The role of working memory sub-components in food choice and dieting success.

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Abstract

Evidence suggests a role for self-reported working memory (WM) in self-reported food intake, but it is not known which WM sub-components are involved. It is also important to consider how individual differences in dietary restraint and disinhibition influence WM and the impact of this on food choice. The current study assessed the relationship between WM sub-components and food choice, using computerised measures of WM sub-components and a direct assessment of food intake. The role of dieting success (measured by restraint and disinhibition) as a distal predictor of food choice that influences food choices via WM, and the role of WM more generally in dieting success were investigated. Female undergraduate students (N = 117, mean age: 18.9 years, mean BMI: 21.6 kg/m^2) completed computer tasks assessing three components of WM (updating, phonological loop and visuospatial sketchpad) and a snack food taste-test. Greater visuospatial WM span was associated with a higher (lower) percentage of food intake that was low (high) energy dense. It was also found that unsuccessful dieters (high restraint, high disinhibition) had poorer visuospatial WM span and consumed a lower (higher) percentage of low (high) energy dense food. Visuospatial WM span significantly mediated the relationship between dieting success and percentage of low energy dense food intake. Further, dietary restraint was associated with poorer updating ability, irrespective of disinhibition. These findings suggest that better visuospatial WM is associated with a greater (reduced) preference for low (high) energy dense foods, and that deficits in visuospatial WM may undermine dieting attempts. Future work should assess whether the ability to deal with food cravings mediates the relationship between visuospatial WM and dieting success and investigate how WM may influence the mechanisms underlying behavioural control.

Keywords: working memory, food intake, restraint, disinhibition, successful dieting

The factors affecting food intake decisions are far-reaching and include both internal and external influences (Herman & Polivy, 2008). Important internal influences include cognitive functions, such as episodic memory, learning and executive functions (Higgs, Robinson, & Lee, 2012). Executive functions are a set of cognitive abilities that allow individuals to regulate their behaviour according to their higher-order goals or plans. They can be recruited when behaviour is effortful and deliberate (Diamond, 2013), but also as part of a learned reflex in the form of automatic inhibition (Verbruggen, Best, Bowditch, Stevens, & McLaren, 2014). Executive functions may be a key determinant of the strength of reflective processes in the dual-process theories of behaviour control (Hofmann, Schmeichel, & Baddeley, 2012; Strack & Deutsch, 2004). The current consensus is that there are three core executive functions: inhibition, working memory and cognitive flexibility/set-shifting (Diamond, 2013; Miyake et al., 2000). The importance of executive functions in controlling eating behaviour has been shown repeatedly, with findings suggesting that better executive functions are associated with more healthful eating habits (Allom & Mullan, 2014; Hall, Fong, Epp, & Elias, 2008; Hall, 2012). Studies have shown that training inhibitory control can improve eating behaviour and aid weight loss (Lawrence et al., 2015; Veling, Koningsbruggen, Aarts, & Stroebe, 2014). However, the results of meta-analyses have revealed inconsistent effects, and the mechanisms by which these work are varied (Allom, Mullan, & Hagger, 2015; Jones et al., 2016).

The second of these core executive functions, working memory (WM), and its role in eating behaviour has been relatively less well studied. Nonetheless, WM is now considered an important executive function, alongside inhibitory control ability, that may play a role in the reflective processes that influence eating behaviour (Hofmann, Friese, & Wiers, 2008). Important components of WM relevant to self-regulation of behaviour include not only the amount of information that can be held active at any given time, but also the ability to hold in mind information stored in long-term memory and to maintain focused attention on currently active information while preventing the interference of other potentially distracting information (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008). Applied to eating behaviour, WM capacity may be important in retrieving long-term memories and holding these active in WM (e.g. dieting goals); resisting attending to eye-catching stimuli in the environment (e.g. tempting foods); protecting active goals from distracting stimuli by maintaining focused attention on the active goals; and down-regulating emotions (e.g. reducing cravings in a given situation) (Hofmann et al., 2012).

Working memory capacity has been reported to moderate the role of impulsive processes in predicting health behaviours. For example, in people with low WM capacity, impulsive processes were better predictors of high energy dense (HED) food consumption than in people with higher WM capacity (Hofmann, Friese, & Roefs, 2009; Hofmann, Gschwendner, et al., 2008). Few studies have examined the direct relationship between WM and food intake, and the findings are contradictory. Two studies found that WM negatively correlated with snack food intake (Riggs, Chou, Spruijt-Metz, & Pentz, 2010; Riggs, Spruijt-Metz, Sakuma, Chou, & Pentz, 2010), whereas two other studies found no association with fat intake (Allom & Mullan, 2014; Limbers & Young, 2015). The former two studies assessed self-reported executive functioning using the Behavioural Rating Inventory of Executive Functioning (using the subscales “emotional control”, “inhibitory control”, “working memory” - e.g. “I forget what I’m doing in the middle of things” and “organisation of materials”) (Guy, Isquith, & Gioia, 2004). The final analysis in both studies combined scores on all subscales to form a composite executive function score (Riggs, Chou, et al., 2010; Riggs, Spruijt-Metz, et al., 2010). Therefore, little can be said about the role of WM in food intake, because an overall composite score leaves the contribution of the WM subscale unclear. Limbers and Young (2015) found that the relationship between WM and saturated fat intake disappeared when controlling for demographic factors, BMI and eating styles. While this study also used the BRIEF measure of executive functioning, the relationship between food intake and performance on the individual subscales was assessed, increasing confidence that these findings relate to WM specifically. Allom and Mullan (2014) used the n-back and operation span tasks to assess WM (updating ability specifically), which are validated measures of WM that do not rely on self-reports of behaviour (Diamond, 2013; Miyake et al., 2000). Overall, the strength of evidence suggests that perhaps WM is not important for intake of high energy dense foods.

Research on the relationship between WM and fruit and vegetable intake also appears to be contradictory but may be explained by the differing methods used to assess WM across studies. Allom and Mullan (2014) and Sabia et al. (2009) used computerised assessment of WM and found a positive correlation between WM and fruit/vegetable intake. Limbers and Young (2015) did not find a relationship between WM and fruit/vegetable intake, but these authors assessed WM via self-report. On the other hand, Riggs, Chou et al., (2010), who also used a self-report measure of WM ability, did report a positive relationship between WM and fruit/vegetable intake. Theoretically, WM may play a more important role in intake of low energy dense foods than high energy dense foods. Allom and Mullan (2014) based on their finding that WM was associated with fruit/vegetable intake and not saturated fat intake, argued that inhibitory control is not important for health improving behaviours, but rather updating, or working memory is important as it directly supports activation and maintenance of long-term goals (such as weight loss) that encourages low energy dense (LED) food consumption.

Several factors limit the research conducted to date on the relationship between WM and food intake. While the self-report measures of WM may provide greater ecological validity due to assessment of WM performance in everyday situations, these measures are subject to self-report bias. A further limiting factor is the lack of consideration of the role of WM sub-components. The traditional view of WM is that there are three core components of WM: the central executive is an attentional control system that allocates, divides and switches attention across two slave sub-systems. The two slave sub-systems (the phonological loop and the visuospatial sketchpad) deal with different information, namely verbal and acoustic information and visual and spatial information, respectively (Baddeley, 2007). The three core components of WM have different functions that could differentially relate to food intake. For example, the slave sub-systems could be important in the processing of visual aspects of food (e.g. what looks appetizing and food cravings) and the auditory aspects (e.g. the sound of food cooking or unwrapping food), whereas the central executive could be important for the allocation of attention to these sub-components and retrieving long-term memories about health goals. More recent literature argues for retiring the central executive in favour of multiple specialised skills, such as updating the contents of WM and inhibition of distraction for items held in WM (Logie, 2016). Updating is one central executive function that has been shown to relate to food intake (Hofmann, Gschwendner, et al., 2008; Hofmann et al., 2012). A final limitation of previous studies is that food frequency questionnaires have been used to measure food intake, which is subject to self-report bias and recall error. More reliable measures of food intake are needed, such as a laboratory-based taste-test that measures actual food consumption.

It is also important to consider potential moderators of the relationship between WM and food intake, such as psychological eating styles that are associated with differences in WM. Dieting in individuals high in cognitive restraint is related to WM deficits such as deficits in sustained attention (Rogers & Green, 1993), poorer immediate recall and slower reaction times compared with non-dieters (Green & Rogers, 1995; Green, Rogers, Elliman, &

Gatenby, 1994). Specific deficits have also been shown in sub-components of WM (Green & Rogers, 1998; Green, Elliman, & Rogers, 1997), including the central executive (Green et al., 2003; Kemps & Tiggemann, 2005; Kemps, Tiggemann, & Marshall, 2005) and phonological loop (Green & Elliman, 2013; Shaw & Tiggemann, 2004; Vreugdenburg, Bryan, & Kemps, 2003), but not the visuospatial sketchpad (Green & Rogers, 1998; Kemps, Tiggemann, & Marshall, 2005; Kemps & Tiggemann, 2005; Shaw & Tiggemann, 2004; Vreugdenburg et al., 2003). However, evidence for deficits in phonological loop functions is somewhat contradictory (see Green et al., 2003; Kemps & Tiggemann, 2005; Shaw & Tiggemann, 2004; Vreugdenburg et al., 2003). Overall, these data suggest a negative impact of dieting behaviour on some aspects of WM, which could mediate the relationship between dieting and food intake.

A further consideration is that studies investigating the effects of dieting on WM have compared current dieters with non-dieters and have not usually distinguished between successful and unsuccessful dieters (Kemps & Tiggemann, 2005; Kemps, Tiggemann, & Marshall, 2005). Individuals who score high on cognitive restraint but low on the tendency towards disinhibition (successful dieters) respond differently to individuals scoring high in restraint and high in the tendency towards disinhibition (unsuccessful dieters) in a task assessing WM guidance of attention to food cues (Higgs, Dolmans, Humphreys, & Rutters, 2015). Successful and unsuccessful dieters have also been shown to differ in their experiences of food cravings: unsuccessful dieters reported more food cravings relating to difficulties in self-control over food intake and intentions to consume food than did successful dieters (Meule, Lutz, Vögele, & Kübler, 2012). Cravings are believed to be visual in nature (May, Andrade, Kavanagh, & Penfound, 2008; May, Andrade, Panabokke, & Kavanagh, 2004; Tiggemann & Kemps, 2005) and to consume visuospatial WM resources, impairing performance on other visuospatial WM tasks (Green, Rogers, & Elliman, 2000;

Kemps, Tiggemann, & Grigg, 2008; Meule, Skirde, Freund, Vögele, & Kübler, 2012; Tiggemann, Kemps, & Parnell, 2010). It is therefore possible that successful dieters have greater visuospatial WM capacity, allowing them to deal with demands on visuospatial WM more appropriately, such as food cravings.

In summary, there has been little investigation of the role of specific WM processes in eating behaviour to date. The aim of the present study was to investigate the role of WM sub-components in food choice using computerised measures of WM and a measure of actual food intake (food taste-test paradigm). In addition, the role of dieting success (measured by restraint and disinhibition) as a distal predictor of food intake that influences food choices via WM, and the role of WM more generally in dieting success were assessed. The association between WM and food choice, with dieting success as a distal predictor can be conceptualised within a mediation framework, in which the effects of dieting success on food choice are mediated by WM. It was therefore predicted that there would be a significant relationship between WM and food choice, such that better WM would be associated with a greater (lower) percentage of total food intake that was LED (HED; hypothesis 1). There is currently little evidence to suggest that any one sub-component or function of WM may play a more important role in food choice over other WM components, and therefore predictions regarding specific WM sub-components were not made. Considering the research that has found dieting to be associated with WM deficits, it was expected that dietary restraint, irrespective of disinhibition, would be associated with poorer updating and phonological loop functioning (but not visuospatial span, hypothesis 2). However, it was also predicted that dieting success would be associated with WM (such that successful dieters would show better visuospatial WM than unsuccessful dieters, hypothesis 3). It was also expected that dieting success would be associated with food choice, such that successful dieters would consume a greater (lower) percentage of their total food intake from LED (HED) food (hypothesis 4).

Finally, it was predicted that there would be a significant indirect relationship between dieting success and food choice via WM (hypothesis 5). Again, no predictions about the specific WM components or functions involved here were made, as current research does not suggest any one specific WM component is more involved in food intake than others.

Methods

Participants

Female undergraduate students at the University of Birmingham received course credit for taking part in this study (N=117). Only females were included because eating habits are known to differ between men and women, and dieting to control weight is more common in women (Kiefer, Rathmanner, & Kunze, 2005; Wardle et al., 2004). Participants were required to have normal or corrected-to-normal vision, but there were no restrictions based on age or BMI. One participant was excluded from the analyses as she was an outlier on a number of measures, and reported that she was sad during the experiment (final N = 116). There were no outliers on any of the WM outcome measures. However, one participant failed twice on the lowest level of the backwards digit task, which was most likely because they did not understand the instruction to reverse the sequence, and therefore this participant was excluded on that task.

To disguise the aims, the study was advertised as investigating the relationship between cognitive functioning and food taste perceptions. The sample size was decided a priori via a power calculation using G Power (Faul, Erdfelder, Lang, & Buchner, 2007). With power set at 0.8 and alpha 0.05, to identify a medium effect size ($f^2 = 0.15$) in a multiple linear regression, a sample size of 92 participants would be needed. Previous studies assessing the association between WM and food intake identified medium to large effect sizes when WM was included in the models (Allom & Mullan, 2014; Limbers & Young, 2015), and hence it was reasonable to expect a similar effect size. As it would not be possible to predict which group participants would fall into prior to testing them (allocation to groups was based on levels of restraint and disinhibition using questionnaire responses), more than 92 participants were recruited to ensure there were sufficient numbers in each group. However, further targeted recruitment was required towards the end of the study to obtain more balanced groups. The final sample size (116) powered the study to identify a medium effect size with up to 9 predictors, although a maximum of 5 were actually used in any given analysis. This study was approved by the Middlesex University Psychology Ethics Sub-committee and the University of Birmingham Research Ethics Committee.

Measures

Demographic information. Participants were asked to report their age, ethnicity, when they last ate, whether and how often they drink alcohol and smoke, whether they have any food allergies, or have past or current psychological issues. These were used to characterise the sample, and anyone with food allergies were excluded (none were excluded on this basis).

Working memory assessments

Updating. Updating was assessed using the validated Spatial Working Memory test of the Cambridge Cognition Neuropsychological Test Automated Battery (CANTAB, Cambridge Cognition, Cambridge, UK). This task required updating within the visuospatial domain. Participants had to search for blue tokens hidden inside coloured boxes. Once a token was found inside a box, a token would not be hidden inside that box again. Therefore, participants had to remember where they had already found tokens and update the information held in WM so as not to return to the same box twice. Updating ability is considered an important component of WM for self-regulation of behaviour (Hofmann et al., 2012). The task started with 4 boxes and 4 tokens to find, and increased to 6, 8 and finally 10 boxes and 10 tokens. The key outcome measure for updating ability was the degree to which participants used a strategy to perform the task (Goghari et al., 2014; Owen, Downes, Sahakian, Polkey, & Robbins, 1990). The best strategy for this task was to search the boxes in the same order every time a new search commenced. The number of times a participant started the search from a different box was counted, and a higher score therefore indicated poorer use of this strategy.

Phonological loop. The phonological loop component of WM was assessed using the backwards digit span task. Participants were shown a sequence of numbers on screen and had to recall the sequence in reverse order, using the on-screen number pad. The first sequence contained 3 items and increased by one after two consecutive correct answers. The task finished when two consecutive incorrect answers were given. The longest sequence of numbers remembered correctly was taken as a measure of the participant's phonological loop capacity. The digit span task is a validated measure of short-term memory, specifically phonological loop capacity (Baddeley, Gathercole, & Papagno, 1998) and has previously been used to identify poorer phonological loop capacity in unsuccessful dieters compared to non-dieters (Kemps, Tiggemann, & Marshall, 2005).

Visuospatial sketchpad. The visuospatial sketchpad component of WM was assessed using the Spatial Span Task from the Cambridge Cognition Neuropsychological Test Automated Battery (CANTAB, Cambridge Cognition, Cambridge, UK), which is a computerised version of the Corsi blocks task (a validated measure of visuospatial sketchpad capacity; Hanley, Young, & Pearson, 1991). White squares were shown on screen, and several of these briefly changed colour. Participants had to touch the squares in the correct order in which they changed colour (on a touch screen monitor). The first sequence contained

2 square colour changes, and increased by one after every correctly recalled sequence. The task finished when three consecutive sequences were recalled incorrectly. Visuospatial WM capacity was taken as the highest level of this task successfully completed.

Taste test

Eating behaviour was assessed in the laboratory using a bogus taste-test paradigm (Houben, 2011). Participants were presented with a snack buffet box containing 4 high energy dense (HED) foods (chocolate chip cookies ~65g, ~323 kcal; cheese and onion rolls ~65g, ~201 kcal; MnM's, ~165g, 799 kcal; and ready salted crisps, ~25g, ~133 kcal) and 4 low energy dense (LED) foods (carrot sticks ~110g, ~44 kcal; plum tomatoes ~139g, ~28 kcal; grapes, ~153g, ~101 kcal; and salt and vinegar rice cakes, ~10.5g, ~40 kcal). All food was manufactured by Sainsbury's UK, except for the M&Ms (Mars, France) and rice cakes (Snack a Jacks, UK). These foods were chosen to provide a range of high and low energy dense foods from both sweet and savoury categories to account for different preferences. To bolster the cover story, participants were given 10 minutes to taste each of the foods and rate them on three 100mm visual analogue scales, with the questions above "How pleasant was the taste of the…?"; "how bitter was the taste of the…?" and "how sweet was the taste of the…?", with anchors "not at all" and "extremely". Participants were told they could eat as much or as little of the foods as they wished, as any remaining food would be thrown away afterwards. To create an outcome measure that reflected the healthiness of food choices when participants were offered both low and high energy dense food options (our primary interest in this study), the percentage of total food intake that was LED was calculated. Specifically, the amount consumed by each participant was first calculated by subtracting the post taste-test weight from the pre taste-test weight for each of the food items. This was then totalled separately for the HED and LED foods. Total LED intake (grams) was divided by the total amount eaten (HED + LED grams), and multiplied by 100 to give the percentage of total snack intake that was LED food.

Dieting behaviour

The cognitive restraint and disinhibition subscales of the Three Factor Eating Questionnaire (TFEQ) were used to identify successful and unsuccessful dieters (Stunkard & Messick, 1985). In the majority of our analyses restraint and disinhibition remain as continuous variables. However, for the categorical analyses to identify baseline group differences those who scored ≥9 on the restraint subscale and ≥7 on the disinhibition subscale were classified as unsuccessful dieters (Higgs et al., 2015). Those scoring ≥9 and <7 on these subscales (respectively) were classified as successful dieters. Classification of dieting status took place after participants had taken part in the study, therefore reducing any experimenter-induced expectancy effects as the researcher was blind to dieting status during the testing sessions. Appended to the end of the TFEQ was the question "are you currently dieting to lose weight?" to characterize the sample.

Procedure

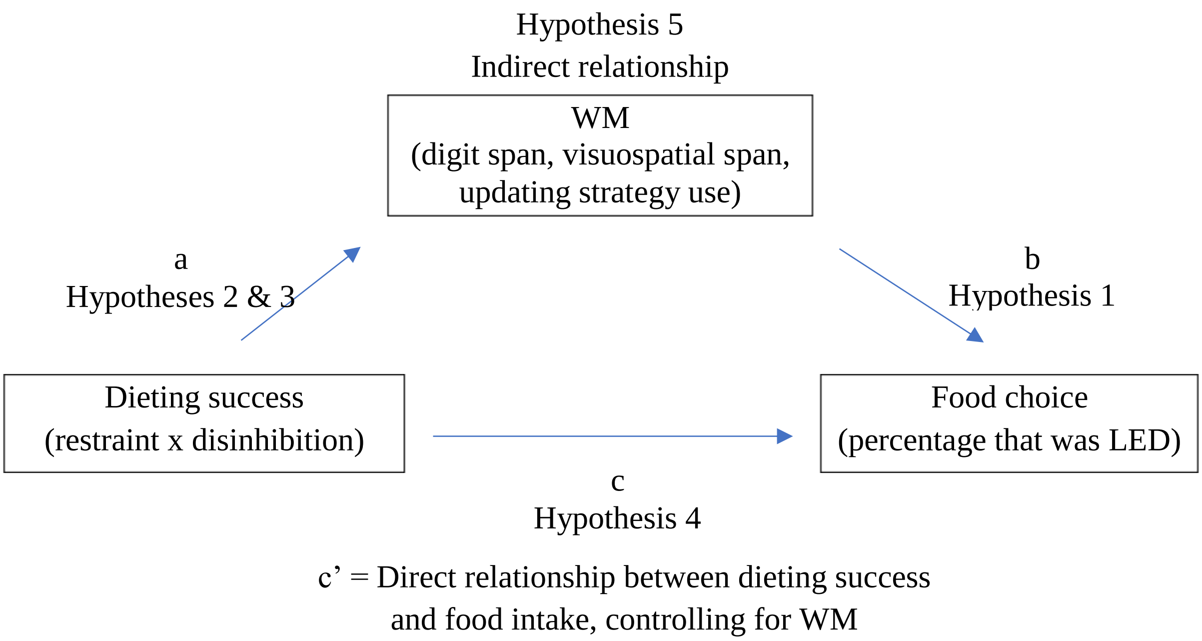
Testing sessions took place between 9:30am-12pm and 1:30pm-5pm, and participants were tested individually in a cubicle. Upon arrival, participants provided informed consent, completed the medical history and food allergies screening questionnaire, and rated their baseline hunger and fullness on 100mm VAS scales asking "how hungry/full do you feel right now?" with the anchors "not at all hungry/full" and "extremely hungry/full". As a further distraction to the aims of the study, participants completed a number of 100mm VAS scales asking about their mood. These consisted of the question "How …. do you feel right now?", with various emotions inserted, for example, happy, sad, nervous and irritable. Anchors were "not at all" and "extremely". The participant then completed the WM tests and repeated the hunger and mood questions. Then the participant completed the snack food taste-test and another set of hunger and mood questions. The questionnaire pack that contained questions on demographics and the TFEQ was then completed. To probe awareness of the study aims, participants were asked the following open ended questions: 1) "what do you think was the purpose of the study?" and 2) "in the snack buffet, what do you think the researchers were interested in?" Height and weight were measured using a stadiometer and body weight scales (heavy clothing and shoes removed) in order to calculate BMI (kg/m^2). Participants were then debriefed. The first participant did not eat until 10am, and the last participant ate at 4:30pm, as these are considered normal snacking times.

Data analysis

Group differences on baseline characteristics were checked with a multivariate ANOVA with restraint (high, low) and disinhibition (high, low) as factors and BMI, age and baseline hunger as outcomes. Correlations were also conducted to identify if food intake correlated with baseline characteristics (e.g. age, BMI, hunger, when last ate, and liking of each food).

Mediation analysis was conducted using model 4 of the PROCESS macro for SPSS (Hayes, 2013), entering the interaction between restraint and disinhibition (mean centred) as the independent variable, WM performance (digit span, visuospatial span and updating strategy use) as the mediator, and percentage of food consumed that was LED as the dependent variable. Bayesian linear regressions were conducted to identify the strength of evidence supporting the alternative and null hypotheses regarding the relationship between WM components and food choice. A Bayes factors close to 1 represents evidence that is insensitive and inconclusive, a Bayes factor much greater than 1 reflects strong evidence of the alternative hypothesis, whereas closer to 0 represents strong evidence of the null hypothesis (Dienes, 2014). More specific cut-offs have been suggested, whereby a value of 3 or higher is substantial evidence of the alternative hypothesis and less than 0.3 is substantial evidence for the null hypothesis (Dienes, 2016; Jeffreys, 1961). Values between 0.3 and 3 are considered anecdotal evidence.

In order to understand associations between dieting success and WM/food choice, regressions were run with restraint, disinhibition and the interaction between the two as independent variables and WM performance (digit span, visuospatial span and updating strategy use) and percentage of food consumed that was LED as the dependent variables. Simple slopes analyses were used to visualise interaction effects. Bias-corrected and accelerated bootstrapping (based on 1000 bootstrap samples) was applied to overcome any issues with bias. The regression results for the interaction between restraint and disinhibition replicated the effects found in the mediation analyses, and so to avoid repeating results, only the simple slopes analyses for significant interaction effects are reported. Main effects of restraint and disinhibition are also only reported where significant. Figure 1 shows a model of how we expected WM to be associated with food choice and dieting success, and how WM was



expected to mediate the relationship between dieting success and food choice.

Figure 1. Model of dieting success as a predictor of food choice, mediated by WM.

Results

Participant characteristics

Mean age of the sample was 18.9 years (*SD* = 1.0, range = 18-24 years) with a mean BMI of 21.6 kg/m^2 (*SD* = 2.6, range = 16.9-30.6). Seventy-nine participants self-reported as being white, 21 Asian/Asian British, 8 Black/African/Caribbean/Black British; 7 mixed/multiple ethnic group, and 1 as "other". Twenty-three participants reported that they were currently dieting to lose weight. A small number of participants (5.2%) were self-reported light smokers or had past or current psychological health problems (11.2%), and 92.2% said that they drink the government guideline of 14 units of alcohol per week or less (Department of Health UK, 2016). Participants last ate on average 364 minutes prior to participating in the study (range = 80-1440 minutes), indicating that in general they had complied with the instruction to not eat for at least 2 hours before taking part. However, one person ate 80 minutes and two ate 90 minutes prior to the study. Excluding these from the analyses did not alter the results, and so their data were included in the analyses. Mean hunger and fullness ratings at the beginning of the study were 48.4 (*SD* = 20.2) and 29.9 (*SD* = 20.3), respectively. Mean restraint, disinhibition and hunger on the TFEQ were 8.7 (*SD* = 6.0), 7.0 (*SD* = 3.4) and 6.8 (*SD* = 3.3), respectively. Participant's characteristics grouped by restraint and disinhibition scores are in Table 1.

Baseline group differences

BMI differed according to restraint scores (F(1,113) = 5.92, p = 0.02), and there was a marginally significant effect on age (F(1,113) = 3.81, p = 0.05), but no effect of group on baseline hunger (smallest $p = 0.28$). High restraint participants tended to be older and have a higher BMI. There were significant correlations between baseline hunger and food intake and between rated liking and intake of the foods, therefore baseline hunger and average liking of the foods were included as covariates in the analyses (and as nuisance variables in the Bayesian linear regressions).

Table 1. Participant characteristics grouped by restraint and disinhibition scores.

	LRLD	LRHD	HRLD	HRHD
N	30	26	24	36
Age (years)	18.73 (0.94)	18.77 (0.71)	19.33 (1.40)	18.89 (0.82)
BMI (kg/m^2)	20.71 (3.14)	21.34 (2.05)	22.14 (2.80)	22.32 (2.28)
Hunger VAS (mm)	44.80 (19.44)	52.73 (21.27)	48.58 (17.43)	48.22 (21.78)

Note. LRLD = low restraint, low disinhibition; LRHD = low restraint high disinhibition; HRLD = high restraint low disinhibition; HRHD = high restraint high disinhibition. High restraint ≥9 on restraint subscale; high disinhibition ≥7 on the disinhibition subscale.

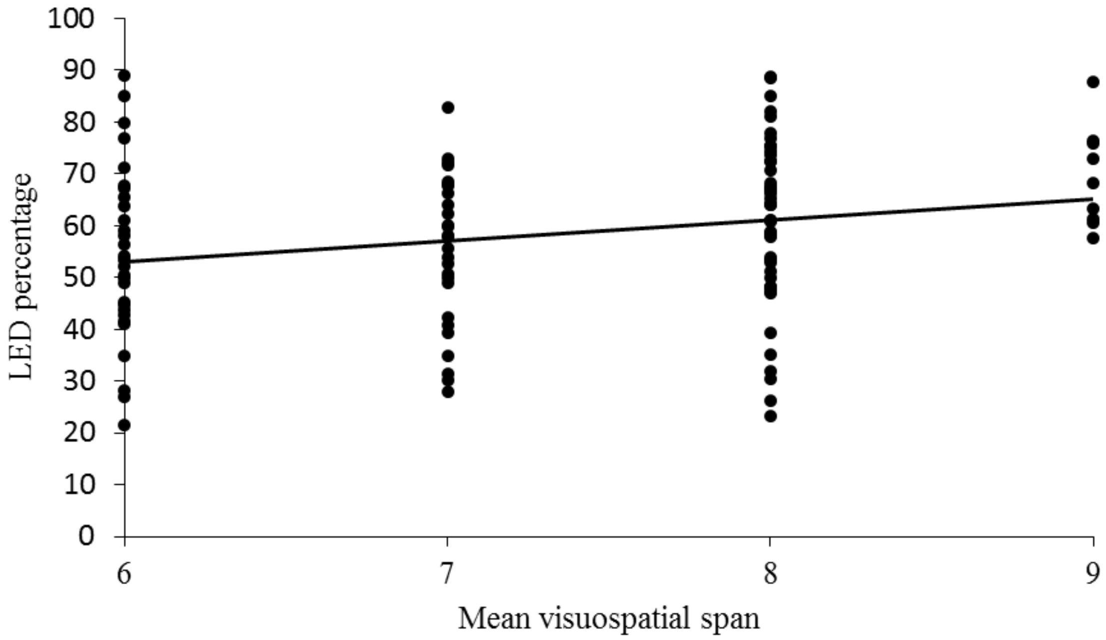
Awareness of study aims

None of the participants guessed the exact purpose of the study, although 18% guessed the broad purpose (e.g. "the relationship between cognitive functioning and food intake").

Working memory as a mediator of the relationship between dieting success and food choice

Better visuospatial span was associated with a greater (lower) percentage of total food intake that was LED (HED, hypothesis 1). See Table 2 for the results and Figure 2 for a scatterplot of this relationship.

Figure 2. Percentage of food intake that was LED plotted against visuospatial WM span (with a regression line).



Dieting success (the interaction between restraint and disinhibition) was significantly associated with visuospatial span (hypothesis 3), and was directly associated with percentage of total food intake that was LED (hypothesis 4). The direct relationship between dieting success and LED percentage intake was no longer significant when controlling for visuospatial span, and the indirect effect via WM was significant (hypothesis 5). See Table 2 for the results of all the mediation analyses and Figure 3 for a model of the results involving just visuospatial span.

Table 2. The relationships between WM, food choice and dieting success (restraint x disinhibition) in a mediation model.

Path	Digit span (*b, p*)	Visuospatial span (*b, p*)	Updating strategy use (*b, p*)
a	-0.01 (0.27)	-0.01 (0.02)	-0.02 (0.55)
b	1.77 (0.18)	3.49 (0.03)	-0.13 (0.63)
c	-0.19 (0.03)	-0.19 (0.03)	-0.19 (0.03)
c’	-0.18 (0.04)	-0.15 (0.08)	-0.19 (0.03)
Standardised indirect effect of dieting success on food intake (bootstrapped 95% CIs)	-0.02 (-0.08, 0.01)	-0.04 (-0.12, -0.01)	0.003 (-0.01, 0.05)

Note. a = association between dieting success and WM; b = association between WM and percentage of intake that was LED food; c = association between dieting success and percentage of intake that was LED food; c’ = direct association between dieting success and percentage of intake that was LED food when controlling for WM.

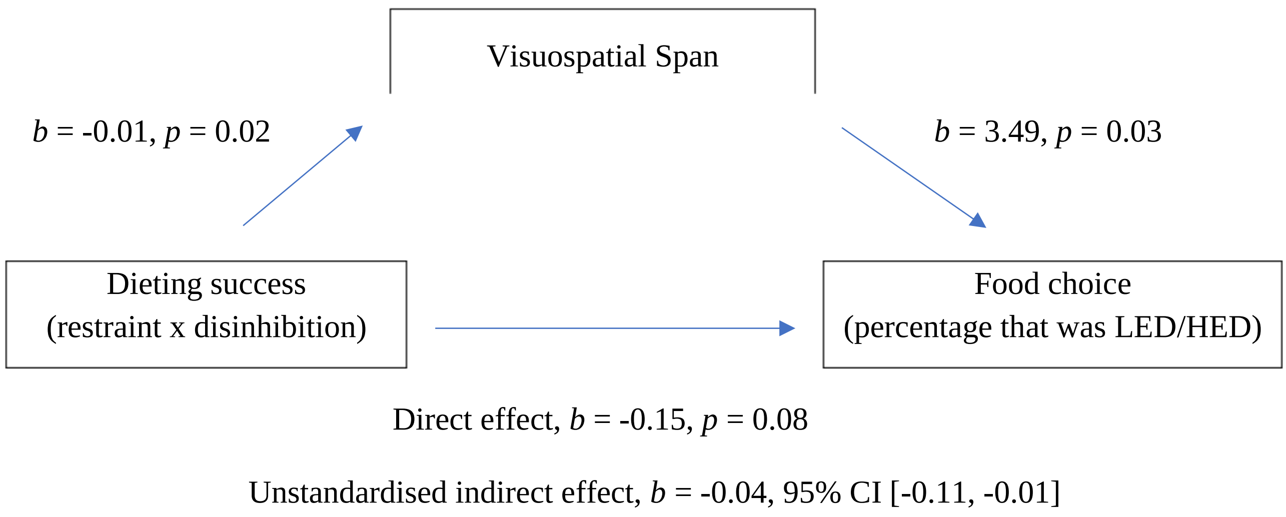


Figure 3. Model of dieting success as a predictor of food choice, mediated by visuospatial span.

Bayesian linear regressions showed moderate evidence for the association between visuospatial span and greater LED (lower HED) percentage intake when controlling for baseline hunger and liking of the LED foods (BF_{10} = 7.75). Bayes factors for updating strategy use and digit span reflect anecdotal evidence for the null hypotheses (BF_{10} = 0.34 and 1.06, respectively).

Dieting success and working memory

As plotted in Figure 4, simple slopes analysis showed that at high levels of restraint, visuospatial WM span decreased as disinhibition increased, *b* = -.08, *t*(112) = -2.47, *p* = 0.01 (relating to hypothesis 3).

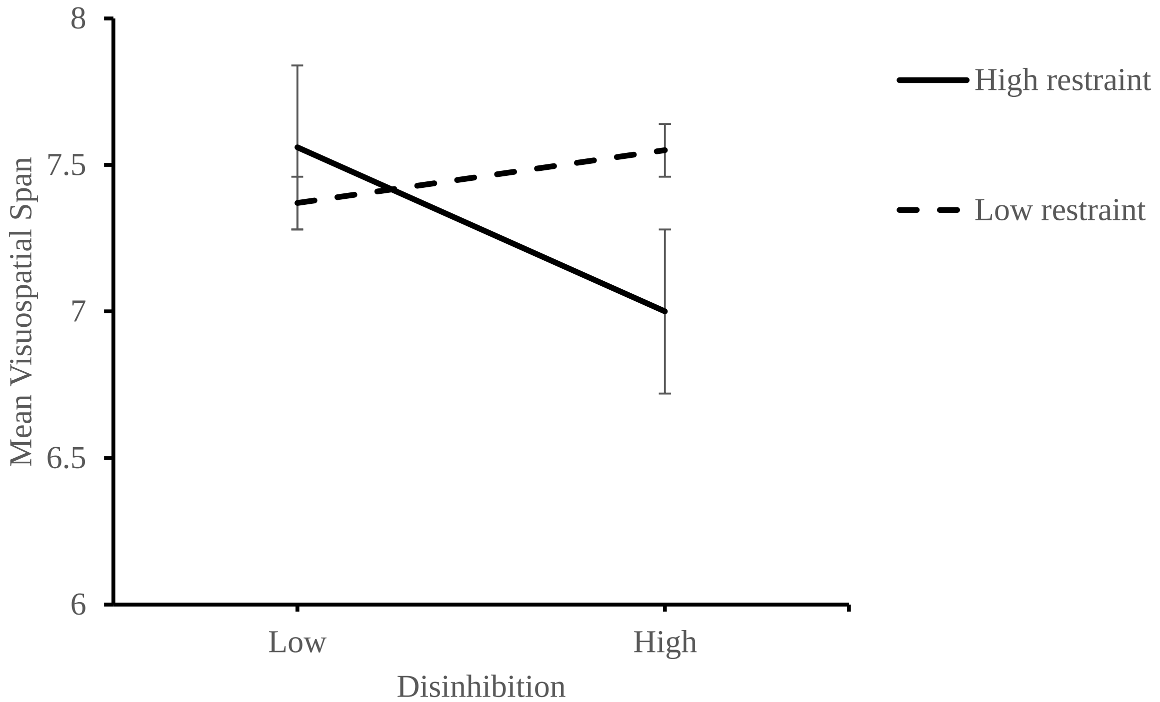


Figure 4. Mean visuospatial span as a function of restraint and disinhibition (with standard error bars).

There was also a significant positive relationship between restraint and updating strategy use score, *b* = 0.23, t(112) = 2.38, p = 0.02 (hypothesis 2). A higher score means poorer use of the strategy, suggesting that those high in restraint used the strategy less than those low in restraint. There were no main effects of restraint or disinhibition on any other WM outcomes.

Dieting success and food intake

Simple slopes analysis showed that those high in restraint, and low in disinhibition (successful dieters) ate a higher (lower) percentage of LED (HED) foods than those high in disinhibition (unsuccessful dieters), b = -1.70, $t(105)$ = -2.49, p = 0.01 (hypothesis 4).

Post-hoc examination of food intake

Consumption data split by restraint and disinhibition (dieting status) for LED grams, HED grams and total intake (kcal) are provided in Table 3. The pattern of data presented here suggests that successful dieters (HRLD) ate less HED food and total kcal, but ate a similar amount of LED food, compared to unsuccessful dieters (HRHD).

Table 3. Descriptive statistics for food intake measures grouped by restraint and disinhibition scores.

	LRLD	LRHD	HRLD	HRHD
LED percentage	62.3 (15.9)	57.02 (12.2)	60.4 (18.8)	54.7 (15.7)
LED (grams)	101.2 (66.9)	88.9 (52.1)	89.6 (56.8)	87.0 (49.1)
HED (grams)	53.6 (30.7)	60.0 (27.5)	49.0 (25.3)	66.2 (36.2)
Total (kcal)	270.1 (143.0)	294.0 (136.5)	246.7 (118.6)	322.4 (173.1)

Note. LRLD = low restraint, low disinhibition; LRHD = low restraint high disinhibition; HRLD = high restraint low disinhibition; HRHD = high restraint high disinhibition. High restraint ≥9 on restraint subscale; high disinhibition ≥7 on the disinhibition subscale.

Discussion

The aim of this study was to investigate the relationship between WM components and food intake, using computerised non self-report measures of WM and a measure of actual food intake (food taste-test paradigm). In addition, the role of dieting success (measured by restraint and disinhibition) as a distal predictor of food intake that influences food choices via WM, and the role of WM more generally in dieting success were assessed. Our first prediction, that there would be a significant relationship between WM and food choice, such that better WM would be associated with a greater (lower) percentage of total food intake that was from LED (HED) food (hypothesis 1), was partially supported. Greater visuospatial WM span was associated with a higher (lower) percentage of food intake that was LED (HED). Specifically, for every 1 item increase in visuospatial span, the percentage of food consumed that was LED (HED) increased (decreased) by 3.49%. In someone with the highest visuospatial span in the current study (9 items), this represents 10.47% more (less) LED (HED) food than those with the poorest visuospatial span (6 items). The Bayes factor for the association between visuospatial span and LED percentage intake (when controlling for baseline hunger and liking of LED food) showed moderate evidence for this effect. However, the Bayes factors for no involvement of updating strategy use and digit span were anecdotal, preventing a conclusion that these components of WM are not related to food choice. Future research can address this by applying a stopping rule whereby recruitment continues until there is strong evidence for either the null or alternative hypotheses using Bayesian statistics (Dienes, 2016). These findings are in line with studies showing that WM is related to food intake (Allom & Mullan, 2014; Riggs, Chou, et al., 2010; Sabia et al., 2009), and extend this to suggest that visuospatial WM in particular is important. Better visuospatial WM may enable people to deal with demands on visuospatial WM such as cravings (Green et al., 2000;

Kemps et al., 2008; Meule, Skirde, et al., 2012; Tiggemann et al., 2010), ultimately changing food preferences if these can be dealt with appropriately.

This study also investigated the role of WM in dieting success. It was predicted that dieting success would be associated with better visuospatial WM and a higher (lower) percentage of food intake that was LED (HED; hypotheses 3 and 4, respectively). It was also expected that the relationship between dieting success would be mediated by WM (hypothesis 5). Supporting hypotheses 3 and 4, those high in restraint and low in disinhibition (successful dieters) showed better visuospatial WM span and ate a higher (lower) percentage of LED (HED) food than those high in restraint and high in disinhibition (unsuccessful dieters). The former effect represents a decrease of 0.08 items recalled for every 1 point increase in disinhibition (at high levels of restraint). Therefore, visuospatial span in a person scoring 16 on tendency towards disinhibition (the maximum score) would be 1.28 items less than someone scoring 0 on the disinhibition subscale. Considering the relatively small range of visuospatial working memory found in the present study (6-9 items), we argue that this is not a small effect and could have clinical relevance. Another study published since this study was conducted also found dieting success to be associated with WM (Meule, 2016). Specifically, Meule found that dieting success was associated with fewer omission errors on a food versus a neutral block in an n-back task in current dieters (Meule, 2016). The association between dieting success and percentage intake reflects a 1.7% decrease (increase) in percentage of LED (HED) intake for every 1 point increase in disinhibition (in those high in dietary restraint). This means that in someone with a score of 16 on tendency towards disinhibition, percentage of LED (HED) food intake would be 27.2% less (more) than some scoring 0 on this subscale. This is a strong effect.

Visuopatial WM span was found to significantly mediate the relationship between dieting success and percentage of food intake that was LED, supporting hypothesis 5. This suggests that poorer visuospatial WM may undermine dieting success. The pattern of the data for consumption of LED and HED food (grams) and total intake (kcal) in successful compared to unsuccessful dieters, suggests that better WM processes may facilitate the ability to resist and inhibit HED seeking behaviour (influencing total kilocalorie intake), but may not facilitate LED seeking behaviour. Considering the evidence that food cravings are associated with visuospatial WM deficits (Kemps, Tiggemann, & Hart, 2005; Tiggemann et al., 2010), and differences between successful and unsuccessful dieters in their experiences of cravings (Meule, Lutz, et al., 2012), better visuospatial WM functioning in successful dieters may better enable them to deal with demands on visuospatial WM, such as preoccupying thoughts about food and advertising. Specifically, elaboration intrusion theory argues that it is elaboration of intrusive thoughts about food in WM that guide overt behaviour (Kavanagh, Andrade, & May, 2005; May, Kavanagh, & Andrade, 2015). Better visuospatial WM in successful dieters may, therefore, enable these people to prevent elaboration of food thoughts into cravings (e.g. imagining smelling and consuming food), or to activate and retrieve alternative thoughts, such as health or dieting goals. Indeed, studies have found that food cues elicit health goals in successful dieters and not in unsuccessful dieters (Papies, Stroebe, & Aarts, 2008a; Papies, Stroebe, & Aarts, 2008b). Alternatively, it is possible that successful dieters experience fewer food cravings, leaving them with greater capacity to deal with other visuospatial WM demands. To better understand the mechanism underlying this finding, future research should compare experiences of cravings between successful and unsuccessful dieters, how successful dieters deal with induced food cravings, and examine whether visuospatial WM mediates the relationship between food cravings and food intake/dieting success. Initial research on this has found that slower reaction times on a food-specific n-back task mediated the effect of current dieting status on food cravings (Meule, 2016).

Finally, it was predicted that restraint would be associated with impairments in updating ability and phonological loop WM functioning irrespective of tendency towards disinhibition (hypothesis 2). This hypothesis was partially supported, as higher levels of restraint were associated with poorer updating (strategy use), irrespective of levels of disinhibition. This suggests that the negative effect of dieting on central executive functioning that has previously been found, is independent of tendency towards disinhibition (Green et al., 1997; Shaw & Tiggemann, 2004). There was no effect of restraint on phonological loop functioning. This is in line with some research (Green et al., 2003; Kemps & Tiggemann, 2005), but not others (Green & Elliman, 2013; Shaw & Tiggemann, 2004; Vreugdenburg et al., 2003). It could be that assessing overall phonological loop functioning masked the effects of the two components of the phonological loop, since previous studies have found a relationship between dieting and articulatory control processes and not the phonological store (Shaw & Tiggemann, 2004) or vice versa (Vreugdenburg et al., 2003).

The current study assessed associations between WM and food choice, and so no claims can be made about causality. Indeed, there is evidence to support the suggestion that food intake influences WM as well as vice versa (Crichton, Murphy, Howe, Buckley, & Bryan, 2012). It will be important in future studies to investigate the effectiveness of WM training to improve food intake and measures of dieting success, such as weight loss and maintenance of weight loss. Initial evidence suggests that WM training in overweight/obese adults reduces food intake in individuals scoring high on a measure of dietary restraint (Houben, Dassen & Jansen, 2016). The current sample was a group of undergraduate women with a low BMI (although BMI was still within the normal range). It would be interesting to see if the effects reported here would be replicated in higher BMI men and women, who may also have greater experience of dieting success and failure. The present study utilised computerised measures of WM as a way of measuring basic WM capacity. However, it is possible that participants' WM was already taxed in some way, impairing their performance on these tasks. It is therefore important that future research tries to identify and control for such potential influences on WM, such as food cravings.

The conclusions that can be drawn from the current findings may be limited to the specific tasks used. For example, the backwards digit span task used in this study required memorizing a sequence of verbal information and manipulating this sequence in order to recall it in the reverse order, therefore using both the phonological loop and the central executive sub-components of WM. Similarly, the Spatial Working Memory Task used to assess updating ability required remembering visuospatial information as well as updating of this information, and so engaged both the visuospatial sketchpad and central executive sub-components of WM. The present findings may therefore be limited to phonological loop functioning that also involves manipulation, and updating ability that also involves the visuospatial sketchpad. The use of tasks that assess WM sub-components both independently and in conjunction, such as simple span and complex span tasks (Daneman & Carpenter, 1980) is recommended in future research.

Future research should explore the specific role of working memory processes in behavioural control. Verbruggen, McLaren, and Chambers (2014) argue that three processes underlie behavioural control: signal detection, action selection and action execution. Importantly, the retrieval of goals and task rules (that is, how goals can be achieved) from long-term memory, and maintenance of these in WM, are likely to modulate signal detection, action selection and action execution. For example, if health goals are not retrieved from long-term memory and activated, then task rules and actions associated with achieving these goals cannot be selected. Difficulties maintaining task rules in mind may hamper continued action execution (e.g. remembering to not over eat during a meal throughout the meal). The three processes, signal detection, action selection and action execution are also continually monitored and updated. WM is likely to play a key role here, where new information must be incorporated into subsequent action selection and execution. For example, when finding out about a price reduction on deserts (signal detection), this information needs to be incorporated into goals currently held in WM, which will influence activation of task rules and ultimately action selection and execution (choosing to order desert or not). This is where shielding goals from interference may also be important, such as by preventing distracting information (e.g. signal detection in the form of a price reduction on deserts) from being incorporated into goals and task rules that could then influence action selection and execution. Future research should therefore investigate the specific processes that explain how working memory functions influence the processes underlying behavioural control. Focusing on mechanisms and processes may better inform interventions for behavioural control. For example, people who struggle to activate and retrieve long-term health goals in the presence of food (food being the signal that requires detection) may benefit from training in this area, such as via implementation intentions to think of their health/dieting goals when they see palatable food (Van Koningsbruggen, Stroebe, Papies, & Aarts, 2011). This is likely to facilitate appropriate action selection and execution. In people who struggle to maintain such health/dieting goals in mind once initially activated, training to improve this (such as via rehearsal) may facilitate continued appropriate action execution.

In summary, the present results provide new insights into the specific components of WM that play an important role in determining food choices. Specifically, it appears that visuospatial WM span is associated with the healthiness of food choices, and may play a role in a person’s ability to choose LED food and resist HED food when both options are available. The finding that visuospatial WM mediated the relationship between dieting success and percentage of food intake that was LED suggests that poorer visuospatial WM may undermine dieting attempts. Previous findings that dietary restraint is associated with deficits in central executive functioning were also clarified, by supporting that this effect is independent of tendency towards disinhibition.

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Declaration of interest

The authors have no conflicts of interest.

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