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Research report

Individual differences in executive function predict distinct eating behaviours ☆

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ABSTRACT

Executive function has been shown to influence the performance of health behaviours. Healthy eating involves both the inhibitory behaviour of consuming low amounts of saturated fat, and the initiatory behaviour of consuming fruit and vegetables. Based on this distinction, it was hypothesised that these behaviours would have different determinants. Measures of inhibitory control and updating were administered to 115 participants across 2 days. One week later saturated fat intake and fruit and vegetable consumption were measured. Regression analyses revealed a double dissociation effect between the different executive function variables and the prediction of eating behaviours. Specifically, inhibitory control, but not updating, predict saturated fat intake, whilst updating, but not inhibitory control, was related to fruit and vegetable consumption. In both cases, better executive function capacity was associated with healthier eating behaviour. The results support the idea that behaviours that require stopping a response such as limiting saturated fat intake, have different determinants to those that require the initiation of a response such as fruit and vegetable consumption. The findings suggest that interventions aimed at improving these behaviours should address the relevant facet of executive function.

Introduction

Healthy eating can facilitate the maintenance of a healthy weight and reduce the risk of chronic diseases, such as cancer, diabetes and coronary heart disease (Mente, de Koning, Shannon, & Anand, 2009). Specifically, it is recommended that individuals limit saturated fat intake and increase consumption of fruit and vegetables (National Health and Medical Research Council, 2003; World Health Organization, 2000). In Australia, the national guidelines suggest that saturated fat intake should not exceed 24 g per day; and that individuals should consume two servings of fruit and five servings of vegetables each day (National Health and Medical Research Council and New Zealand Ministry of Health, 2006). Similar guidelines exist in other countries (Food Standards Agency, 2007; US Department of Agriculture & US Department of Health and Human Services, 2010).

Despite awareness of the benefits, individuals experience difficulty adhering to guidelines (Australian Institute of Health and Welfare, 2012; McLennan & Podger, 1998). This is reflected in the consistent finding that individuals often fail to carry out their intentions (McEachan, Conner, Taylor, & Lawton, 2011), and suggests that whilst motivation to carry out a goal-directed behaviour is important, the ability to translate this motivation into action is key. A construct that has been implicated in the successful execution of health behaviour is self-regulation (Hagger, 2010; Hofmann, Schmeichel, & Baddeley, 2012). Self-regulation has been defined as the capacity for regulating cognitions and responses in order to support the pursuit of long-term goals (Baumeister, Vohs, & Tice, 2007). Research has found that self-regulation is important for both the initiation of health-enhancing behaviours, such as breakfast consumption (Wong & Mullan, 2009), and the inhibition of health-risk behaviours, such as binge drinking (Mullan, Wong, Allom, & Pack, 2011).

Executive function is a multifaceted construct comprised of several higher-order cognitive processes that are said to subserve the capacity to self-regulate (Gazzaley & D'Esposito, 2007), wherein individual differences in these processes predict the translation of intention into action (Hofmann et al., 2012). Executive function processes can be broadly thought of as falling into three categories: (1) *shifting*, i.e. flexibly altering goals and plans in response to chang-

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ing contingencies; (2) *inhibitory control*, i.e. inhibiting goal-irrelevant information and impulses in order to maintain focus on goals; and (3) *updating*, i.e. updating and monitoring goals (Miyake et al., 2000; Suchy, 2009). Importantly, when measured in early childhood, individual differences in executive function predict a range of important life outcomes, including health and academic performance (Marteau & Hall, 2013; Moffitt et al., 2011), and furthermore, individual differences in these constructs amongst adults have been shown to relate to the performance of numerous health behaviours (Booker & Mullan, 2013; Hall, Fong, Epp, & Elias, 2008).

Executive function and eating behaviour

Limited research has examined whether individual differences in shifting capacity in normal-weight populations relate to eating behaviours, such as saturated fat intake and fruit and vegetable consumption. Whilst Allan, Johnston, and Campbell (2011) demonstrated that superior performance on shifting tasks accounted for variance in both snacking and fruit and vegetable consumption within normal-weight adults, the majority of research appears to suggest that shifting deficits are primarily involved in the eating behaviour of underweight or obese individuals (Gunstad et al., 2007; Roberts, Demetriou, Treasure, & Tchanturia, 2007; Roberts, Tchanturia, Stahl, Southgate, & Treasure, 2007). Therefore, shifting ability was not the focus of the current study.

Conversely, evidence suggests that inhibitory control and updating are influential determinants of eating behaviour amongst normal-weight adults. In order to meet the goal of adhering to a healthy diet, the desire to consume unhealthy palatable foods needs to be inhibited, and information relevant to this goal has to be maintained and updated. Previous research has demonstrated that deficits in inhibitory control are associated with poorer eating behaviour and weight outcomes (Allan, Johnston, & Campbell, 2010; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010). Specifically, Allan et al. (2011) demonstrated that individuals with poor inhibitory control were less likely to carry out their healthy eating intentions. Hofmann, Friese, and Roefs (2009) and Hofmann, Gschwendner, Friese, Wiers, and Schmitt (2008) demonstrated that implicit attitudes rather than explicit dietary goals predicted chocolate consumption within individuals who performed poorly on a measure of updating. Conversely, amongst those who performed better on the task, goals rather than implicit attitudes predicted behaviour (Hofmann et al., 2008). These results indicate that having a goal to eat healthily may only be beneficial when an individual has sufficient ability to maintain and update this goal. This assumption is supported by the findings of Allan, Sniehotta, and Johnston (2013) in which goals were only predictive of behaviour amongst those with sufficient planning ability.

Thus poorer inhibitory control and updating ability appear to be associated with increased consumption of unhealthy foods; however, the relationship between executive function and consumption of healthy foods, such as fruit and vegetables, is less clear (Allom & Mullan, 2012). In one study, inhibitory control was found to moderate the relationship between intention and fruit and vegetable consumption, such that intention was more likely to lead to behaviour amongst those with greater inhibitory control (Hall et al., 2008). However, Hall (2012) failed to demonstrate a comparable relationship with non-fatty food consumption. Several other researchers have also struggled to replicate this effect (Allan et al., 2011; Collins & Mullan, 2011), suggesting that inhibitory control may not play a role in the consumption of healthy foods. In contrast, Sabia et al. (2009) found that eating less than two serves of fruit and vegetables a day was associated with poorer updating in later life. As the direction of causality is unclear, it is important to examine whether updating capacity contributes to the prediction of fruit and vegetable consumption.

Avoiding consumption of unhealthy foods versus initiating consumption of healthy foods

Previous research has established that different types of self-control can distinguish between conceptually distinct behaviours (de Boer, van Hooft, & Bakker, 2011; de Ridder, de Boer, Lugtig, Bakker, & van Hooft, 2011). Through a series of confirmatory factor analyses it was demonstrated that the Tangney, Baumeister, and Boone (2004) Self-control Scale consisted of two factors: inhibitory self-control and initiatory self-control. It was found that behaviours which required stopping a response, such as alcohol consumption and cigarette smoking, were predicted by inhibitory self-control, whilst behaviours that required starting a response, such as studying or exercising, were predicted by initiatory self-control (de Ridder et al., 2011). Therefore, it is plausible that tasks that index inhibitory control will be more relevant to the avoidance of unhealthy food consumption than to the initiation of healthy food consumption.

Aims and hypotheses

The aim of this study was to determine whether individual differences in two categories of executive function could predict two healthy eating behaviours: saturated fat intake and fruit and vegetable consumption, amongst participants with healthy eating intentions. As executive function refers to the ability to carry out goal-directed behaviour, it was necessary for participants to already have healthy eating intentions, so that the influence of executive function on the ability to carry out these intentions could be measured. It was hypothesised that those with a superior inhibitory control capacity would consume less saturated fat. However, inhibitory control was not expected to play a role in fruit and vegetable consumption. It was also expected that those with a superior updating capacity would consume less saturated fat and more fruit and vegetables. Based on previous research that demonstrated the importance of controlling for factors such as sex and BMI (Hall, 2012; Hall, Lowe, & Vincent, 2013), and eating style (Brignell, Griffiths, Bradley, & Mogg, 2009; Jansen et al., 2009; Jasinska et al., 2012), when examining the role of executive function in eating behaviour, these variables were controlled for in the current study.

Method

Participants

One hundred and fifteen normal to overweight undergraduate students from a variety of disciplines (mean age: 19.79 years, $SD = 1.95$, 83 females) were recruited to participate in a study on self-control and eating behaviour in exchange for course credit. Inclusion criteria included holding an intention to eat healthier, not colour blind, fluent in English, having regular access to the internet, and having no current or prior diagnosis of an eating disorder. All participants provided informed consent before taking part in the study, which was approved by the university Human Research and Ethics Committee.

Materials and measures

BMI and eating disorder status

BMI was calculated from participants' self-reported height and current weight. Participants were also asked to indicate the presence of a current or lifetime eating disorder diagnosis.

Eating style

Eating style was measured using the Dutch Eating Behaviour Questionnaire (van Strien, Frijters, Bergers, & Defares, 1986), which consists of 10 items assessing restrained eating (i.e., the tendency to restrict food intake due to a concern for weight), 10 items assessing external eating (i.e., the tendency to eat in response to external food-related cues), and 13 items assessing emotional eating (i.e., the tendency to eat in response to negative emotions such as anxiety and depression). Responses ranged from never (1) to very often (5) and subscale scores reflected the weighted average of relevant items. These subscales have been shown to have high internal consistency, high validity for food consumption, and high convergent and discriminative validity (van Strien, Frijters, Van Staveren, Defares, & Deurenberg, 1986). All subscales had good internal consistency in the present sample (restrained eating: $\alpha = .91$; external eating: $\alpha = .83$; emotional eating: $\alpha = .94$).

Eating behaviour

The Block Food Screener, which has been validated against a 100-item food frequency questionnaire in which it was demonstrated to effectively index saturated fat intake and fruit and vegetable consumption (Block, Gillespie, Rosenbaum, & Jenson, 2000), was used to measure saturated fat intake and fruit and vegetable consumption. For saturated fat intake, participants indicated how often they ate 17 meat and snack items (e.g. bacon, full-fat ice cream, fried potatoes) on a 5 point scale ranging from never (0) to five or more times per week (4), separately for each item. Scores were summed and entered into the validated formula in order to calculate daily saturated fat intake in grams. For fruit and vegetable consumption, participants indicated how often they ate seven fruit and vegetable items (e.g., fresh fruit, fruit juice, any kind of vegetable) on a 6 point scale ranging from less than once per week (0) to two or more times per day (5), separately for each item. Scores were summed and entered into the validated formula to calculate servings per day according to the pyramid definition of a serving of fruit or vegetables (US Department of Agriculture & US Department of Health and Human Services, 2010).

Inhibitory control

As inhibitory control is not a unitary construct (Spierer, Chavan, & Manuel, 2013; Verbruggen, Liefooghe, & Vandierendonck, 2004), it was deemed important to include two measures in order to more accurately index this capacity. Inhibitory control was assessed using the Stroop interference task and the stop-signal task; two measures that have previously been used together to index this capacity (Miyake et al., 2000).

In the Stroop interference task, participants are required to name the colour in which a written colour word is printed whilst inhibiting the tendency to read the word itself. Inhibitory control is required when the colour in which the word is printed, and the word itself, are incongruent. For example, when the word 'red' is printed in blue, the tendency to respond 'red' must be inhibited in order to provide the correct response of 'blue'. In the current study a computerised version of the Stroop task, which included three experimental blocks of 60 trials each and one practice block of 20 trials, was used. *Congruent trials* consisted of colour words that were printed in the corresponding colour. In *incongruent trials*, the colour of the colour word was different to the word itself. *Control trials* consisted of strings of letters matched in length to the colour words. Stimuli were displayed until the participant responded, and the response–stimulus interval was 500 ms. The Stroop interference score was calculated as the difference between mean response time of correct responses on incongruent trials and control trials (MacLeod, 2005), where a larger score indicated poorer inhibitory control. Response times that fell three standard deviations above or below a participant's mean reaction time per block were deemed to be outliers and were deleted (MacLeod, 2005).

In the stop-signal task participants are required to categorise a set of stimuli as quickly as possible, unless a signal to stop responding is presented. Inhibitory control is required to stop the ongoing response. The stop-signal task consisted of three experimental blocks of 64 trials each and one practice block of 32 trials. Each trial began with a fixation cross (+) presented in the centre of the screen for 500 ms. After this fixation cross, an image of a left arrow or a right arrow was presented. Participants were required to quickly categorise the content of the picture by pressing the "D" key for a left arrow or the "K" key for a right arrow, counterbalanced across participants. On 25% of trials an auditory tone occurred after a delay, which signified that participants should inhibit their response on that trial and wait for the next trial. The stop-signal delay was initially set at 250 ms and was adjusted dynamically according to participants' responses using a staircase tracking procedure: when inhibition was either successful or unsuccessful the delay increased or decreased by 50 ms respectively. Inhibitory control was assessed using the mean stop-signal reaction time, which was calculated using the subtraction method in which mean stop-signal delay is subtracted from the raw mean reaction time for all no-signal trials (Logan, 1994; Verbruggen, Logan, & Stevens, 2008). A greater stop-signal reaction time indicated poorer inhibitory control.

Updating

Two tasks were used to index updating capacity: the *n*-back and the operation-span task. Like inhibitory control, updating is not a unitary construct and tasks said to measure this construct maintain some independence (Kane, Conway, Miura, & Colflesh, 2007).

In the *n*-back, a sequence of stimuli is presented and participants must indicate when the current stimulus matches one *n* steps earlier in the sequence. Updating is required with each new stimulus presentation in order to correctly identify whether the current stimulus matches the target stimulus. In the current study a single adaptive *n*-back (Jaeggi et al., 2010) was used. Participants were shown a series of random yellow shapes presented centrally on a black background for 500 ms each followed by a 2500 ms interstimulus interval. Participants began on the one-back level and the level of *n* was adjusted after each block according to performance: if less than three errors were made, *n* increased by one, whilst if more than five errors were made, *n* decreased by one, if three to five errors were made, *n* stayed the same. The task consisted of 15 blocks of 24 trials. Updating ability reflected the proportion of hits minus false alarms averaged over all *n*-back levels, such that higher scores indicated greater updating capacity.

The operation-span task involves determining whether mathematical equations are correct whilst maintaining a mental representation of a string of letters that are to be recalled. Updating is required as the string of letters increases in length across trials. In the current study an automated operation-span task (Kane et al., 2007; Turner & Engle, 1989) was used in which participants firstly indicated whether the answer to a math equation (e.g., $[1 \times 2] + 1 = 4$) was true or false. Following the equation, participants were presented with a letter for 800 ms, which was to be recalled. The presentation of equations and letters continued until the set size had been reached for that block and then the recall screen consisting of a 4×3 matrix of letters was presented in which participants indicated the letters that had been presented to them in the correct order. Set sizes ranged from three to seven equation–letter presentations, with three blocks of each set size, presented in random order so that participants could not predict the number of items to be recalled. If the participants took more time to solve the math equations than their average time calculated from practice trials plus 2.5 *SD*, the programme moved to the next trial and this trial was considered an error in order to prevent participants from rehearsing the letters when they should be solving the equations. To ensure participants were attempting to solve both the math equations and remember the letters, an 85% accuracy criterion was imposed for math problems. Updating was assessed by operation-span, which was the sum of all perfectly recalled sets such that if an individual correctly recalled two letters in a set size of two, four letters in a set size of four, and three letters in a set size of five, operation-span would be six (2 + 4 + 0). A higher operation-span indicated greater updating ability.

Procedure

The study was conducted entirely online. Following sign-up and consent, participants received the link to a survey containing demographic variables and the Dutch Eating Behaviour Questionnaire. They were then directed to the first two executive function tasks. The next day participants were emailed a link to the remaining tasks and finally, 1 week later, were emailed a link to a survey containing the eating behaviour questionnaires. The order of executive functioning tasks across the 2-day period was counterbalanced across participants to control for the possible influence of order effects. Participants were also instructed to take a 5-minute break between executive function tasks to avoid a diminished performance effect on subsequent tasks. All executive function tasks were administered through Inquisit 3 by Millisecond Software, whilst the survey was administered through LimeSurvey.

Data analysis

Pearson product correlations were computed to examine the relationships between BMI, eating styles, inhibitory control, updating, saturated fat intake and fruit and vegetable consumption. Two identical hierarchical regression analyses were conducted to measure the utility of executive function (step 3) for predicting either saturated fat intake or fruit and vegetable consumption whilst controlling for BMI and gender (step 1) and eating style (step 2). All measures of executive function were entered in one step as there was no theoretical basis on which to determine the order of entry of inhibitory control or updating variables. Squared semi-partial correlation coefficients of the executive function variables that were significant predictors of behaviour were examined in order to determine the unique contribution of these variables to the prediction of either saturated fat intake or fruit and vegetable consumption.

Results

Outliers

The responses on the Stroop task of five participants exceeded the recommended quantity of acceptable outliers (3%; Ratcliff, 1993) and their responses were therefore removed from analysis. On average, 3.71 (2.06%) responses were removed for each participant.

BMI

BMI ranged from 18.52 to 33.20 ($M = 21.96$, $SD = 3.10$), and 85% of the sample were within the normal BMI range.

Correlations

BMI was correlated with eating behaviour, such that those with a higher BMI tended to consume more saturated fat and less fruit and vegetables (see Table 1). All three eating styles correlated with saturated fat intake such that those with more restrained eating styles ate less saturated fat, and those with higher external and emotional eating styles ate more saturated fat. Both measures of inhibitory control were positively correlated with saturated fat intake, such that those with poorer inhibitory control consumed more saturated fat; however, neither measure of updating was correlated with saturated fat intake. Both measures of updating were positively correlated with fruit and vegetable consumption, such that greater updating ability was related to higher consumption of fruit and vegetables. Neither of the measures of inhibitory control were related to fruit and vegetable consumption, nor were any of the eating styles.

Saturated fat intake

Sex and BMI accounted for 6% of the variance in saturated fat intake, although sex was the only significant predictor in this step, with males tending to consume more saturated fat (see Table 2). At step 2, eating styles accounted for an additional 14.2% of variance in saturated fat intake, with both restrained and emotional eating significantly predicting saturated fat intake. External eating was not a significant predictor. At step 3, executive function accounted for an additional 13.4% of variance in saturated fat intake. Both measures of inhibitory control were significant predictors of saturated fat intake; however, updating did not significantly predict saturated fat intake. Examining the squared semi-partial correlation coefficients of the executive function variables that were significant in the final model revealed that Stroop performance accounted for 3.73% of the unique variance in saturated fat intake, whilst stop-signal performance accounted for 4.88% of the variance in saturated fat intake. The final model accounted for 33.6% of the variance in saturated fat intake, with restrained eating, emotional eating,

Table 1
Means, standard deviations, and Pearson's correlations of BMI, eating styles, executive function and behaviour measures of saturated fat intake and fruit and vegetable consumption.

	BMI	RE	XE	EE	Stroop	SST	*n*-back	OSPAN	SF	FV
BMI	1	.191*	–.115	–.049	.075	.016	–.053	–.056	.192*	–.204*
RE		1	–.008	.146	–.068	–.088	.063	–.078	–.259**	–.179
XE			1	.554**	.020	–.031	.075	–.064	.206*	.103
EE				1	–.054	–.005	–.120	.039	.210*	.132
Stroop					1	.237*	.003	–.190*	.300**	–.014
SST						1	.052	.049	.274**	–.029
n-back							1	.216*	.120	.195*
OSPAN								1	.029	.280**
SF									1	.240**
FV										1
Mean	21.964	2.637	3.163	2.423	183.639	251.265	1.627	48.886	30.882	6.696
SD	3.102	.824	.604	.778	130.589	55.168	.944	15.625	7.001	2.032

Note: BMI = body mass index; RE = restrained eating; XE = external eating; EE = emotional eating; SST = stop-signal task performance; OSPAN = operation span task performance.
* $p < .05$.
** $p < .01$.

Table 2
Hierarchical regression analysis for prediction of saturated fat intake.

	Step 1			Step 2			Step 3		
	β	ΔR²	ΔF	β	ΔR²	ΔF	β	ΔR²	ΔF
Sex	–.246*	.060	3.429*	–.188	.142	6.214**	–.191	.134	5.093**
BMI	–.005			.104			.083		
RE				–.277**			–.250**		
XE				.095			.066		
EE				.241*			.284**		
Stroop							.201*		
SST							.234**		
n-back							.129		
OSPAN							.008		

Note: BMI = body mass index; RE = restrained eating; XE = external eating; EE = emotional eating; SST = stop-signal task performance; OSPAN = operation span task performance; overall $R^2 = .336$.
* $p < .05$.
** $p < .01$.

and inhibitory control making significant independent contributions whilst gender remained a marginally significant predictor ($p = .053$).

Fruit and vegetable consumption

As can be seen in Table 3, sex and BMI accounted for 6.8% of the variance in fruit and vegetable consumption; however, BMI was the only significant predictor in this step indicating that those with a higher BMI tended to eat less fruit and vegetables. Eating styles at step 2 did not account for a significant proportion of variance in fruit and vegetable consumption. At step 3, updating accounted for an additional 7.8% of the variance in fruit and vegetable consumption; however, operation-span was the only significant predictor. Examining the squared semi-partial correlation coefficient of operation-span in the final model revealed that operation-span accounted for 4.33% of the unique variance in fruit and vegetable consumption. The final model accounted for 18.2% of the variance in fruit and vegetable consumption, with operation-span making a significant independent contribution, whilst BMI remained a marginally significant predictor ($p = .058$).

Discussion

The aim of this study was to determine whether particular elements of executive function were related to saturated fat intake and fruit and vegetable consumption, whilst controlling for demographic variables and eating styles. As hypothesised, those with a higher inhibitory control capacity consumed less saturated fat; however, contrary to expectations, updating ability was not related to saturated fat intake. In contrast, updating was related to fruit and vegetable consumption, such that those with a higher updating ability consumed more fruit and vegetables, and as expected, inhibitory control was not related to fruit and vegetable consumption.

The current results suggest that amongst people with healthy eating intentions, individual differences in inhibitory control capacity predict saturated fat intake. These results support the findings of Hofmann et al. (2009) in which it was demonstrated that impulsive processes directed the behaviour of individuals low in inhibitory control. Hofmann et al. (2009) contextualised these findings using a dual-systems approach to explaining behaviour in which it is suggested that behaviour is governed by two systems: the impulsive and the reflective (Hofmann, Friese, & Wiers, 2008; Strack & Deutsch, 2004). When conflict arises between achieving a goal and engaging in automatic tendencies that thwart goal attainment, these tendencies must be inhibited to successfully carry out goal-directed behaviour. Therefore, it appears that inhibitory control may be influential in the execution of healthy eating goals.

Hofmann et al. (2008) also demonstrated a similar relationship between impulsive processes and chocolate consumption within those who performed poorly on the operation-span task, suggesting that updating is also required to carry out goal-directed behaviour. Therefore, it was surprising that updating ability did not relate to saturated fat intake in the current study. Research suggests that updating enables individuals to resist the attentional capture of stimuli at early stages of processing (Friese, Bargas-Avila, Hofmann, & Wiers, 2010). However, strategies which assist goal-directed behaviour once attention has been captured, such as stopping a response to tempting stimuli, may be more relevant to avoiding consumption of foods high in saturated fat. Alternatively, it is possible that updating does not play a direct role in saturated fat intake, such that it is only predictive amongst those with strong

Table 3
Hierarchical regression analysis for prediction of fruit and vegetable intake.

	Step 1			Step 2			Step 3		
	β	ΔR²	ΔF	β	ΔR²	ΔF	β	ΔR²	ΔF
Sex	–.183	.068	3.941*	–.172	.036	1.391	–.132	.078	2.412*
BMI	–.272**			–.236*			–.204		
RE				–.113			–.127		
XE				–.034			–.030		
EE				.189			.191		
Stroop							–.073		
SST							.053		
n-back							.128		
OSPAN							.225*		

Note: BMI = body mass index; RE = restrained eating; XE = external eating; EE = emotional eating; SST = stop-signal task performance; OSPAN = operation span task performance; overall $R^2 = .182$.
* $p < .05$.
** $p < .01$.

implicit preferences for unhealthy foods. As such, future research should attempt to clarify this by including measures of impulsive determinants of saturated fat intake, and testing both direct and indirect relationships between updating and saturated fat intake. Additionally, alternative measures of updating, particularly those which include stimuli related to the behaviour of interest, such as the food *n*-back used by Hege et al. (2013) and Stingl et al. (2012), may further elucidate the role of updating in saturated fat intake.

As expected, inhibitory control did not play a role in fruit and vegetable consumption. This is consistent with previous research that has failed to find a relationship between executive function and healthy eating behaviours such as fruit and vegetable consumption (Allan et al., 2011; Collins & Mullan, 2011; Hall, 2012), and breakfast consumption (Wong & Mullan, 2009). The current findings are also consistent with a series of studies by Mullan and colleagues that failed to find a relationship between inhibitory control and many health-enhancing behaviours including, safe food-handling (Fulham & Mullan, 2011), and sun protection behaviour (Allom, Mullan, & Sebastian, 2013). It appears that for health-enhancing behaviours, which usually require the initiation of a response, inhibitory control is not necessary.

The novel finding that updating predicted fruit and vegetable consumption sheds light on how health-enhancing behaviours are successfully carried out. Updating is said to directly support active representations of self-regulatory goals and the associated means by which these goals can be attained (Kruglanski et al., 2002; Miller & Cohen, 2001). It appears that goal representation and maintenance are particularly important for health-enhancing behaviours, which require initiation rather than inhibition of a response. Specifically, a superior updating ability may enable the management of attentional resources, which in turn, results in individuals seeking out opportunities to eat fruit and vegetables.

These results appear to indicate that the predictive utility of executive function constructs differs according to the nature of the behaviour in question. For example, behaviours that involve stopping impulsive responses, such as avoiding the consumption of foods high in saturated fat, appear to be related to inhibitory control capacity, whilst behaviours that involve actively seeking out a stimulus, such as consuming the appropriate amount of fruit and vegetables, are conversely related to updating. The results are similar to previous research, which has suggested that different types of self-control can distinguish between conceptually distinct behaviours (de Boer et al., 2011; de Ridder et al., 2011), and lend greater support to the notion that self-control is multifaceted. Furthermore, taken together, the results of the current study, and that of de Ridder et al. (2011), suggest that updating may be conceptually similar to initiatory self-control and thus important in the initiation of goal-directed behaviour.

Finally, that eating styles were only related to saturated fat intake, further solidifies the difference between these two behaviours and highlights the importance of understanding not only what leads to the consumption of unhealthy foods but also the consumption of healthy foods. Additionally, the overall variance accounted for in healthy eating behaviour was much lower than that accounted for in unhealthy eating behaviour. It appears that eating styles are more strongly predictive of unhealthy eating behaviour. The constructs of external and emotional eating, and restrained eating reflect eating based on impulse or resisting an impulse, respectively (Ebneter, Latner, Rosewall, & Chisholm, 2012). Therefore, it is plausible that these styles only relate to behaviours that involve stopping impulsive tendencies.

Strengths and limitations

One of the strengths of the current study was the examination of how executive function relates to healthy eating behaviour, rather than focusing only on unhealthy eating behaviour. However, although a double dissociation was observed, the difference in correlations between eating behaviours and *n*-back scores was small ($r = .120$, $p = .203$, for saturated fat intake; $r = .195$, $p = .036$, for fruit and vegetable consumption). Whilst this finding suggests that updating is more important for fruit and vegetable consumption, further research testing this relationship is warranted. The use of self-report measures of behaviour is a limitation of the current study, as these measures are subject to social desirability biases; however, these measures offer a less artificial assessment of eating behaviour than laboratory-based measures such as pseudo taste tests (Thompson & Subar, 2013). Additionally, the current study recruited a university sample, which limits the generalisability of the findings; however, evidence suggests that university students often eat unhealthily and are at a greater risk of weight gain than other populations (Racette, Deusinger, Strube, Highstein, & Deusinger, 2005; Strong, Parks, Anderson, Winett, & Davy, 2008). Therefore, it is important to understand the eating behaviour of this population.

The current research was also limited by the correlational nature of the data. From these results, it is difficult to determine whether individuals who were better able to carry out their goals did so due to superior executive function or whether healthy eating behaviour led to improvements in executive function. For example, a recent review of cognitive function and the Western diet (i.e., high in saturated fat and refined carbohydrates), suggested that the Western diet leads to impaired brain function and also contributes to the development of neurodegenerative conditions (Francis & Stevenson, 2013). It is likely that the relationship between executive function and diet is bidirectional. Studies aiming to manipulate executive function in order to alter eating behaviour have shown that inducing a mindset of inhibition versus impulsivity results in less food consumed in a pseudo taste test (Guerrieri, Nederkoorn, Schrooten, Martijn, & Jansen, 2009). Additionally, Smith, Hay, Campbell, and Trollor (2011) reviewed the literature on the association between obesity and cognitive function across the lifespan and concluded that weight gain results, at least in part, from a neurological predisposition that is characterised by reduced executive function, and in turn obesity itself has a compounding negative impact on the brain and cognitive function.

Implications

The current results have numerous implications for the understanding of eating behaviour, and health behaviour in general. Firstly, the current results may add to the development of frameworks that allow for greater understanding of similarities and differences between health behaviours; for example, the classification framework put forth by McEachan, Lawton, and Conner (2010), which describes three dimensions on which health behaviours may fall and provides specific predictions about how health behaviours are executed. Understanding the characteristics of health behaviours, and how these characteristics determine the performance of health behaviours, may aid in the development of effective intervention strategies. Specifically, the current results clarified the relationship between particular facets of executive function and eating behaviours, suggesting that interventions aiming to improve these behaviours may benefit from targeting the appropriate element of executive function.

Current evidence suggests that inhibitory control can be augmented to decrease consumption of unhealthy foods (Houben, 2011; Houben & Jansen, 2011). For example, Houben (2011) demonstrated that participants with initially low inhibitory control who completed a modified stop-signal task, which trained the inhibition of responses to high calorie foods, consumed less than those who were not trained to inhibit responses. In terms of updating training, much research has focused on using tasks such as the *n*-back to improve fluid intelligence; however, evidence suggests that training does not transfer to improvement in intelligence (for review, see: Melby-Lervåg & Hulme, 2013). Whilst updating training may not improve intelligence, conclusions cannot be drawn as to whether updating training transfers to other outcomes such as healthy eating and this is an avenue worthy of further exploration. Furthermore, future research aimed at determining the mechanisms by which such training works may elucidate the efficacy of such interventions. Additionally, programmes which combine executive function training with established behaviour change techniques such as implementation intentions may be particularly useful for the improvement of eating behaviour (Harris et al., 2014; Tapper, Jiga-boy, Maio, & Haddock, 2013).

Conclusions

These results of this study further our knowledge of the processes involved in healthy eating, and lend support to the distinction between different types of self-regulation put forth by de Ridder et al. (2011) by dissociating two related, but conceptually distinct, eating behaviours using several measures of executive function. Taken together these results indicate that superior executive function in one domain does not necessarily lead to the successful performance of all health behaviours, and moreover, that the ability to resist the performance of unhealthy behaviours may not generalise to the ability to initiate healthy behaviours. Specifically, inhibitory control is important for behaviours that require stopping a response such as limiting the intake of foods high in saturated fat, whilst updating is important for carrying out behaviours that require the initiation of a response such as fruit and vegetable consumption.

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