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Impairments in working memory associated with spontaneous dieting behaviour

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ABSTRACT

Background. The current study investigated the fundamental nature of the cognitive processing deficit that has been demonstrated to be associated with dieting to lose weight. Previous work has characterized this deficit as being primarily one of a reduction in working-memory capacity. The present study investigated the particular components of the working-memory system affected during dieting.

Method. A sample of female subjects was classified as either low/medium restrained eaters ($N = 34$), highly restrained eaters ($N = 18$) or current dieters ($N = 19$), based on their responses to a modified version of the Dutch Eating Behaviour Questionnaire (DEBQ). Each subject completed tasks that assessed the Visuo-Spatial Sketchpad (mental rotation), Phonological Loop (effect of phonological similarity on recall) and the Central Executive (Tower of London Task) components of working memory.

Results. Those subjects who reported themselves to be currently dieting displayed poorer recall on the Phonological Loop task and slower planning times on the Tower of London Task. Performance on both these tasks correlated significantly with a self-report measure of body shape concern.

Conclusions. These results support the hypothesis that the mediating variable in this deficit is that of preoccupying cognitions concerning food and body shape.

INTRODUCTION

Dieting can be defined as the deliberate attempt to achieve weight loss by means of the restriction of caloric intake. Although there are obvious health benefits to be gained from successful weight loss, there are a number of other associated negative consequences. For instance, it has been found that dieting behaviour is associated with swings in mood state (Tiggeman, 1994), depression (Smoller *et al*. 1987) and increased concern with body shape (Warren & Cooper, 1988; Green & Rogers, 1993).

Dieting has also been associated with impaired cognition (Wing *et al*. 1995). For example, female dieters performed more poorly than non-dieters on a task of sustained attention (Rogers & Green, 1993), in addition to poorer performance on immediate free recall and simple reaction time tasks (Green *et al*. 1994). Furthermore, performance had been demonstrated to be poorer, within the same individuals, when dieting than when not dieting (Green & Rogers, 1995); indicating that the phenomenon is related to dieting *per se*, rather than pre-existing individual differences between dieters and non-dieters.

In view of the previously mentioned affective states associated with dieting, it is possible that these deficits are similar to the effects of other types of disordered affect on cognitive processing efficiency. The preoccupying cognitions that accompany anxiety (Darke, 1988) and depression (Channon *et al*. 1993) have been found to result in relative impairments in working-memory capacity. By analogy, therefore, it should be the case that the preoccupying cognitions that accompany dieting behaviour will result in a reduction in the overall amount of working-memory capacity available for task performance. Significantly, current dieters have

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also been demonstrated to perform more poorly on the same working-memory capacity measure used by Darke (1988) than non-dieters (Green *et al*. 1997). Further support for this analogy between the effects on working memory of preoccupying cognitions present in dieters and those of dysphoric affective states comes from the finding that the reading spans of current dieters were related to their self-reported desire to eat (Green *et al*. 1997).

Assuming that the deficits in cognitive processing efficiency demonstrated by current dieters can be conceived as basically a reduction in available working-memory capacity, the central question addressed by the present study was which particular subsystems of the working-memory model proposed by Baddeley (1986) are affected. Working memory is commonly believed to represent the basic cognitive system, in that it underlies the capacity to remember moment to moment rules of activity and serves to allocate cognitive processing capacity to the various other cognitive systems, according to need and importance. The term 'working memory' is perhaps something of a misnomer and the system could be better conceptualized as a processing buffer, serving to allocate limited processing resources according to the importance of each cognitive operation to the individual. The most widely investigated model of working memory (Baddeley, 1986) proposes a tripartite structure for this system. At the apex of this model is a system termed the Central Executive, which serves to allocate processing resources both to the other two slave-systems and to cognitive processing resources in general. The remaining two slave-systems comprise the Phonological Loop (dealing with the processing of verbal information) and the Visuo-Spatial Sketchpad (dealing with the processing of visuo-spatial information).

It was hypothesized that, since preoccupying cognitions in the form of 'worry' have been found to consume the resources of the Central Executive and Phonological Loop components of the model (Rapee, 1993), that current dieters would perform more poorly on tasks that selectively rely on the capacity of these components of the working memory system, but not on tasks which load on to the Visuo-Spatial Sketchpad subsystem of working memory. The reasoning behind this hypothesis is twofold. First, theoretical models of worry conceptualize it as being predominantly verbal and linguistic, rather than spatial in nature (e.g. Borkovec & Inz, 1990). Processing Efficiency Theory (Eysenck & Calvo, 1992) also predicts that the worry component of anxiety takes the form of subvocal preoccupying cognitions relating to fear of failure and low self-esteem. Secondly, there is a body of evidence indicating both the primarily verbal nature of such concerns (e.g. Eysenck, 1979), in addition to their selective effects on the Phonological Loop and Central Executive (e.g. Channon *et al*. 1993; Rapee, 1993; Ikeda *et al*. 1996).

METHOD

Subjects

The subjects were female students at the University of Reading ($N = 71$), recruited by means of an advertisement asking for individuals to participate in a study relating to eating habits and mental performance. All subjects were between the ages of 18 and 30, reported themselves as being in good health and possessed normal (or corrected to normal) visual acuity. Informed consent was obtained prior to testing and subjects were paid for participation.

Design and procedure

Each subject was tested individually, in a session lasting 1 h, under uniform lighting conditions. During the session, the subjects completed a number of cognitive performance tasks (two computer based and one manual), each of which preferentially loaded onto a different subsystem of the working memory system. In addition, subjects completed a number of self-report measures of eating behaviour, body shape concern, somatic sensations and recent dieting history. The computer based tasks were presented on a Viglen 100 MHz Pentium, running MEL v.2 (Psychology Software Tools, Pittsburgh PA.). All subjects were also weighed (using digital scales) and their height measured using a stadiometer. The testing procedure was identical for each subject and followed the following order.

Mental rotation task

This task was included to assess the capacity of the Visuo-Spatial Sketchpad subsystem of working memory. Subjects were presented with a number of pairs of random shapes, comprising the 8-point and 12-point forms used by Cooper (1975). Each pair was presented on screen simultaneously, positioned in the centre of two circles. The subjects' task was mentally to rotate the form on the right hand side of the screen until they believed that it was in the same orientation as the form on the left. They were then to decide whether the right hand form was identical to the left hand form or was a mirrored image that form. Subjects were instructed to respond by pressing the 1 key on the numeric keypad if they believed the two forms to be identical and to press the 2 key if they believed the right hand form to be a mirror image. The right hand forms either required a 0°, 60°, 120°, 180°, 240° or 300° clockwise mental rotation. In total, there were 96 trials, comprising eight trials each of each of the two images, in each of the possible rotation positions.

Phonological similarity task

This task was identical to the modification of the Wilding & Mohindra (1980) procedure used by Channon *et al.* (1993) to assess the effects of depression on working memory, and is designed to assess the storage capacity of the Phonological Loop subsystem of working memory. In this task, subjects were presented with a number of letter recall trial sets. Each trial set comprised a set of five letters, appearing in the centre of a VDU at the rate of 1 letter per second. After each trial set, subjects were given 5 s to recall and write down the letters which had appeared in that trial, in the same order in which they had appeared. The trial sets comprised either sets of phonologically confusable letters (e.g. CPTDG) or phonologically non-confusable letters (e.g. HMJRZ). In addition, subjects were required to perform the task in the presence of articulatory suppression (having to articulate verbally the numbers 1 and 2 while the letters appeared on screen) or the absence of articulatory suppression. Within the suppression/non-suppression condition, subjects were presented with 12 trial sets each of the confusable and non-confusable letter sets (each set presenting the letters in a non-repeated random arrangement).

Tower of London Task

Subjects were also required to complete a manual version of the Tower of London Task (Shallice, 1982). This has been established as one of the main methods of assessing the capacity of the Central Executive system within working memory (Baddeley, 1986). The task comprised a three peg board with three moveable wooden discs, one white, one green and one black. The subjects' task was to move the discs from a standard start position to a target position in a minimum number of moves. There were two target positions that could be reached in two moves, two that could be reached in three moves, four that could be reached in four moves and four in five moves. Administration of the test followed the standardized procedure outlined by Krikorian *et al.* (1994).

Self-report measures

Upon completion of the cognitive task battery, subjects completed a number of self-report measures of eating behaviour and body-shape concern. These comprised the Dutch Eating Behaviour Questionnaire (DEBQ) (van Strien *et al.* 1986), modified to include questions on current dieting status and the Body Shape Questionnaire (BSQ) (Cooper, *et al.* 1987). Affective state was measured via the Hospital Anxiety and Depression Scale (HADS) (Snaith & Zigmond, 1994).

Analysis

For the purposes of the statistical analysis, the subjects were divided into three groups. The first group was those subjects who self-defined themselves as being currently dieting to lose weight. The remaining two groups were classified according to a tertile split of their DEBQ restraint scores. They were non-dieting highly restrained eaters (the third tertile) and low-to-medium restrained eaters (the first and second tertiles). This was a similar classification to that adopted in a number of previous studies (e.g. Green *et al.* 1994). Initial analysis was carried out via ANOVA, followed by *post-hoc* Fishers' least significant difference (lsd) test where appropriate.

RESULTS

Subject characteristics and weight status

The self-report and Body Mass Index (BMI) data are presented in Table 1. These data were analysed via one-way ANOVA (subject group as a factor). There was found to be a significant group difference in the DEBQ emotional ($F(2, 68) = 4{\cdot}26$ $P = 0{\cdot}018$) and external eating ($F(2, 68) = 6{\cdot}63$ $P = 0{\cdot}002$) subscales. *Post-hoc* analysis revealed that the dieters and non-dieting restrained eaters scored significantly higher on these measures than the low-to-medium restrainers ($P < 0{\cdot}05$). Each group displayed a significantly different BSQ score from the other ($F(2, 68) = 12{\cdot}5$ $P < 0{\cdot}001$; lsd $< 0{\cdot}05$). There were no significant group differences in BMI scores (calculated as kg/m²) ($F(2, 68) = 0{\cdot}40$ $P = 0{\cdot}8$). The dieters reported themselves as having been dieting for a mean of 7·21 weeks (±S.D. 4·81), with a mean 1·46 kg (±S.D. 1·78) weight loss. There were no group differences in self-reported HADS depression score ($F(2, 68) = 0{\cdot}82$ $P = 0{\cdot}4$). There was, however, a significant group difference in HADS anxiety score ($F(2, 68) = 4{\cdot}32$ $P = 0{\cdot}017$), with dieters reporting a significantly lower level of anxiety than the two non-dieting groups (lsd $= 0{\cdot}67$ $P < 0{\cdot}05$).

Table 1. *Mean dietary restraint, external eating, emotional eating, BSQ scores, Body Mass Indices (BMI) and untransformed HADS subscale scores for all subject groups (±S.D. in parentheses)*

	Low/medium restraint (N = 34)	High restraint (N = 18)	Current dieters (N = 19)
DEBQ			
Restraint	2·32 (0·59)	3·69 (0·45)	3·61 (0·64)
External eating	2·96 (0·54)	3·45 (0·47)	3·37 (0·56)
Emotional eating	2·82 (0·72)	3·39 (0·76)	3·18 (0·63)
BSQ	107 (13·4)	118 (19·3)	132 (21·0)
BMI	22·3 (2·69)	22·3 (3·07)	22·5 (2·93)
HADS			
Anxiety	7·09 (1·26)	7·44 (0·61)	6·37 (1·30)
Depression	4·04 (0·88)	4·17 (0·79)	3·82 (0·78)

Table 2. *Mean response times and number of correct responses on the mental rotation task for all three subjects groups (±S.D. in parentheses)*

	Low/medium restraint (N = 34)	High restraint (N = 18)	Current dieters (N = 19)
Response times (ms)			
0° rotation	2718 (538)	2583 (283)	2786 (667)
60° rotation	3524 (1092)	3113 (623)	3431 (857)
120° rotation	3862 (1399)	3635 (1051)	3808 (1264)
180° rotation	4219 (1536)	3539 (1011)	4106 (1840)
240° rotation	3843 (1090)	3756 (1224)	3600 (1179)
300° rotation	3374 (1049)	3131 (639)	3511 (1422)
Correct decisions (maximum per cell = 18)			
0° rotation	17·4 (2·03)	17·3 (1·71)	18·0 (0·00)
60° rotation	17·1 (1·67)	16·2 (1·96)	17·9 (1·25)
120° rotation	16·2 (1·83)	16·1 (2·35)	16·9 (1·41)
180° rotation	16·1 (2·79)	15·3 (2·61)	16·7 (3·11)
240° rotation	16·1 (3·47)	15·7 (2·45)	17·6 (2·87)
300° rotation	16·6 (1·67)	16·1 (1·73)	17·8 (1·72)

Cognitive performance

Mental Rotation Task

The mean scores for the mental rotation task are presented in Table 2. These were expressed both in terms of the number of correct trials and decision times. Both were analysed via two-way ANOVA (subject group and angle of rotation as factors).

The effect of angle of rotation on decision times differed across group, ($F(5, 340) = 42{\cdot}1$ $P < 0{\cdot}001$). *Post-hoc* analysis revealed that the larger the degree of mental rotation required to make the same/mirror image decision, the longer the decision time ($P < 0{\cdot}05$). This, however, did not differ across ($F(2, 68) = 0{\cdot}66$ $P = 0{\cdot}5$), or interact with ($F(10, 340) = 1{\cdot}02$ $P = 0{\cdot}4$) subject group.

The number of correct responses made differed as a function of subject group ($F(2, 68) = 4{\cdot}84$ $P = 0{\cdot}011$), with the dieting subjects making significantly more correct decisions than the two groups of non-dieting subjects (lsd, $P < 0{\cdot}05$). The angle of mental rotation also affected the number of correct responses made ($F(5, 340) = 6{\cdot}23$ $P < 0{\cdot}001$), with fewer correct responses being made in the 120°, 180° and 240° rotation conditions than the 0°, 60° and 300° conditions ($P < 0{\cdot}05$). This did not differ as a function of subject group ($F(10, 340) = 0{\cdot}44$ $P = 0{\cdot}9$).

Phonological similarity task

The mean recall scores are shown below in Table 3. The number of letter sequences correctly

Table 3. *Mean number of letter sequences correctly recalled in phonological suppression task for all three groups (±S.D. in parentheses)*

	Low/medium restraint (N = 34)	High restraint (N = 18)	Current dieters (N = 19)
Without articulatory suppression			
Confusable	7·58 (3·06)	7·39 (2·50)	5·79 (2·64)
Non-confusable	8·85 (3·47)	9·89 (2·27)	8·00 (3·32)
With articulatory suppression			
Confusable	4·35 (2·42)	4·39 (2·55)	2·05 (2·09)
Non-confusable	4·35 (2·99)	4·39 (2·95)	1·89 (2·16)

recalled were analysed via three-way ANOVA (articulatory suppression, phonological confusability and subject group as factors). Correct recall was found to differ as a function of subject group ($F(2, 68) = 4.99$ $P = 0.010$), with the dieting subjects recalling fewer correct letter sequences than either of the two non-dieting groups ($P < 0.05$).

There were a number of other significant main effects. The current data replicated previous work (Wilding & Mohindra, 1982), in that fewer of the phonologically confusable letter strings were recalled than the non-confusable letter strings ($F(1, 68) = 30.7$ $P < 0.001$) and fewer letter strings overall were correctly recalled under conditions of articulatory suppression ($F(1, 68) = 14.4$ $P < 0.001$). There was a significant interaction between suppression and confusability ($F(1, 68) = 44.7$ $P < 0.001$), revealing that the relative advantage in recall for the phonologically non-confusable letters strings was only present when encoding took place without articulatory suppression ($P < 0.05$). There were no other significant interactions ($P > 0.05$).

Tower of London Task

There were three components of task performance measured; planning time, execution time and the total number of moves taken to reach the target position. Each was analysed via two-way ANOVA (subject group and minimum moves possible to reach the target position as factors). In view of the fact that the mean planning and execution times violated the assumption of homogeneity of variance necessary for ANOVA, analyses were carried out on a logarithmic transformation of the raw data. The mean untransformed scores for this task are shown in Table 4.

Table 4. *Mean planning times, execution times and total moves required to achieve target position in the Tower of London Task for all three subjects groups (± S.D. in parentheses)*

	Low/medium restraint ($N = 34$)	High restraint ($N = 18$)	Current dieters ($N = 19$)
Planning times (s)			
2 move target	2·85 (0·97)	3·19 (1·19)	3·08 (1·17)
3 move target	4·24 (2·1)	4·11 (2·84)	4·15 (2·36)
4 move target	7·71 (4·28)	6·69 (4·47)	15·8 (12·4)
5 move target	10·8 (6·63)	9·49 (5·86)	24·9 (27·9)
Execution times (s)			
2 move target	4·58 (1·49)	4·07 (1·36)	3·80 (1·81)
3 move target	8·58 (6·08)	7·43 (1·87)	6·36 (2·34)
4 move target	17·7 (9·19)	19·3 (11·3)	19·9 (18·0)
5 move target	20·3 (10·0)	19·7 (11·8)	13·2 (27·3)
Moves taken to achieve target position			
2 move target	2·09 (0·29)	2·00 (0·00)	2·00 (0·00)
3 move target	3·32 (1·03)	3·17 (0·24)	3·17 (0·26)
4 move target	5·86 (1·52)	5·86 (2·24)	6·62 (2·01)
5 move target	6·35 (1·32)	7·04 (2·38)	6·38 (1·07)

Planning times were found to differ according to the minimum number of moves required to reach the target position ($F(3, 204) = 119$ $P < 0.001$), with times significantly increasing according to the moves required ($P < 0.01$). This was found to significantly differ as a function of subject group ($F(6, 204) = 4.46$ $P < 0.001$), with the dieting subjects exhibiting significantly longer planning times in the two most complex sets of target positions (four and five minimum moves) than the two non-dieting groups ($P < 0.01$).

Execution times were found to increase as a function of the minimum number of moves required to achieve each target position ($F(3, 204) = 172$ $P < 0.001$). There were no other significant main effects or interactions for the analysis of the execution times ($P > 0.05$).

The number of moves taken to reach each target position did not differ according to group ($F(2, 68) = 0.74$ $P = 0.5$), although it was found that, overall, more moves were taken to complete each puzzle, as those puzzles increased in complexity ($F(3, 204) = 312$ $P < 0.001$). There was a significant interaction between subject group and required minimum moves on the total number of moves made ($F(6, 204) = 3.20$ $P < 0.01$). *Post-hoc* analysis revealed no clearly interpretable pattern of results, although there were no group differences, within each level of task difficulty ($P > 0.05$).

Relationships between task performance and self-report measures

Correlations were calculated between the self-report measures for each subject group and task performance. Among the dieters, there was found to be a significant correlation between BSQ score and planning times for the collapsed four- and five-move problems on the Tower of London Task ($r = 0.51$ $P < 0.01$) and a significant negative correlation between BSQ score and overall mean recall scores ($r = -0.58$ $P < 0.01$). There were no other significant corre-

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lations between performance on these tasks and the self-report scores ($P > 0{\cdot}05$).

DISCUSSION

The present study revealed several important findings. The first of these is a further demonstration that dieting to lose weight is associated with relatively poorer cognitive processing efficiency, and that this impairment is fundamentally one of working-memory capacity rather than a failure in the ability to maintain the spatial focus of attention (Green *et al*. 1997). This finding is extended with the demonstration that current dieters perform more poorly than either non-dieting, highly restrained eaters or non-restrained eaters in tasks that primarily load on the Central Executive and Phonological Loop slave systems, but not on a visuo-spatial task.

Current dieters displayed poorer planning times on the two most difficult sets of target positions in the Tower of London task. Although there were no clear group differences in the two other measures gained from this task (execution time and total number of moves made), the problem-solving ability indicated by the time spent planning a solution to each problem has been commonly taken as an indicator of both Central Executive capacity (Baddeley, 1986) and the Supervisory Attentional System of the Norman & Shallice (1989) model of attention (both systems serving similar functions).

In contrast, there was no difference between dieters and non-dieters on the task which preferentially loaded onto the Visuo-Spatial Sketchpad component of the working memory model (i.e. mental rotation). In terms of the correct decisions made on this task, the dieters actually performed significantly better than non-dieters. Although it is difficult to explain precisely why dieters perform better than non-dieters on this measure, the finding mitigates against the possible hypothesis that dieters' preoccupations concerning weight and body shape contain an element of viso-spatial processing. It may, however, be possible to argue that dieters are unimpaired on the mental rotation task due to this task placing an insufficient processing load on the Visuo-Spatial Sketchpad. The present finding of an increase in response times with angle of rotation does not support this hypothesis, in that they indicate an increasing load on the Visuo-Spatial Sketchpad, which would not be apparent if mental rotations did not reach the limit of the processing capacity of this component of the system.

Taken together, this evidence is consistent with the view that the negative effects of dieting upon cognitive processing efficiency are related to preoccupying cognitions, thus supporting a close analogy with (but not resultant from) the effects of anxiety and depression on cognitive function. Although the present data do not allow for conclusions as to the direction of causality of this effect, this can be established from previous data. First, it has been found that performance is poorer among the same individuals, over a 3-week period, when dieting than not dieting (Green & Rogers, 1995). Secondly, it seems likely that these effects are related to the psychological stresses related to the decision to 'go on a diet', rather than weight loss *per se*, since experimentally induced weight loss is not associated with impaired cognitive function (Green *et al*. 1995; Kretsch *et al*. 1997). Thirdly, it has been found that dieters exhibit dysfunctional degrees of concern with food and body shape related issues, as measured by impaired Stroop colour-naming times for food and body shape related words (Green & Rogers, 1993).

The present finding that dieters perform more poorly than non-dieters on Central Executive and Phonological Loop tasks, but not on a Visuo-Spatial Sketchpad task, supports the hypothesis that the apparent cognitive performance deficits found in dieting are related to the weight, food low self-esteem (with regards to body shape) (Casper & Offer, 1990; French *et al*. 1995) related cognitions characteristically found among dieters. This conclusion is further supported by the finding of higher BSQ, emotional and external eating scores among the dieters, and the significant correlations between task performance and BSQ score, since the BSQ is essentially a measure of body shape related self-esteem. It may be possible to argue that these differences in cognitive processing efficiency are due to the presence of eating disordered psychopathology among the dieters. Certainly, dieters' BSQ scores are within the clinical range. This possibility is, however, made unlikely by the fact that the dieters' BMIs were within the normal range. Critically, however, as in previous studies (Green & Rogers, 1995; Green *et al.* 1997), task performance was unrelated to self-reported anxiety or depression. In fact, the dieters reported lower levels of anxiety than the non-dieters, making the argument that the performance differences are unrelated to disordered mood state among the dieters. Thus, the effects of dieting upon cognitive processing efficiency do not appear to be related to anxiety or depression *per se*, but instead to a dieting related affective state.

Although the present results bear a close similarity with the effects of preoccupying worry upon working memory, there are still several possible physiological mechanisms which may offer an explanation for these data. The most promising concerns depletion of tryptophan levels resulting from controlled food deprivation and weight loss (Anderson *et al.* 1990). This is because depletion of tryptophan levels, induced by ingestion of a tryptophan depleted amino acid laden drink, has in turn been shown to impair cognitive performance (Park *et al.* 1994). These impairments include increased planning times on the Tower of London Task. There is a problem with this explanation, however, in that spontaneous dieting is unlikely to be accompanied by substantial tryptophan depletion. Although the dieters in the present study did actually report a small weight loss over the course of their diet, deficits in cognitive functioning have been found between dieters and non-dieters in the absence of any significant weight loss on the part of the dieters (Green & Rogers, 1995).

Furthermore, it is also unlikely that the impaired cognitive performance of dieters is related to poorer micronutrient status, since the micronutrient intakes of dieters appear to be generally adequate, and at least as good as those of non-dieters (Gregory *et al.* 1990). It has also been hypothesized (e.g. Pollitt *et al.* 1981) that lowering blood glucose levels by food deprivation (outside of the levels experienced in hypoglycaemia of 3 mmol/l or less) has a negative effect on cognitive processing efficiency. This hypothesis is, however, not entirely supported by experimental evidence (see Rogers & Lloyd, 1994 for review).

In conclusion, the present study confirms and extends the body of evidence relating to the negative effects of dieting on cognitive function. Specifically, the data demonstrate that dieters display a pattern of impairments in working memory that is consistent with the hypothesis that the observed deficit in cognition among this population results from preoccupying cognitions concerning weight and body shape in a similar fashion to which the preoccupying cognitions associated with worry impair cognition. In addition, previous work (Green *et al.* 1997) has demonstrated that food related cognitions also mediate this effect.

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