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REVIEW ARTICLE

A Review of the Evidence that Chewing Gum Affects Stress, Alertness and Cognition

A. P. Allen* & A. P. Smith
Cardiff University

Research is reviewed on the effects of chewing gum on stress, alertness and cognition (including findings from cognitive neuroscience). There is some evidence that chewing gum reduces chronic stress, while effects on acute stress have been less clear in an experimental context. A robust effect of gum chewing on subjective alertness has been observed. However, findings on chewing gum and cognition have been more variable. It is suggested that length of chewing may be a key moderator in chewing gum effects. Possible mechanisms are highlighted for effects of chewing gum on stress and cognition, and suggestions for future research are made.

Key Terms: *Chewing Gum, Stress, Cognition, Attention, Vigilance, Alertness, Memory, Cognitive Neuroscience*

In a survey of American undergraduate students, nearly 87% reported chewing gum at least occasionally (Britt, Collins, & Cohen, 1999), and 61% of respondents in a recent survey of full-time workers in the UK indicated that they were gum chewers (Smith, 2009a). People may chew gum in the belief that it will reduce stress (e.g. Zibell & Madansky, 2009), or that it will aid concentration (e.g. Wilkinson, Scholey, & Wesnes, 2002), so it is worthwhile establishing if these beliefs are well-founded.

Chewing gum seems to be associated with reduced chronic stress, but the research does not suggest an effect on acute stress. A relatively robust effect on acute reported alertness has been found. There have been contradictory findings from different studies investigating chewing gum's effects on cognition. There are a number of possible mechanisms through which chewing gum may affect stress, alertness and cognition, such as brain activity, exercise effects or demand characteristics. In addition, the length over which gum is chewed may moderate any effects.

*Corresponding Author
Andrew P. Allen
Centre for Occupational and Health Psychology
63 Park Place
School of Psychology
Cardiff University
CF10 3AS, UK
AllenAP@cardiff.ac.uk

This review aims to clarify why differing results have been found, to suggest which research may be of greater merit, to posit factors that mediate and moderate chewing gum effects on cognition and stress, and to show how future research could expand on existing findings.

Search Methodology and Evaluative Criteria

ScienceDirect, PubMed and Google Scholar were used as search engines. The search term "chewing gum" was used along with "stress", "anxiety", "alertness", "cognition", "attention", "reaction time", "vigilance" and "memory". References within papers were checked for useful research. In addition, papers which had previously been made available to the authors were reviewed. Research which primarily concerned nicotine chewing gum is not reviewed, given the psychopharmacological effects of nicotine.

Studies were judged according to the following criteria: they were given a point if there was a baseline in the case of between-participants design or if a within-participants/crossover design was used (plus an extra point if trial order was entered into the analysis for crossover designs). They were given a further point if there were sufficient participants per condition to detect a large effect size (Cohen's d = 0.8/Cohen's f = 0.4), assuming a power of 0.8; n = 26 per condition for a t-test, n = 21 per

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condition for ANOVA with 3 conditions and n = 18 per condition for 4 conditions (J. Cohen, 1988). Studies which met none of these criteria were not considered (Baker, Bezance, Zellaby, & Aggleton, 2004, Experiment 2; Miles & Johnson, 2010, Experiment 3). Forty-two papers on the effects of gum chewing on stress, alertness and attention have been included in this review. Where a multiple comparisons adjustment was not performed in the original paper, a Bonferroni adjustment was made to critical *p*-values, based on the total number of comparisons made.

CHEWING GUM AND STRESS

The term "stress" can be used to describe people's response to a variety of situations (Jones & Bright, 2001). These can include disruptions to normal functioning that can come from within the systems people operate (e.g. car breaking down) or from outside these systems (e.g. bad weather) (Hammond, 2000). Stress can lead to or aggravate health problems (L. M. Cohen, 2003) and can impair cognitive performance (e.g. Sliwinski, Smyth, Hofer, & Stawski, 2006; Vedhara, Hyde, Gilchrist, Tytherleigh, & Plummer, 2000), and occupational stress can have detrimental effects on family life (Repetti, Wang, & Saxbe, 2009). Although chewing gum may have little to do with an individual's exposure to stressors, it could reduce experienced stress by attenuating the level of affect associated with these stressors.

Chewing Gum and Acute Stress

In an experimental investigation, chewing gum was not associated with reduced self-reported stress or anxiety after correcting for multiple tests following performance of a stressful multi-tasking framework that requires participants to work on multiple tasks at the same time (Scholey et al., 2009). However, chewing gum was associated with reduced cortisol (a biological indicator of stress and alertness).

Johnson, Jenks, Miles, Albert and Cox (2011) also tested the effects of chewing gum on a multi-tasking framework. Two tasks used in Johnson et al.'s multi-tasking framework (auditory monitoring and visual tracking) differed from those used in that of Scholey et al. (visual monitoring and Stroop), although both frameworks used four tasks in total. Johnson et al. did not find an effect of chewing gum on reported stress or anxiety. They did not replicate the effect of gum on cortisol during multi-tasking observed by Scholey et al.

Torney, Johnson and Miles (2009) failed to find a benefit of chewing gum on self-reported stress following attempts at an insoluble anagram. Torney et al. argued that their task differed from Scholey et al.'s in that it should lead to a more social form of stress, as one may be embarrassed about the inability to solve an anagram, although there were other methodological differences between the two studies (e.g. Torney et al.'s task did not last as long as the framework used by Scholey et al.). Torney et al. analysed the changes in self-reported stress in response to the stressor for the no gum condition in both their study and that of Scholey et al., and found no significant difference. This suggests that chewing gum does not affect different types of acute stress of equivalent intensity.

Smith (2010) tested participants under either quiet or noisy conditions. A battery of cognitive tests as well as stress measures was administered. No effect of chewing gum was observed on a self-report measure of anxiety, although noise was rated as less annoying during gum conditions. Trait anxiety was measured and controlled for. Reported anxiety was greater during noise conditions. Chewing gum led to higher levels of heart rate and salivary cortisol. Smith emphasised the rise in cortisol as indicating increased alertness (which was supported by the self-reported alertness data), but a rise in cortisol also indicates a heightened physiological stress response, though this interpretation is somewhat problematic given the lack of an increase in reported anxiety. The number of interaction effects found was no higher than would be expected by chance, indicating that the chewing gum should have similar effects regardless of levels of typical chewing gum consumption, levels of anxiety and level of noise in one's surroundings.

Smith (2009b) found that participants reported lower anxiety after chewing non-caffeinated "placebo" gum (caffeinated gum was also investigated), relative to a no-gum control, although this was non-significant. Participants also performed cognitive tasks in this study, but these were not designed to be stress-inducing.

Following a stress loading condition (having to perform a mental arithmetic task for twenty minutes), both chewing paraffin wax and clenching one's teeth reduced salivary cortisol levels (Tahara, Sakurai, & Ando, 2007). Some participants (five out of seventeen in the chewing study and four out of seventeen in the clenching study) were excluded from the analysis as the stress loading condition did not lead to an increase in salivary cortisol. Although the authors attributed this to such participants not realising there was a time limit for the stress loading task, the large proportion of participants not

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undergoing an increase in salivary cortisol may instead suggest that there are individual differences in vulnerability to stress that the analysis did not take account of.

A significant difference in cortisol levels has been found between chewing flavourless gum quickly and chewing it slowly, using an arithmetic task for stress loading (Tasaka, Tahara, Sugiyama, & Sakurai, 2008), with faster chewing leading to a greater reduction in salivary cortisol. This could be interpreted as indicating that greater levels of activity during chewing will have a greater effect, and that the rate of chewing should be controlled in experiments investigating chewing gum and stress. However, with regard to the second implication, slow and fast chewing were defined as 15% faster or slower than each participant's habitual speed of chewing. Consequently, assuming that participants will chew at their own habitual rate in an experiment unless instructed otherwise, this study may not have really identified a confounding variable.

In summary, experimental research looking at short-term, induced stress has shown contradictory findings for cortisol and a lack of significant effects on self-reported stress and anxiety. Cortisol may be considered one of the most objective indicators of stress but Scholey et al. (2009) have pointed out that giving a saliva sample can be a social stressor. The observed effects sizes on self-reported stress and anxiety have been small or moderate. Calm may be seen as the opposite end of a spectrum from anxiety or stress, so the consistent lack of a significant effect of gum on self-reported calm gives further evidence that chewing gum does not affect short-term self-reported stress (See Table 3).

Long-Term Effects of Chewing Gum on Chronic Stress

In a large survey of workers (n = 2,248), gum chewers reported more exposure to negative characteristics at work (e.g. long or unsociable hours), but fewer participants in this group described themselves as being "extremely stressed" at work (Smith, 2009a). Gum chewers were also less likely to report high levels of life stress than non-chewers. This suggests that chewing gum may ameliorate strong, chronic stress, or instead that it is used in an attempt to reduce occupational stress; this data was correlational, and so cannot establish the direction of causality. Nonetheless, the implication that chewing may be related to stress is further supported by an occupational survey by Ahlberg et al. (2002), which found that stress was strongly associated with bruxism, i.e. parafunctional teeth grinding, gnashing, clenching or bracing (AAOP, 1993), although stress may lead to bruxism without the condition necessarily acting as a coping mechanism for stress.

In two studies (one using frequent gum chewers as participants and another using infrequent chewers) 56% of frequent gum chewers (those who chewed 11 or more pieces of gum a week, and chewed gum on four or more days per week) and 42% of infrequent chewers said that dealing with everyday stress was a reason that they chewed gum (Zibell & Madansky, 2009). Following initial questioning, frequent chewers (n = 280) were required to abstain from chewing gum for 3 days and chew gum as normal for another 3 days, and non-regular chewers (n = 212) were required to abstain for 7 days and chew at least three times a day for another 7 days. At the end of each period, participants were questioned about stress (using a simple 5-point scale) and anxiety levels (using the State-Trait Anxiety Inventory/STAI; Spielberger, 1983). Abstaining from chewing gum resulted in significant increases in stress and anxiety for frequent and non-frequent chewers, and reductions in stress and anxiety were observed following periods of chewing. The fact that stress was reduced for non-regular chewers suggests that factors other than familiarity of chewing gum are at work.

Suh, Kim, Chang and Kim (2008) had participants in a two-week intervention chew gum with yeast hydrolysate or "placebo" gum. They found that the placebo gum led to a non-significant reduction in anxiety between pre- and post-intervention.

In summary, chewing gum has been found to reduce self-reported, naturally occurring stress when chewed over a relatively long period of time, although the findings of Suh et al. were non-significant. One useful aspect of such non-experimental research is that it has dealt with chronic stress that occurs in everyday life, rather than short-term stress manipulated using laboratory tasks. Nonetheless, future research could perhaps combine an acute experiment with a longer-term intervention within a single study to allow for a clear comparison of the effects of chewing gum on short-term and long-term stress. There does not appear to be longer-term research on the effects of chewing gum on levels of cortisol - this could also be addressed in future research.

CHEWING GUM AND ALERTNESS

Although Torney et al. (2009) failed to find an effect of chewing gum on self-reported alertness, such an effect of chewing gum has been found on pre-test alertness (Smith, 2009b), and on post-test alertness (Scholey, et al., 2009; Smith, 2009c, week one; 2010). Johnson et al. (2011) and Smith (2009c) also observed increased alertness in gum conditions, although these observed differences were non-significant.

In addition to research on self-reported alertness, the effect of chewing gum on biomarkers of alertness has also been conducted. Physiological evidence for an alerting effect has been provided by research that measured pupil diameter fluctuations, with participants in the chewing condition scoring lower than a no-gum control on a pupillary unrest index (Johnson et al., 2009). Some research has not shown a significant effect of gum on heart rate (O. Tucha, Mecklinger, Maier, Hammerl and Lange 2004), although other studies have (e.g. Wang, Gitelman & Parish, 2009), and it has been argued that the literature overall suggests that chewing gum increases heart rate in the short run (Weijenberg, Scherder, & Lobbezoo, 2011). Two studies have indicated that chewing reduces cortisol (Scholey et al., 2009; Tahara et al., 2007), while another has shown an increase (Smith, 2010).

In summary, chewing gum seems to have a positive effect on subjective alertness, but the evidence on alertness biomarkers has been less consistent. As the effect of chewing gum on subjective alertness appears to be quite robust, one might expect cognitive performance to be enhanced by chewing gum. However, the mixed findings from cognition discussed below indicate that chewing gum's enhancing of subjective alertness may not necessarily translate into behavioural effects.

CHEWING GUM AND COGNITION

Chewing Gum and Attention

In an experiment by O. Tucha et al. (2004), chewing gum did not lead to a significant improvement in performance on a computerised test of sustained attention taken from a battery of cognitive performance tasks (Zimmerman & Fimm, 2001). Smith (2010) found a positive effect for a sustained attention task (repeated digits vigilance), although a main effect of gum on a sustained attention task (taken from Zimmerman & Fimm, 1993) was not observed in an experiment by L. Tucha and Simpson (2011). Performance on the DL-KG test (Kleber, Kleber, & Hans, 1999) (a 16-minute concentration task which required participants to either cross or dot symbols), was higher towards the end of the task when participants (schoolchildren aged eight to nine) chewed gum (Tänzer, von Fintel, & Eikermann, 2009). The fact that participants were together in class would undermine the independence of the observations, and suggests that a multilevel models analysis for hierarchical data would have been more appropriate (c.f. Field, 2009).

Neither Scholey et al. (2009) nor Johnson et al. (2011) found a significant effect of gum on divided attention (assessed using multi-tasking frameworks), although performance was better in the gum group for Scholey et al. (2009). O. Tucha et al. (2004) did not find a significant effect on reaction time or accuracy for a divided attention task.

With regard to selective attention, Smith (2010) found that chewing gum led to wider breadth of attention, using a choice reaction time task developed by Broadbent, Broadbent and Jones (1986, 1989) which involves responding to a target stimulus in the centre of the screen while ignoring distracting stimuli elsewhere. This effect may be mediated by positive mood; it has generally been found that positive mood broadens attention (e.g. Rowe, Hirsh, & Anderson, 2007; Wadlinger & Isaccowitz, 2006). However, Smith did not find a positive effect of gum on hedonic tone for the 2010 study. Chewing gum was also associated with faster reaction times on a categoric search task (also developed by Broadbent et al.), although O. Tucha et al. (2004) did not find a significant effect of gum on a selective attention task.

To summarise, the evidence does not indicate that gum affects divided attention. There is mixed evidence for an effect on sustained attention and selective attention.

Chewing Gum and Reaction Time

There is evidence that chewing gum does not improve simple reaction time (Smith, 2009b, 2010). In two experiments by O. Tucha et al., (2004), tonic alertness reaction time was significantly slower for a spearmint gum condition compared to not chewing, although there was no significant difference between these two conditions for reaction time on a phasic alertness task (c.f. Zimmerman & Fimm, 2001). It is unusual that this pattern of effects would be observed in an experimental context, as tonic alertness changes slowly over the course of the day, while phasic alertness involves enhancing arousal in response to a relevant stimulus (Van Zomeren & Brouwer, 1994). Smith (2010) found that chewing gum reduced the difference between reaction time to new stimuli and repeated stimuli, suggesting that speed of encoding was enhanced by chewing gum. It would be of interest to see if either of these specific reaction time effects could be replicated.

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Wilkinson et al. (2002) found that participants in a sham-chewing group did worse than the quiet control group on a simple reaction time task. Although this has been interpreted as indicating that the level of resistance in what one is chewing may have an effect on reaction time (Scholey, 2003), Wilkinson et al. themselves pointed out that participants in the sham-chewing group could have been distracted by having to perform the novel task of making chewing movements with nothing in their mouths.

With regard to the effect of chewing gum before testing on reaction time, Sakamoto, Nakata and Kakigi (2009) found that reaction time was shorter than at baseline for three post-chewing gum sessions on an auditory oddball task. This pattern was not evident in a control group, who were instructed to relax (a possible confound) without chewing gum. Rhythmic jaw movement and finger tapping in a second experiment did not produce similar effects in reaction time to chewing gum in the first experiment, suggesting that the effect of chewing is not simply due a general effect of motor activity. It should be noted, however, that more than half of the participants in the second experiment had also participated in the first experiment, so the lack of a difference between conditions in the second experiment could be due to practice on the oddball task. Another experiment on prior chewing has similarly indicated that reaction time falls over repeated sessions following chewing gum and increases over repeated control sessions (Sakamoto, Nakata, Honda, & Kakigi, 2009).

Overall, the research suggests that chewing gum quickens simple reaction time to an auditory, but not a visual stimulus. More specific effects on reaction time have been observed, but further research will clarify whether or not these are robust.

Chewing Gum and Memory

Recall: Immediate and delayed recall have been found to be better in a gum condition than in a no-gum control (Baker et al., 2004, experiment one; Wilkinson et al., 2002), although later research has not supported this finding (Smith, 2009c, 2010; O. Tucha, et al., 2004). Smith (2009c) also found that chewing gum did not improve recall of a story. In contrast, Stephens and Tunney (2004a) found that chewing gum (compared to sucking a sweet) led to an improvement in immediate recall and delayed recall.

Smith (2010) found that chewing gum impaired recognition of words that had been presented earlier when they were presented alongside distracters; he speculated that this could be due to an effect of chewing gum on sub-vocal rehearsal. The recall tasks used by Smith (2010) were more difficult than those used elsewhere, although a sub-vocal rehearsal mechanism could apply to simpler recall tasks as well.

Context-Dependent Memory: Aggleton (personal communication cited in Scholey, 2004) suggested that a change in context may induce disparities in recall, as the flavour or texture of chewing gum may change between learning and recall. There is some evidence that chewing gum induces context-dependent memory effects (i.e. if participants chew gum in the learning trial, their recall will be improved by chewing gum during recall) (Baker et al., 2004, Experiment 1; Miles, Charig, & Eva, 2008). Miles et al. required participants to count backwards from 10 to 0 repeatedly following the learning phase, in order to prevent words from being maintained in short-term memory. Consequently, their findings suggest that a context-dependent effect may persist over time. Baker et al. concluded that the evidence for a context-dependent effect on memory indicated that chewing gum can aid learning.

However, other research has failed to find a context-dependent effect of chewing gum (Johnson and Miles, 2007; Miles and Johnson, 2008; Overman, Sun, Golding, & Prevost, 2009). Two separate experiments by Johnson and Miles (2008) showed that although flavourless gum and mint-flavoured strips led to reported change in current mouth activity and mint intensity respectively, they did not induce context-dependent memory, which indicates that neither flavour nor the sensation of chewing leads to context effects in memory. Research by Miles and Johnson (2008) showed that chewing gum at learning was associated with poorer recall, which suggests that chewing gum impairs word encoding. Overman et al. (2009) did not find a difference between sucking and chewing on context-dependent memory (where context was the oral activity undertaken during learning). They used sweets (for sucking) and chewing gum that had the same flavour.

In addition to failing to find an effect on context-dependent memory in two experiments, Miles and Johnson (2010) also measured number of errors in recall, and found that chewing gum had no context effect. It should be noted that gum was only chewed for a short amount of time in these experiments, compared to other investigations of the cognitive effects of chewing gum.

Any effects (or lack thereof) of chewing gum on rote learning of word lists used in most of the studies discussed above may not generalise to the sort of learning that undergraduates typically undertake (most participants in these experimental studies are undergraduate students). Using a more ecologically valid measurement of memory, Allen, Norman and Katz (2006) found a slight improvement in exam performance between students who chewed gum during a lecture and those who did not. However, Allen, Norman and Katz (2008) did not find an improvement in exam performance between students who chewed gum during a lecture and those who did not, after controlling for Grade Point Average and gender. Allen et al.'s studies differed from others that aimed to measure context-dependent memory in that there were no conditions that were inconsistent in terms of the context of chewing gum condition (e.g. chewing during learning and not chewing during recall/exam).

Working memory: Stephens and Tunney (2004a) found that chewing gum (compared to sucking a sweet) led to an improvement in digit span and spatial span. Another measure of working memory used in chewing gum research has been the *n*-back task. Hirano et al. (2008) found that performance on two *n*-back tasks (2-back and 3-back) improved following chewing gum. The chewing gum condition came after the control condition for all participants in Hirano et al.'s study-it is possible that chewing gum may have improved working memory by increasing alertness during a fatiguing task although this findings may also be explained by a practice effect. Wang et al. (2009) failed to find an effect of chewing on *n*-back performance, although this may have simply been due to insufficient power (there were only ten participants).

In summary, although it has been suggested that chewing gum may impair recall by restricting sub-vocal rehearsal (Smith, 2010), another study has found a positive effect (Stephens & Tunney, 2004a), and three studies on gum and recall have not indicated any effect. Some initial findings that chewing gum has a context-dependent effect on memory have not been replicated elsewhere. Finally, there appears to be reasonable evidence that chewing gum does have a positive effect on working memory, although further research is required to test the robustness of this finding.

FINDINGS ON CHEWING GUM FROM ELECTROPHYSIOLOGICAL AND BRAIN IMAGING RESEARCH

EEG Findings

Sakamoto, Nakata & Kakigi (2009) found that chewing gum had an effect on event-related potentials (ERPs) when participants performed an auditory oddball paradigm. The peak latencies of P300 and N100 were shorter in the post-chewing sessions. This was not observed in the control group or either of the conditions in their second experiment (jaw movement and finger tapping). The finding that P300 was affected by chewing gum suggests that the effect on reaction time was due to faster stimulus evaluation, rather than response selection. Similarly, Sakamoto et al. proposed that the N100 effect represented an effect of chewing on target detection processing. Although they did not speculate on what areas of the brain could be associated with the changes in peak latencies, Sakamoto et al. offered hypotheses as to why the ERP data was different in the chewing gum trials, including increased arousal and increased activity of serotonergic neurons. Research has indicated that gum chewing for twenty minutes leads to enhanced serotonin levels in the blood (Kamiya et al., 2009).

Other ERP research has indicated that chewing flavourless gum leads to increased amplitude in contingent negative variation (CNV) (an ERP which is associated with cognitive processing, motivation and expectancy), but not in movement-related cortical potentials (MRCPs) (which are associated with movement preparation processing) (Sakamoto, Nakata, Honda, et al., 2009). CNVs were evoked by presenting a warning tone before a second tone; participants had to press a button in response to this second stimulus. For the measurement of MRCPs, participants were required to extend a finger. The change in CNV was observed during a second and third post-chewing session, so the effect took time to occur. As with the effects on P300 and N100 (Sakamoto, Nakata, & Kakigi, 2009), the authors speculated that the observed effect may be due to an increase in arousal. They proposed that this increase in arousal stems from an effect of chewing on the ascending reticular activating system (ARAS), and suggested that the change in CNV is consistent with positive findings on chewing gum and working memory.

Other EEG research has looked at chewing *per se*, rather than the effects of chewing gum during a cognitive task. Masumoto, Morinushi, Kawasaki, and Takigawa (1998) did not find any significant

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differences in electroencephalogram (EEG) frequencies between a control and post-gum condition. However, findings from a later experiment indicated that chewing flavourless and odourless gumbase leads to increased alpha and theta activity, inhaling spearmint scent increases alpha and beta activity and that chewing gumbase with sucrose leads to increased alpha activity but reduced beta activity (Masumoto, Morinushi, Kawasaki, Ogura, & Takigawa, 1999). The gumbase was made with polyvinyl acetate, natural resin, synthetic rubber, natural wax, softener and calcium carbonate. Masumoto et al. found no significant effects for chewing gum with spearmint oil (this may not generalise to marketed mint gum, which often contains sweeteners). They interpreted their findings as indicating that chewing gumbase or inhaling spearmint will lead to arousal, while chewing gumbase with sucrose will lead to relaxed concentration. The interpretation that chewing gum with sucrose leads to relaxed concentration is also consistent with findings that indicate that chewing gum increases self-reported alertness (e.g. Smith, 2010) and reduces chronic stress (Zibell & Madansky, 2009).

Morinushi, Masumoto, Kawasaki and Morikuni (2000) also found that chewing gumbase with sucrose led to increased alpha and decreased beta activity. They found that alpha and beta waves were increased by chewing flavoured gum, and obtained similar results when participants inhaled a scent based on the same substances as the flavour (with the ingredients being middle chain tri-glycerides, peppermint, lavender, chamomile and lemon verbena).

Using multichannel EEG, Yagyu et al. (1998) found that chewing flavoured gum (containing a number of flavours including lavender and peppermint) led to activation in different neural populations than chewing flavourless gum, which they interpreted as indicating a different functional state in the brain. Specifically, they suggested that the anteriorisation of the alpha band during chewing of flavoured gum could be associated with a state of drowsiness, which contrasts with the arousal account of chewing gum offered by Sakamoto et al. Similar to other contrasts in the EEG research, this sense of drowsiness may have been related to the specific flavour they used. Chewing gum has also been found to reduce global omega complexity of EEG (Yagyu et al., 1997). Although Yagyu et al. speculated this may reflect a relaxation effect, they admitted that the implications of global omega complexity are difficult to interpret.

Brain Imaging Findings

Evidence for a prefrontal effect of chewing gum was provided by Takada and Miyamoto (2004), who found co-activation of the prefrontal cortices using a conjunction analysis whereby the differences between chewing gum and chewing movements without gum were compared to the differences between chewing gum and rest. This analysis also indicated the co-activation of the parietal cortices.

Momose et al. (1997) found increased regional cerebral blood flow in the primary motor areas, supplementary motor areas, striatum and cerebellum during chewing gum using positron emission tomography (PET) images superimposed on magnetic resonance images (MRI). Similarly, functional magnetic resonance imaging (fMRI) research comparing brief periods of chewing flavourless gum to not chewing has also indicated increased activation in the supplementary motor area and cerebellum during chewing, and this study also indicated increased activity in the thalamus and sensorimotor cortex (Onozuka et al., 2002). The chewing and non-chewing trials in Onozuka et al.'s study were quite short (32 seconds each), and they suggested that this may explain why more areas associated with more voluntary action were activated and fewer areas associated with more automatic processing. The conscious nature of the chewing may have been increased by the fact that the chewing task was "rhythmic chewing, at a rate of approximately 1 Hz" (Onozuka, et al., 2002, p. 744), as opposed to asking participants to chew at their own pace.

Onozuka et al.'s (2002) observation of increased activation of the sensorimotor cortex was developed in a later study, where chewing gum was associated with an increased activity in the primary sensorimotor cortex for young adults (Onozuka et al., 2003), but with a smaller increase in this area's activation for middle-aged and older participants. A greater increase in activation was observed in the right prefrontal area for middle-aged and older participants, with this difference being more pronounced for the older group. Other research has indicated differences between young and aged participants during chewing for activity change in the supplementary motor area and insula (Sasaguri et al., 2004). This study also found that, while performing a picture encoding task, aged participants showed greater hippocampal activity when they chewed. Such a gum effect was not observed for younger participants, and the authors suggested that chewing gum may help to counteract hippocampal degeneration in the elderly. Unfortunately, given the lack of analysis of age in other cognitive studies, it is

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Table 1: Findings from ERP/EEG research on the effects of chewing gum

	Design	**Sample size**	**Effect of chewing gum**	**Chewing time**	**Flavour/type of gum**	**Complementary behavioural task**	**Gum before or during recording**
Masumoto et al. (1998)	Repeated measures	11	No EEG effect	3 minutes	Spearmint	None	Before (1 minute rest between gum and measure)
Masumoto et al. (1999)	Repeated measures	20	No EEG effect	3 minutes per flavour	Spearmint oil	None	Before (1 minute rest between gum and measure)
			Higher α and θ activity and lower β activity		Sucrose		
			Increased β and decreased θ activity		Flavourless		
Morinushi et al. (2000)	Repeated measures	9	Higher α and lower β activity	3 minutes per flavour	Sucrose	None	Before (1 minute rest between gum and measure)
			Higher α and β activity		Prepared flavour (see text)		
Sakamoto, Nakata and Kakigi (2009)	Crossover	11 (first experim ent) 9 (second)	Shorter peak latency of P300 and N100	15 minutes (Three 5-minute sessions)	Flavourless	Auditory oddball	Before
Sakamoto, Nakata, Honda et al. (2009)	Crossover	12	Increased amplitude for CNV but no effect on MRCPs	15 minutes (Three 5-minute sessions)	Flavourless	Warning-imperative stimulus RT	Before
Yagyu et al. (1997)	Repeated measures (Pseudo-randomis ed)	20	Reduced global omega complexity (GOC) and no effect on global dimensional complexity (GDC)	5 minutes per flavour	Flavourless	None	Before
			Reduced GOC and no effect on GDC		Theanine		
			Reduced GOC and no effect on GDC		Sugar + herbal essence oils and perfumes		
Yagyu et al. (1998)	Repeated measures (Pseudo - randomis ed)	20	Alpha-2: source model shifted posterior and global field power decrease	5 minutes per flavour	Flavourless	None	Before
			Alpha-2: source model shifted anterior and global field power decrease		Sugar + herbal essence oils and perfumes		

difficult to comment on how chewing gum and age interact for behavioural effects.

Some other imaging analysis of chewing gum has included the performance of cognitive tasks: fMRI data has shown increased activation in the right premotor cortex, precuneus (the right posterior region of the medial parietal cortex), inferior parietal lobe, thalamus and hippocampus during performance on *n*-back tasks after chewing flavourless gum (Hirano, et al., 2008). Wang et al. (2009) also observed increased neural activity in the hippocampus, as well as in the amygdala, during performance of an *n*-back task after chewing flavoured gum, but only when the initial threshold was reduced. There was no significant change in accuracy of performance or reaction time on the *n*-back task. As well as using concurrent behavioural tasks, Wang et al. and Hirano et al. used 3 Tesla scanners, which would allow for higher spatial resolution than earlier research, which relied on 1.5 Tesla scanners.

Summary and Discussion of Electrophysiological and Brain Imaging Findings

Electrophysiological research has indicated mixed evidence for an effect of chewing gum on EEG frequency. However, ERP research has allowed for the closer examination of an effect of gum on reaction time to an auditory stimulus. Brain imaging research has associated chewing gum with activation in the sensorimotor cortex, supplementary sensorimotor area, insula, precuneus, cerebellum and the thalamus in at least two studies.

Much of the heterogeneity of findings in this area can be attributed to different measures being used – in many cases (e.g. some ERPs) a replication of effects has yet to be attempted. Only five of the

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Table 2: Findings from neuroimaging research on the effects of chewing gum

	Design	Sample size	Areas affected by chewing gum	Chewing time	Flavour of gum	Gum before or during recording	Complementary behavioural task
Hirano et al. (2008)	Repeated measures	31	Right premotor cortex, precuneus, inferior parietal lobe, thalamus, hippocampus	5 minutes	Flavourless	Before	*n*-back (2- or 3-back)
Momose et al. (1997)	Repeated measures	12	Primary and supplementary sensorimotor areas (PMA & SMA), insulae, striatum and cerebellum	2 ½ minutes + time to begin scanning	Flavourless	60 seconds before tracer injection (for PET) + during	None
Onozuka et al. (2002)	Repeated measures	14	Sensorimotor cortex, SMA, insula, thalamus, and cerebellum (all bilaterally)	2 minutes 8 seconds (Four 32-second sessions)	Flavourless	During	None
Onozuka et al. (2003)	Repeated measures	10 young	Primary sensorimotor cortex (PSC), operculum, insula, cerebellum, right prefrontal area (RPA), SMA, thalamus, cerebellum)	4 minutes 16 seconds (Eight 32-second sessions)	Flavourless	During	None
		8 middle-aged	Less than young in PSC, thalamus, cerebellum. Higher in RPA				
		10 aged	Parietal, temporal, occipital association cortices				
Sasaguri et al. (2004)	Repeated measures	42 young	Sensorimotor cortex, supplementary motor area, insula, amygdala, thalamus, cerebellum	2 minutes 8 seconds (Four 32-second sessions)	Flavourless	Before and after	Picture recognition
		33 aged	Less than young in the sensorimotor cortex, supplementary motor area, and insula and higher in the cerebellum				
Takada and Miyamoto (2004)	Crossover (gum, sham chewing)	12	Middle frontal cortex bilaterally, left inferior cortex, inferior parietal lobule, right superior parietal lobule	14 minutes 56 seconds (Four 3 minutes 44 second sessions)	Flavourless	During	None
Wang et al. (2009)	Repeated measures	10	Precentral gyrus, inferior parietal lobule, superior parietal lobule, precuneus *When threshold reduced:* amygdala, hippocampus, insula	n/a	Peppermint	Before	*n*-back + mental arithmetic task

reviewed papers included complementary behavioural data (Sakamoto, Nakata, & Kakigi, 2009; Sakamoto, Nakata, Honda et al., 2009; Hirano et al., 2008; Sasaguri et al., 2004; Wang et al., 2009). Such data should be collected and reported more consistently, to determine if increased activity in brain areas leads to changes in performance. Where such data is absent, caution should be exercised in assuming that increased activity in a given brain area will improve performance associated with that area. Stephens and Tunney (2004a) have suggested that increased availability of blood-borne glucose to activated areas could improve functioning. It has also been noted that the highest effect of chewing on prefrontal areas has been observed in older adults (Weijenberg et al., 2011); as the majority of behavioural research on cognition has been on younger adults, a greater effect of chewing on cognitive function may be observed as people get older. However, it is unclear how chewing gum leading to increased activity in a given area will necessarily lead to greater ability to use this activity for tasks other than chewing. Ideally, behavioural and brain measures should be taken at differing times in order to establish if there is a chain of causality that leads from chewing to brain to behaviour.

EEG and fMRI data are typically screened for artefacts such as movement which can make them difficult to analyse (e.g. Yagyu, et al., 1998). The need to reduce or avoid motion artefacts has meant that research on chewing gum using neuroimaging or EEG measures has been more likely to measure performance after chewing gum rather than during chewing, when compared to research using purely behavioural measures. In addition, in purely behavioural research control groups have tended to

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involve performance of a cognitive task without chewing gum, whereas control groups in EEG/fMRI have often involved sitting quietly. These factors should be borne in mind when comparing studies that used brain imaging techniques to studies that did not.

POSSIBLE MECHANISMS FOR CHEWING GUM EFFECTS

Brain Activity

The P300 component of EEG has been associated with recognition and classification of stimuli (Hillyard, 1999), and its latency has been described as being associated with speed of encoding stimuli (Kutas, McCarthy, & Donchin, 1977). Sakamoto, Nakata and Kagigi's (2009) finding that the peak latency of the P300 component was reduced in the post-chewing gum condition is consistent with Smith's findings on chewing gum and encoding of stimuli (2010).

The finding that the hippocampus is activated by chewing gum (Hirano, et al., 2008; Wang, et al., 2009) might suggest that chewing gum could increase memory. Although the behavioural evidence that chewing gum improves memory has been unconvincing, the hippocampus has been found to be associated with spatial memory using both imaging methods (Piekema, Kessels, Mars, Petersson, & Fernández, 2006) and research with localised amnesia patients (Olson, Page, Moore, Chatterjee, & Verfaellie, 2006). The discrepancy between brain research and more behavioural research may thus be explained by the fact that behavioural data on chewing gum and memory has tended to assess verbal memory more frequently than spatial memory. Both Stephens and Tunney (2004a) and Wilkinson et al. (2002) found a positive effect of gum on spatial working memory.

It is possible that chewing gum may affect stress through neurotransmission effects. Research by Kamiya et al. (2009) indicated that heightened activity in the ventral prefrontal cortex leads to increased activity of serotonergic neurons in the dorsal raphe nucleus and reduced nocioceptive flexion reflex. Research with rats (Gómez et al., 1999) has found that a stressor (tail pinching) led to a smaller increase in dopaminergic metabolism when rats engaged in non-functional masticatory activity (NFMA), such as gnawing. Gómez et al. proposed that this indicated that NFMA attenuated stress-induced neurochemical changes in the brain. However, as the research by both Kamiya et al. and Gómez et al. investigated responses to pain, care should be taken in assuming the same effects will hold for psychological stress.

Exercise Effects

Reported fatigue has been found to fall significantly following an exercise class (Lichtman & Poser, 1983), and a significant change was not observed during a hobby class, suggesting that physical activity can maintain alertness. The hobby class reduced tension/anxiety, but a greater effect of the exercise class was observed. In a similar vein, early psychological research (Hollingworth, 1939) indicated a reduction in motor restlessness and muscular tension in participants who chewed gum. More consistent findings regarding exercise and stress may be found where response to stress is contrasted between groups who differ in habitual exercise levels, compared to research in which exercise is manipulated acutely (Salmon, 2001), which corresponds to the more consistent findings of an effect of gum chewing on chronic stress.

The finding that chewing paraffin wax and clenching one's teeth following a stressful task reduces salivary cortisol levels (Tahara et al., 2007), suggests that the process of biting or tensing one's jaw has an effect on stress. Although a recent cross-sectional study failed to find a significant effect of exercise on stress (Gerber, Kellmann, Hartmann, & Pühse, 2010), moderate exercise was more likely than strenuous exercise to be associated with reduced stress. Chewing gum is unlikely to induce strenuous exercise effects, but how vigorous does chewing have to be to have a moderate effect? Greater resistance to jaw movement may facilitate a greater discharge of excessive motor energy; research controlling for rate of chewing has found that harder chewing gum leads to increased blood pressure and heart rate compared to softer gum (Farella et al., 1999). Taken with the evidence from the exercise literature, this suggests that chewing gum may enhance alertness (while heart rate is high) with stress reduction occurring after chewing cessation. Scholey et al. (2009) have suggested that increased heart rate induced by chewing might actually reverse the dilation of blood vessels associated with the stress response and consequently reduce stress, although the functional significance of this dilation with regard to stress is currently unknown. This mechanism may take time to work, which could help to explain why research has more consistently suggested that chewing gum reduces chronic rather than acute stress.

Demand Characteristics

The issue of demand characteristics is highly salient for research in chewing gum, particularly when one considers that the more robust effects in this area (reported alertness and chronic stress) are quite subjective. In addition, participation in an intervention study is more of a time investment than participating in a brief experiment, which could explain the more positive findings for chronic stress than acute stress.

Unfortunately, a single- or double-blind methodology for chewing gum has yet to be designed. On the other hand, researchers can highlight the importance of chewing gum in their hypotheses to a greater or lesser extent to participants. Zibell and Madansky (2009) may have heightened demand characteristics by asking participants if they chewed gum to reduce stress during the screening process before their intervention. In contrast, a number of past studies have not explicitly mentioned chewing gum before debriefing. For example, in a study with child participants the children were told that the chewing gum was a thank-you for taking part (Tänzer, et al., 2009). For adults, a method of mimicking a single-blind method could be to describe the study as investigating “additives in a number of foodstuffs”, and telling participants they could be either in an experimental or a placebo group, similar to the method used by Silverman, Evans, Strain and Griffiths (1992) in their research on caffeine effects. In this way, participants will not know if they are in an experimental condition or not, and this will remove the incentive to perform better or report enhanced mood.

TIMING OF CHEWING AND TESTING AS A POSSIBLE MODERATING FACTOR

Post-test alertness has been more likely to be affected by chewing gum than alertness at the beginning of chewing, suggesting that alerting effects of chewing gum are not immediate. A meta-analysis has indicated that exercise impairs cognition for the first twenty minutes of its duration, but cognitive performance is enhanced following exercise (Lambourne & Tomporowski, 2010). Chewing gum, like more strenuous forms of exercise, may lead to an increase in arousal as it happens, followed by relaxation. The initial increase in arousal may lead to effects on cognitive performance after a certain amount of time chewing and being tested, or after the act of chewing has finished.

It is thus worth considering if tasks which are performed later in a cognitive performance battery (where tasks are presented in a fixed order) are more likely to be positively affected by chewing gum. This hypothesis is borne out to some extent in the findings of Smith (2010) and Wilkinson et al. (2002). In the latter paper, performance was better in the gum conditions for spatial and numeric working memory tasks, which were completed later in the battery, while performance was not better in the gum condition for vigilance and reaction time tasks, which were completed earlier. Immediate and delayed recall were both improved despite being early and late in the battery respectively, although this is not surprising given the similarity of these tasks. In Smith (2010), gum had a negative effect on immediate recall and no effect on simple reaction time; both were assessed early in order of testing. However, gum had a positive effect on later tests (focused attention reaction time and sustained attention hits). Similarly, Sakamoto, Nakata, Honda et al. (2009) observed a time-on-task effect for simple reaction time: it was only significantly quicker for those in the gum condition during a final post-chewing session.

Some studies have examined time-on-task effects directly. In Tänzer et al.’s (2009) study, children in the no-gum group performed better on the concentration task for the first twelve minutes but were then overtaken by those in the chewing gum group, which suggests that an enhancing effect of chewing gum may not be instantaneous. L. Tucha and Simpson (2011) tested the effect of chewing gum over consecutive blocks of a sustained attention task. They found that reaction time was initially slower in the gum condition, but it became faster than the no-gum condition during the later parts of the task. L. Tucha and Simpson speculated that a time-on-task moderating effect could be due to an initial distracting effect of chewing gum, followed by a positive effect due to underlying biological factors. However, in another study an interaction between time-on-task and gum condition was not observed for vigilance in either healthy children or children with ADHD, who should typically have greater difficulty with vigilance tasks (L. Tucha et al., 2010).

The possible role of time of chewing was further elaborated in three experiments by Onyper, Carr, Farrer and Floyd (2011). In the first two experiments a battery of cognitive tasks was administered following chewing gum; in the first experiment the tasks were performed in one order and in the second experiment the tasks were performed in the opposite order. For both orders of tasks, prior chewing gum improved performance of

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the tasks that were performed shortly after chewing, but not those that came towards the end of the battery. In a third experiment, participants in a gum condition chewed gum while performing the tasks; they did not show any improvement relative to no-gum controls. The findings indicate that chewing gum enhances performance for a limited time (15-20 minutes) after chewing, but does not have an enhancing effect during chewing. Onyper et al. suggested that the detrimental distracting effect of gum masked the enhancing arousal effect during simultaneous chewing and task performance, leading to a lack of an overall effect. For gum chewing prior to task performance, the arousal effect persisted for a time, but the distracting effect no longer applied. Although this result may be more fragile than the within-task trends observed by L. Tucha and Simpson (2011) and Tänzer et al. (2009), taking all these findings together suggests that the time-on-task moderation of chewing gum effects is quite robust.

The effect of demand characteristics may also vary over the course of a task. Faro (2010) observed that participants who were told that chewing gum caused increased alertness reported a quicker onset of an effect on reaction time compared to participants who were led to believe that improved performance could also come about through practice effects. Faro described this as an instance of causally linked events being perceived as occurring closer together in time, or temporal binding (c.f. Buehner & Humphreys, 2009). However, this temporal trend in demand characteristics would predict that the strongest positive effects of chewing gum would happen at the beginning of testing, rather than the initial detrimental effect and subsequent enhancement that has been observed.

FUTURE RESEARCH

Whether or not there are effects of chewing gum on cognition or acute stress could be established by replication of some earlier studies with higher levels of control. It will be worthwhile investigating if time-on-task effects are replicable for differing measures of cognitive performance. Time-on-task effects could be studied in greater depth, to see if such effects are due to length of time spent chewing or length of performance during which chewing occurs. Specifically, it would be of interest to examine the effect of chewing gum during multiple testing sessions, when gum is introduced towards the end of a long period of cognitive performance. The effects of chewing gum on attention and reaction time in an applied context (e.g. driving) could also be evaluated.

Research should identify mechanisms through which any effects work, whether these be neurochemical changes or general activity of the central and peripheral nervous system. Measurements of physiological variables such as heart rate and EEG should ideally be measured throughout stressors and cognitive tasks to help establish if they are mediating chewing gum and outcome variables. Assuming that differing levels of arousal have differing effects on performance depending on the complexity of tasks, an arousal mechanism will not be noticed if the complexity of tasks is not taken into account, given previous findings that higher arousal levels lead to enhanced performance, but only for simple tasks (Hokanson & Burgess, 1964), and that task complexity itself can affect arousal (Gellatly & Meyer, 1992).

Notwithstanding the flaws with the previous research studying rate of chewing discussed above (Tasaka, et al., 2008), future research could control for rate of chewing, or perhaps take some measure of rate of chewing as participants chew. However, if rate of chewing is controlled when chewing is concurrent to a cognitive task, it should be borne in mind that this will lead to greater dual-task interference, and the distracting effect of chewing may persist over time, rather than dissipating gradually, as seems to be the case with experiments that indicated time-on-task effects.

Another possible mechanism to investigate could be demand characteristics; research which manipulates expectancy regarding the effects of chewing gum could establish the degree to which expectations moderate any effects of chewing gum. Existing expectations with regards to the effects of chewing gum should also be taken into account in this context.

GENERAL DISCUSSION AND CONCLUSIONS

The most consistently observed psychological effect of chewing gum has been the enhancement of reported alertness. An ameliorating effect on chronic stress has been observed in both intervention and survey research, although the effect in Suh et al. (2008) was non-significant, and the findings concerning chewing gum and acute stress have been mixed. The research concerning the effects of gum on stress and alertness, as well as biomarkers for stress and alertness is summarised in Table 3 below.

Despite the enhancing effect on alertness, the research literature does not strongly suggest that chewing gum leads to improved attention or quicker

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Table 3: Chewing gum effects on cortisol, self-reported stress and anxiety, self-reported alertness and alertness biomarkers

	Dependent variable	**Design**	**Sample size**	**Significant Effect?**	**Effect size[1]**	**Chewing time**	**Flavour of gum**	**Gum chewing**	**Order of tasks**
Johnson et al. (2009)	Calmness	Crossover (gum, no gum, sham chewing)	15	No	n/a	11 minutes	n/a	During task	Mood tasks before and after PUI measurement
	Alertness			No	n/a				
	Pupillary unrest index (PUI)			Reduction	0.23 [2]				
Johnson et al. (2011)	Stress	Crossover	30	No	<0.001[2]	20 minutes	Mint	During task	Mood tasks before and after stressful task
	Anxiety			No	n/a				
	Alertness			No	0.17[3]				
Scholey et al. (2009)	Stress	Crossover	40	No	0.2 (LI) 0.39 (MI)	20 minutes[4]	Choice of available flavours	During stressful task	Mood tasks before and after stressful task
	Anxiety			No	0.28 (LI) 0.28 (MI)				
	Calmness			No	0.16 (LI) 0.09 (MI)				
	Cortisol			Reduction	0.81 (LI)[5] 0.17 (MI)				
	Alertness			Increase	0.4 (LI) 0.36 (MI)				
Smith (2009a)	Life stress	Cross-sectional survey	2248	Less stress	1.96[6] (extreme work stress) 1.65 (extreme stress)	n/a	n/a	Habitual chewers versus non-chewers	Survey study
Smith (2009b)	Anxiety (pre-test)	Independent measures	118	No	0.27	20 minutes	Mint	Before task	Random order of performance tasks
	Anxiety (post-test)			No	0.57				
	Alertness (pre-test)			Increase	0.69				
	Alertness (post-test)			No	0.21				
Smith (2009c)	Calm (pre-test)	Crossover (control v. gum at learning and/or test) Measured on two weeks	120	No No	<u>Week 1</u> 0.18 <u>Week 2</u> 0.02	35 minutes (if chewing during both learning and recall)	Choice of available flavours	During task	Mood, recall, logical reasoning, semantic processing, delayed recall, recog. memory, story recall, mood (*part 1*) mood, story recall, Alice Heim task, mood (*part 2*)
	Calm (post-test)			No No	<u>Week 1</u> 0.14 <u>Week 2</u> <0.01				
	Alertness (pre-test)			No No	<u>Week 1</u> 0.04 <u>Week 2</u> 0.16				
	Alertness (post-test)			Increase No	<u>Week 1</u> 0.47 <u>Week 2</u> 0.32				
Smith (2010)	Anxiety (pre-test)	Crossover	133	No	0.07	90 minutes	Spearmint or Juicy fruit	During task	Mood, immediate and delayed free recall, delayed recognition, logical reasoning, spatial memory, semantic processing, simple RT, focussed

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									attention, categoric search, repeated-digits vigilance
	Anxiety (post-test)			No	0.02				
	Cortisol			Increase	0.17				
	Alertness (pre-test)			Increase	0.24				
	Alertness (post-test)			Increase	0.35				
Suh et al. (2008)	Anxiety	Independent measures (intervention)	120	No	0.28 (comparing baseline and post-gum anxiety)	2-week intervention	n/a	Five times a day for thirty minutes	Anxiety tests, intervention, anxiety tests.
Tahara et al. (2007)	Cortisol	Crossover	12	Reduction	1.43[7] 0.8[8]	10 minutes	Flavourless wax	After stressor, during cortisol measures	Rest, stressor, reading while chewing/not chewing
Torney et al. (2009)	Self-reported stress	Independent Measures	40	No	<0.001[9]	10 minutes + time to complete mood tasks	Spearmint	During task	Mood tasks before and after stressful/non-stressful tasks
	Calmness			No	0.005				
	Alertness		40	No	0.01[10]				
O. Tucha et al. (2004) (*Experiment one*)	Heart rate	Crossover (flavoured gum, flavourless gum, sham chewing, no chewing)	58	No	0.16	40 minutes	Spearmint	During	Attention tasks randomised, start and end with recall tasks.
O. Tucha et al. (2004) (*Experiment two*)	Heart rate	Crossover (as above)	58	No	0.17	1 hour 20 minutes	Spearmint	During	Attention tasks randomised, start and end with recall tasks.
Wang et al. (2009)	Heart rate	Repeated measures	10	Increase	n/a	n/a	Peppermint	Before	One task
Wilkinson et al. (2002)	Heart rate	Independent Measures (gum, no gum, sham chewing)	75	Increase	n/a	3 minutes	Spearmint	Before	HR measured throughout cognitive tasks
Zibell and Madansky (2009)	Stress	Crossover (intervention)	280 frequent chewers	Reduction	0.32 (increase during no-gum) 0.21 (reduction during chewing)	3 days per condition	Choice of available flavours	Participants' habitual amount	General anxiety test, abstinence and chewing conditions followed by post-intervention anxiety assessment
	Stress		212 non-frequent	Reduction	0.24 (increase during no-gum) 0.2 (reduction during gum)	7 days per condition		Three times a day minimum	

[1]Effect sizes were calculated by dividing the difference of mean scores for gum and non chewing control by their mean standard deviations (except where otherwise indicated).
[2]Partial eta squared for main effect of gum.
[3]Partial eta squared for interaction between gum and experimental stage (pre- versus post-stressor).
[4]There were two 20-minute gum sessions, but these took place on different days.
[5]Based on change-from-baseline scores (LI = low intensity, MI = medium intensity).
[6]OR's from logistic regression
[7]Based on change scores between stress loading and first post-chewing session.
[8]Based on change scores between stress loading and second post-chewing session.
[9]Partial eta squared for main effect of gum.
[10]Partial eta squared for main effect of gum.

reaction time. Nonetheless, chewing gum may increase sustained attention during the later stages of tasks (Tänzer, et al., 2009; L. Tucha & Simpson, 2011), and prior gum chewing may enhance cognitive performance more generally for a limited time (Onyper, et al., 2011). This may work through chewing gum maintaining alertness during longer periods of attentiveness. Conflicting results have been found for the effects of chewing gum on immediate recall, delayed recall and context-dependent memory, but a positive effect on working memory has been shown.

Although imaging research has found a number of areas to be activated by chewing gum, most of this research has been exploratory in nature, and it is too early to posit an account of which brain areas should be activated by chewing gum. ERP data has helped to elucidate some possible brain mechanisms for cognitive effects of chewing gum, but EEG frequency research has shown inconsistent results. Nonetheless, given the differing findings from flavoured and flavourless gum in Masumoto et al. (1999), future research using these techniques may elucidate if different aspects of gum chewing have differential effects on cognition.

Smith (2010) suggested that there is a lack of research examining stress and cognition at the same time, which could allow for comparison of the magnitude of effects. When the two areas are contrasted, it is interesting that a proposed mechanism for reduced stress (the discharge of excessive motor energy) and a proposed mechanism for improved cognitive performance (increased arousal) seem to suggest that chewing gum is doing two opposing things at once. However, EEG (Masumoto, et al., 1999) and self-report (Smith, 2010) findings suggesting a state of relaxed arousal, or perhaps a change in effect over time (enhanced arousal being followed by a state of relaxation) may help to reconcile these seemingly contradictory ideas.

Stephens and Tunney (2004b) have pointed out that there may be cultural differences in level of familiarity with chewing gum that could lead to different results (this could lead to problems in trying to integrate EEG findings, which mostly come from Asia, with more behavioural studies, which mostly come from the West). Other possible explanations for differing findings in the literature include the use of different flavours of chewing gum, different measures of dependent variables and different timings of gum chewing and measurement. In the case of different measures of cognitive performance, task complexity could be a potential confound where different outcome measures are used.

In conclusion, the current research suggests that chewing gum affects current alertness; further investigation is required before conclusions can be drawn concerning the effect of gum on stress and cognition. Future research using consistent methods should help to establish which effects are robust and which mechanisms are plausible.

References

American Academy of Orofacial Pain (1993). *Temperomandibular disorders: Guidelines for classifaction, assessment and management (2nd Ed.).* Chicago: Quintessence.

Ahlberg, J., Rantala, M., Savolainen, A., Suvinen, T., Nissinen, M., Sarna, S., et al. (2002). Reported bruxism and stress experience. *Community dentistry and oral epidemiology, 30*, 405-408.

Allen, K. L., Galvis, D., & Katz, R. V. (2006). Evaluation of CDs and chewing gum in teaching dental anatomy. *New York State Dental Journal, 72*(4), 30-33.

Allen, K. L., Norman, R. G., & Katz, R. V. (2008). The effect of chewing gum on learning as measured by test performance. *Nutrition Bulletin, 33*(2), 102-107.

Baker, J. R., Bezance, J. B., Zellaby, E., & Aggleton, J. P. (2004). Chewing gum can produce context-dependent effects upon memory. *Appetite, 43*(2), 207-210.

Britt, D. M., Collins, F. L., & Cohen, L. M. (1999). Cigarette smoking and chewing-gum use among college students. *Journal of Applied Biobehavioral Research, 4*(2), 85-90.

Broadbent, D. E., Broadbent, M. H. P., & Jones, J. L. (1986). Performance correlates of self-reported cognitive failure and obsessionality. *British Journal of Clinical Psychology, 25*(4), 285-299.

Broadbent, D. E., Broadbent, M. H. P., & Jones, J. L. (1989). Time of day as an instrument for the analysis of attention. *European Journal of Cognitive Psychology, 1*, 285-299.

Buehner, M. J., & Humphreys, G. R. (2009). Causal binding of actions to their effects. *Psychological Science, 20*(10), 1221.

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences (2nd Edition)*. Hillsdale, NJ: Lawrence Erlbaum.

Cohen, L. M. (2003). Chewing and stress relief. In H. E. E. P. Staff (Ed.), *The benefits of chewing* (pp. 18-29). New York: Health Education Enterprises, Inc.

Faro, D. (2010). Changing the future by reshaping the past: The influence of causal belief on estimates of time to onset. *Journal of Consumer Research, 37*(2), 279-291.

Field, A. (2009). *Discovering statistics using SPSS (Third edition)*. London: Sage.

Gellatly, I. R., & Meyer, J. P. (1992). The Effects of Goal Difficulty on Physiological Arousal, Cognition, and Task Performance. *Journal of Applied Psychology, 77*(5), 694–704.

Gerber, M., Kellmann, M., Hartmann, T., & Pühse, U. (2010). Do exercise and fitness buffer against stress among Swiss police and emergency response service officers? *Psychology of Sport and Exercise, 11*(4), 286-294.

Gómez, F. M., Giralt, M. T., Sainz, B., Arrúe, A., Prieto, M., & García-Vallejo, P. (1999). A possible attenuation of stress-induced increases in striatal dopamine metabolism by the expression of non-functional masticatory activity in the rat. *European Journal of Oral Sciences, 107*(6), 461-467.

Hammond, K. R. (2000). *Judgments under stress.* New York: Oxford University Press.

Hillyard, S. A. (1999). Electrophysiology, electric and magnetic evoked fields. In R. A. Wilson & F. C. Keil (Eds.), *MIT encyclopedia of the cognitive sciences* (pp. 262-264). Cambridge, MA: MIT Press.

Hirano, Y., Obata, T., Kashikura, K., Nonaka, H., Tachibana, A., Ikehira, H., et al. (2008). Effects of chewing in working memory processing. *Neuroscience Letters, 436*(2), 189-192.

Hokanson, J. E., & Burgess, M. (1964). Effects of physiological arousal level, frustration, and task complexity on performance. *Journal of Abnormal and Social Psychology, 68*(6), 698-702.

Hollingworth, H. L. (1939). Chewing as a technique of relaxation. *Science, 90*, 385-387.

Johnson, A. J., Haddrell, B., Harrison, E., Osborne, L., Wilson, N., Miles, C., et al. (2009). *The effects of chewing gum on physiological and self-rated measures of alertness*. Paper presented at the British Psychological Society Psychobiology Section Annual Scientific Meeting, Lake District, UK.

Johnson, A. J., Jenks, R., Miles, C., Albert, M., & Cox, M. (2011). Chewing gum moderates multi-task induced shifts in stress, mood, and alertness. A re-examination. *Appetite, 56*(2), 408-411.

Johnson, A. J., & Miles, C. (2007). Evidence against memorial facilitation and context-dependent memory effects through the chewing of gum. *Appetite, 48*(3), 394-396.

Johnson, A. J., & Miles, C. (2008). Chewing gum and context dependent memory: The independent roles of chewing gum and mint flavour. *Appetite, 50*(2-3), 561-561.

Jones, F., & Bright, J. (2001). Stress: The concept. In F. Jones & J. Bright (Eds.), *Stress: Myth, theory and research* (pp. 3-15). Harlow, UK: Prentice Hall.

Kamiya, K., Fumoto, M., Kikuchi, H., Sekiyama, T., Umino, M., & Arita, H. (2009). Gum chewing evokes activation of ventral prefrontal cortex and suppresson of nocioceptive responses: involvement of brain serotonergic system. *European Journal of Pain, 13*(Supplement 1), S262-S263.

Kleber, E. W., Kleber, G., & Hans, O. (1999). *Differentieller Leistungstest-KG (DL-KG)*. Göttingen: Hogrefe.

Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: the P300 as a measure of stimulus evaluation time. *Science, 197*(4305), 792-795.

Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research, 1341*, 12-24.

Lichtman, S., & Poser, E. G. (1983). The effects of exercise on mood and cognitive functioning. *Journal of Psychosomatic Research, 27*(1), 43-52.

Masumoto, Y., Morinushi, T., Kawasaki, H., Ogura, T., & Takigawa, M. (1999). Effects of three principal constituents in chewing gum on electroencephalographic activity. *Psychiatry & Clinical Neurosciences, 53*(1), 17-23.

Masumoto, Y., Morinushi, T., Kawasaki, H., & Takigawa, M. (1998). Spectral analysis of changes in electroencephalographic activity after the chewing of gum. *Psychiatry and Clinical Neurosciences, 52*(6), 587-592.

Miles, C., Charig, R., & Eva, H. (2008). Chewing gum as context: Effects in long-term memory. *Journal of Behavioral and Neuroscience Research, 6*(Fall), 1-5.

Miles, C., & Johnson, A. J. (2008). Chewing gum and context-dependent memory. *Appetite, 50*(2-3), 563-563.

Miles, C., & Johnson, A. J. (2010). Switching between chewing-gum and no-gum at learning and retrieval does not accentuate error production in free recall. *Journal of Behavioral and Neuroscience Research, 8*(2), 9-19.

Momose T., Nishikawa, J., Wanatanabe, T., Sasaki, Y., Senda, M., Kubota, K., et al. (1997). Effect of mastication on regional cerebral blood flow in humans examined by positron emission tomography with ^{15}O-labelled water and magnetic resonance imagining. *Archives of Oral Biology, 42*(1), 57-61.

Morinushi, T., Masumoto, Y., Kawasaki, H., & Morikuni, M. (2000). Effect on electroencephalogram of chewing flavoured gum. *Psychiatry & Clinical Neurosciences, 54*(6), 645-651.

Olson, I. R., Page, K., Moore, K. S., Chatterjee, A., & Verfaellie, M. (2006). Working memory for conjunctions relies on the medial temporal lobe. *The Journal of Neuroscience, 26*(17), 4596-4601.

Onozuka, M., Fujita, M., Wantanabe, K., Hirano, Y., Niwa, M., Nishiyama, K., et al. (2002). Mapping brain region activity during chewing: A functional magnetic resonance imaging study. *Journal of Dental Research, 81*(11), 743-746.

Onozuka, M., Fujita, M., Watanabe, K., Hirano, Y., Niwa, M., Nishiyama, K., et al. (2003). Age-related changes in brain regional activity during chewing: A functional magnetic resonance imaging study. *Journal of Dental Research, 82*(8), 657-660.

Onyper, S. V., Carr, T. L., Farrer, J. S., & Floyd, B. R. (2011). Cognitive advantages of chewing gum: Now you see them, now you don't. *Appetite*. *57*(2), 321-328.

Overman, A. A., Sun, J., Golding, A. C., & Prevost, D. (2009). Chewing gum does not induce context-dependent memory when flavor is held constant. *Appetite, 53*(2), 253-255.

Piekema, C., Kessels, R. P. C., Mars, R. B., Petersson, K. M., & Fernández, G. (2006). The right hippocampus participates in short-term memory maintenance of object-location associations. *NeuroImage, 33*(1), 374-382.

Repetti, R., Wang, S., & Saxbe, D. (2009). Bringing it all back home: How outside stressors shape families' everyday lives. *Current directions in psychological science, 18*(2), 106-111.

Rowe, G., Hirsh, J. B., & Anderson, A. K. (2007). Positive affect increases the breadth of attentional selection. *Proceedings of the National Academy of Sciences, USA, 104*(1), 383-388.

Sakamoto, K., Nakata, H., Honda, Y., & Kakigi, R. (2009). The effect of mastication on human motor preparation processing: A study with CNV and MRCP. *Neuroscience Research, 64*(3), 259-266.

Sakamoto, K., Nakata, H., & Kakigi, R. (2009). The effect of mastication on human cognitive processing: a study using event-related potentials. *Clinical Neurophysiology, 120*(1), 41-50.

Salmon, P. (2001). Effects of physical exercise on anxiety, depression, and sensitivity to stress: A unifying theory. *Clinical Psychology Review, 21*(1), 33-61.

Sasaguri, K., Sato, S., Hirano, Y., Aoki, S., Ishikawa, T., Fujita, M., et al. (2004). Involvement of chewing in memory processes in humans: an approach using fMRI. *International Congress Series, 1270*, 111-116.

Scholey, A. (2003). Chewing and learning. In H. E. E. P. Staff (Ed.), *The benefits of chewing* (pp. 30-37). New York: Health Education Enterprises, Inc.

Scholey, A. (2004). Further issues regarding the possible modulation of cognitive function by the chewing of gum: response to Stephens and Tunney (2004) and Tucha et al. (2004). *Appetite, 43*(2), 221-223.

Scholey, A., Haskell, C., Robertson, B., Kennedy, D., Milne, A., & Wetherell, M. (2009). Chewing gum alleviates negative mood and reduces cortisol during acute laboratory psychological stress. *Physiology & Behavior, 97*(3-4), 304-312.

Silverman, K., Evans, S. M., Strain, E. C., & Griffiths, R. R. (1992). Withdrawal syndrome after the double-blind cessation of caffeine consumption. *New England Journal of Medicine, 327*, 1109-1114.

Sliwinski, M. J., Smyth, J. M., Hofer, S. M., & Stawski, R. S. (2006). Intraindividual Coupling of Daily Stress and Cognition. *Psychology and Aging, 21*(3), 545-557.

Smith, A. P. (2009a). Chewing gum, stress and health. *Stress and Health, 25*(5), 445-451.

Smith, A. P. (2009b). Effects of caffeine in chewing gum on mood and attention. *Human Psychopharmacology: Clinical and Experimental*, *24*(3), 239-247.

Smith, A. P. (2009c). Effects of chewing gum on mood, learning, memory and performance of an intelligence test. *Nutritional Neuroscience*, *12*(2), 81-88.

Smith, A. P. (2010). Effects of chewing gum on cognitive function, mood and physiology in stressed and non-stressed volunteers. *Nutritional Neuroscience, 13*(1), 7-16.

Spielberger, C. D. (1983). *Manual for the State-Trait Anxiety Inventory (STAI)*. Palo Alto, California: Consulting Psychologists Press.

Stephens, R., & Tunney, R. J. (2004a). Role of glucose in chewing gum-related facilitation of cognitive function. *Appetite, 43*(2), 211-213.

Stephens, R., & Tunney, R. J. (2004b). How does chewing gum affect cognitive function? Reply to Scholey (2004). *Appetite, 43*(2), 217-218.

Suh, H. J., Kim, S. Y., Chang, U. J., & Kim, J. M. (2008). Anti-stress effects of chewing gum prepared with yeast hydrolysate. *European Food Research and Technology 227*(2), 331–336.

Tahara, Y., Sakurai, K., & Ando, T. (2007). Influence of chewing and clenching on salivary cortisol levels as an indicator of stress. *Journal of Prosthodontics, 16*(2), 129-135.

Takada, T., & Miyamoto, T. (2004). A fronto-parietal network for the chewing of gum: A study on human subjects with functional magnetic resonance imaging. *Neuroscience Letters, 360*(3), 137-140.

Tänzer, U., von Fintel, A., & Eikermann, T. (2009). Chewing gum and concentration performance. *Psychological reports, 105*(2), 372-274.

Tasaka, A., Tahara, Y., Sugiyama, T., & Sakurai, K. (2008). Influence of chewing rate on salivary stress hormone levels. *The Journal of the Japanese Prosthodontic Society, 52,* 482-487.

Torney, L. K., Johnson, A. J., & Miles, C. (2009). Chewing gum and impasse-induced self-reported stress. *Appetite*, *53*(3), 414-417.

Tucha, L., & Simpson, W. (2011). The role of time on task performance in modifying the effects of gum chewing on attention. *Appetite*, *56*(2), 299-301.

Tucha, L., Simpson, W., Evans, L., Birrel, L., Sontag, T. A., Lange, K. W., et al. (2010). Detrimental effects of gum chewing on vigilance in children with attention deficit hyperactivity disorder. *Appetite, 55*(3), 679-684.

Tucha, O., Mecklinger, L., Maier, K., Hammerl, M., & Lange, K. W. (2004). Chewing gum differentially affects aspects of attention in healthy subjects. *Appetite*, *42*(3), 327-329.

Van Zomeren, A. H., & Brouwer, W. H. (1994). *Clinical neuropsychology of attention.* New York: Oxford University Press.

Vedhara, K., Hyde, J., Gilchrist, I. D., Tytherleigh, M., & Plummer, S. (2000). Acute stress, memory, attention and cortisol. *Psychoneuroendocrinology*, *25*(6), 535-549.

Wadlinger, H. A., & Isaccowitz, D. M. (2006). Positive mood broadens visual attention to positive stimuli. *Motivation and Emotion, 30*(1), 87-99.

Wang, X., Gitelman, D., & Parrish, T. (2009). Effects of chewing gum on working memory and stress. *NeuroImage, 47*(Supplement 1), S145-S145.

Weijenberg, R.A.F., Scherder, E.J.A., Lobbezoo, F. (2011). Mastication for the mind- The relationship between mastication and cognition in ageing and dementia. *Neuroscience and Biobehavioral Reviews*, *35*(3), 483-497.

Wilkinson, L., Scholey, A., & Wesnes, K. (2002). Chewing gum selectively improves aspects of memory in healthy volunteers. *Appetite, 38*(3), 235-236.

Yagyu, T., Kondakor, I., Kochi, K., Koenig, T., Lehman, D., Kinoshita, T., et al. (1998). Smell and taste of chewing gum affect frequency domain EEG source locations. *International Journal of Neuroscience*, *93*(3-4), 205-216.

Yagyu, T., Wackermann, J., Kinoshita, T., Hirota, T., Kocki, K., Kondakor, I., et al. (1997). Chewing-gum flavor affects measures of global complexity of multichannel EEG. *Pharmacoelectroencephalography, 35*(1), 46-50.

Zibell, S., & Madansky, E. (2009). Impact of chewing gum on stress levels: Online self-perception research study. *Current Medical Research and Opinion, 25*(6), 1491-1500.

Zimmerman, P., & Fimm, B. (1993). *A computerized neuropsychological assessment of attention deficits*. Herzogenrath, Germany: PsyTest.

Zimmerman, P., & Fimm, B. (2001). *A computerized neuropsychological assessment of attention deficits. Version 1.7*. Herzogenrath, Germany: PsyTest.