-tests revealed that craving strength significantly reduced between the pre and during time points in both the Corsi blocks task $t(36) = 10.36$, $p < .001$, and the video task $t(36) = 6.28$, $p < .001$. Independent samples t-tests revealed a significant difference between the Corsi Block and video conditions for during-task scores, $t(72) = -2.35$, $p < .05$, but not for pre-task scores, $t(72) = -1.15$, $p = .26$ (see figure 2).

CEQ- vividness. There was a significant main effect of condition $F(1,72) = 8.77$, $p < .01$, $\eta_p^2 = .11$, and a significant main effect of time, $F(1,72) = 86.56$, $p < .001$, $\eta_p^2 = .55$ but no significant condition x time interaction $F(1,72) = 0.50$, $p = .499$, $\eta_p^2 = .01$. Paired samples t-tests revealed that craving strength reduced significantly during the Corsi blocks task $t(36) = 7.93$, $p < .001$, and the video task $t(35) = 5.24$, $p < .001$ (Figure 2). Independent samples t-tests revealed a significant difference between the Corsi Block and video conditions for

during-task scores, $t(70) = -2.50$, $p < .05$, and also for pre-task scores, $t(72) = -2.26$, $p < .05$ (see figure 2).

CEQ- intrusiveness. There was a significant main effect of condition $F(1,72) = 7.31$, $p < .01$, $\eta_p^2 = .09$, and a significant main effect of time $F(1,72) = 22.67$, $p < .001$, $\eta_p^2 = .24$, but no significant condition x time interaction, $F(1,72) = 2.32$, $p = .132$, $\eta_p^2 = .03$. Paired samples t-tests revealed that craving intrusiveness significantly reduced during both the Corsi blocks task $t(36) = 5.10$, $p < .001$, and the video task $t(36) = 2.06$, $p < .05$. (figure 2). Independent samples t-tests revealed a significant difference between the Corsi Block and video conditions for during-task scores, $t(72) = -3.19$, $p < .01$, but not for pre-task scores, $t(72) = -1.48$, $p = 0.14$ (see figure 2).

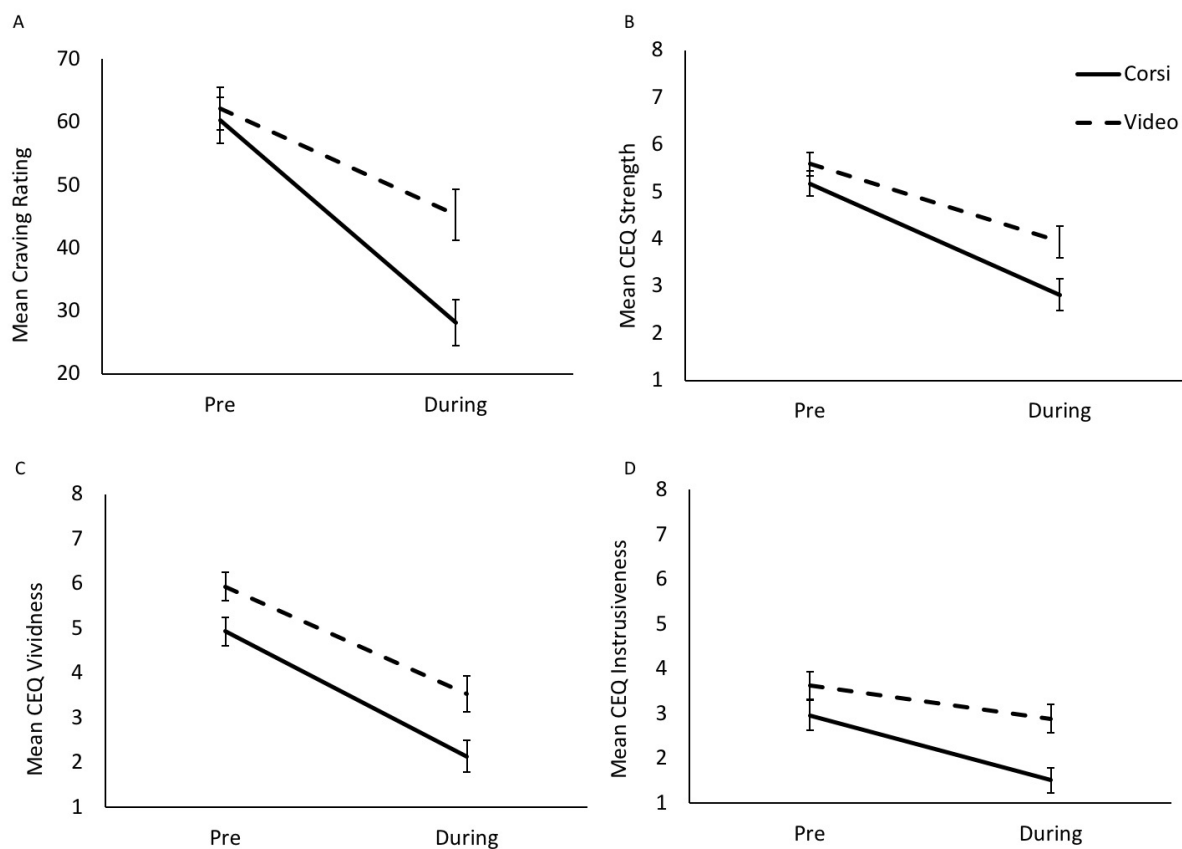


Figure 2: Mean subjective craving ratings at the two timepoints (pre- and during-task) in experiment 2 for the 2 task conditions, Corsi Blocks and Video. A – Overall (1-100) craving scale. B – CEQ strength subscale. C – CEQ vividness subscale. D – CEQ intrusiveness subscale. Error bars represent SEM.

General Discussion

In two experiments we examined the effects of visuospatial WM, verbal WM and distraction on subjective ratings of naturally occurring cravings. In experiment 1 we found an equally large attenuation of subjective craving ratings after performance of three different tasks regardless of their visuospatial content. In experiment 2 we found that subjective craving ratings were reduced after performing a visuospatial WM task and also after watching a video. For ratings of craving strength but not vividness or intrusiveness, the magnitude of this reduction was greater in the visuospatial WM condition than in the video condition.

Taken together, the results of these two experiments show that, consistent with findings from previous studies (Kemps et al., 2004; 2005; Skorka-Brown et al., 2014), performance of WM tasks can interfere with and attenuate subjective craving ratings. Craving plays a key role in the maintenance of addiction and relapse in abstinent individuals (Franken, 2003) and attenuating the strength, vividness and intrusiveness of cravings may therefore help to reduce addictive behaviours and prevent relapse in such individuals. The generalisability of the present findings is of course limited due to the healthy student sample, and we should be careful in extrapolating our findings to situations where cravings are pathological. Nevertheless, the results suggest that using WM-based interventions to target craving may prove an effective strategy in clinical populations.

However, the pattern of results of experiment 1 – in particular the lack of a significant difference between the Corsi Blocks and Digit Span conditions – argues against an account of these results based on a direct, modality-specific interference effect. WM is a limited capacity system with separable systems for the storage of visuospatial and phonological information (Baddeley, 1992) and it is well established that when subjects are required to perform two simultaneous WM tasks, performance suffers more if both tasks require the short-term storage of information in the same storage buffer (Robbins et al., 1996) due to shared reliance on limited visuospatial storage capacity. Similarly, if the interference that has been observed to occur between WM and craving is due to the reliance of the two processes on the same set of visuospatial resources, we should have observed a greater attenuation of cravings in the Corsi Blocks condition than in the Digit Span condition in experiment 1. However, we found that the level of visuospatial content of the task made little difference to its ability to effect a reduction in subjective craving ratings, suggesting that craving does not rely specifically on visuospatial processing.

The process specificity of these effects is key not only for understanding the mechanisms underlying craving but also for designing effective interventions for reducing craving in clinical populations. Follow-up work from the Skorka-Brown et al. (2014) study has focused on designing simple, app-based interventions to reduce cravings that involve participants performing visuospatial games such as Tetris. In designing such interventions, it is important to have a clear understanding of the key processes to be targeted in order for the interventions to be both effective and efficient. Whilst the magnitude of the effects of WM on craving in the present study, together with their replication across two experiments, provides support for the idea that performance of demanding WM tasks may be an effective intervention for reducing cravings outside the laboratory, the results suggest that any demanding WM task might be sufficiently distracting to serve as an intervention to reduce craving, regardless of the visuospatial content of the task.

An alternative explanation for the WM-driven attenuation of cravings in experiment 1 is that the tasks used in that experiment simply distracted subjects from the target of their craving. The attenuation of cravings in the video condition in experiment 2 provides some support for this idea. However, the fact that the magnitude of the craving attenuation was greater in the Corsi Blocks condition suggests that the efficacy of the intervening task at attenuating cravings is greatest when that task involves cognitively demanding WM processes. Nevertheless, the interaction between time and condition in experiment 2 only reached significance for ratings of craving strength, and not for vividness or intrusiveness, which were equally reduced in the video condition and the Corsi Blocks condition. Thus, to some extent a simple distraction effect may account for these effects, at least in terms of ratings of the sensory quality and impact of the cravings. One possible interpretation of this is that any distraction involving visuospatial processing is able to interfere with the sensory component of craving, but that active WM processing is more effective at disrupting the subject's appraisal of that sensory experience.

In terms of the longevity of the effects we observed, the post-test measure of cravings was taken directly after the participants had engaged in their allocated task. Thus, although visuospatial interference attenuated cravings as predicted, further research is required to establish whether the interference with craving processes continues beyond this point. If these cognitive tasks only provide momentary relief from cravings (Kemps & Tiggemann, 2015) then this limits the utility of such tasks as a craving reduction technique, so future research needs to measure cravings after a longer delay. It is also unknown whether the present

findings generated from a non-clinical sample generalise to a clinical sample who have problematic cravings, which may be more resistant to such craving reduction techniques.

In considering the implications of these findings for addiction, it is also worth taking into account individual differences in WM capacity. A consistent finding in the addiction literature is that subjects with high WM capacity tend to fare better than subjects with low WM capacity in terms of addiction-based outcomes, for example control over craving, dependence and abstinence (Khurana et al., 2017; Houck & Ewing, 2018). These findings seem at first glance to be incompatible with EI theory, which appears to make the opposite prediction – if craving is dependent on WM, then subjects with high WM capacity should be *more* susceptible to craving than subjects with low WM capacity. However, it may be possible to accommodate such findings within the EI framework. For example, one possibility is that in subjects with low WM capacity, craving exhausts the limited supply of cognitive resources, leaving little capacity for additional cognitive control over behaviour and leading to poor impulse control. In contrast, subjects with high WM capacity may have spare capacity remaining even during periods of high craving, allowing them to exercise better impulse control.

Limitations

The present study has certain limitations that should be taken into account. Firstly, the versions of the PANAS used here (PANAS-SF_{now} and PANAS-SF_{then}), which were designed to assess mood both now and in the recent past, have not been previously used and are therefore not yet validated. Secondly, the sample in both experiments consisted of psychology students and therefore may not be representative of the wider population. Future studies should try to reproduce these findings in clinical populations with more severe, pathological craving.

Summary

The findings from these two experiments support the hypothesis that WM processes play a key role in maintaining subjective craving but are not consistent with the prediction that such maintenance of craving is specifically dependent on visuospatial processes. The efficacy of a particular intervention in reducing naturally occurring cravings may lie in its

ability to distract from the focus of the craving by focusing attention instead on current task demands.

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