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Research report

Cognitive advantages of chewing gum. Now you see them, now you don't

Serge V. Onyper [*], Timothy L. Carr, John S. Farrar, Brittney R. Floyd

Department of Psychology, St. Lawrence University, Canton, NY 13617, USA

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ABSTRACT

The current series of experiments investigated the effects of the timing of gum chewing on cognitive function, by administering a battery of cognitive tasks to participants who chewed gum either prior to or throughout testing, and comparing their performance to that of controls who did not chew gum. Chewing gum was associated with performance advantages on multiple measures when gum was chewed for 5 min before, but not during, cognitive testing. The benefits, however, persisted only for the first 15–20 min of the testing session, and did not extend to all cognitive domains. To explain this pattern of results, it is proposed that the time-limited nature of performance benefits can be attributed to mastication-induced arousal. Furthermore, the lack of improvement in cognitive function when gum is chewed throughout testing may be because of interference effects due to a sharing of resources by cognitive and masticatory processes. This dual-process mechanism is not only consistent with the outcome of present experiments but can potentially account for a wide range of findings reported in the literature.

Introduction

The study of the cognitive benefits of chewing gum has received increased attention from researchers in the past few years. In one of the first studies on the subject, Wilkinson, Scholey, and Wesnes (2002) demonstrated that chewing a piece of sugar-free gum improved immediate and delayed recall as well as working memory, compared to sham chewing (i.e., mimicking chewing motions) or quiet control conditions. Similar results were reported by Stephens and Tunney (2004). Furthermore, the chewing of gum was associated with a small overall increase in performance on a battery of cognitive tests (Scholey et al., 2009). In other studies, chewing gum was found to benefit verbal working memory (Hirano et al., 2008; Zoladz & Raudenbush, 2005), free recall (Baker, Bezance, Zellaby, & Aggleton, 2004; Johnson & Miles, 2008), attention (Smith, 2010; Tucha, Mecklinger, Maier, Hammerl, & Lange, 2004; Tucha & Simpson, 2011), as well as performance on reaction time measures (Sakamoto, Nakata, & Kakigi, 2009; Smith, 2010).

Several mechanisms have been proposed to account for the facilitation in performance observed when gum is chewed during (as well as prior to) cognitive testing. For instance, Stephens and Tunney (2004) argued that the improved performance of those who chewed gum was due to an increased availability of glucose in the brain associated with increased metabolic activity. Others have relied on the optimum arousal theory (e.g., Sanders, 1986; Yerkes & Dodson, 1908) to suggest that the facilitative effects of gum chewing on cognitive performance were due to the accompanying increases in alertness and arousal. For instance, numerous studies have shown that gum chewing elevates heart rate and blood pressure (Farella, Bakke, Michelotti, Marotta, & Martina, 1999; Hasegawa et al., 2009; Smith, 2010; Wilkinson et al., 2002), cortisol levels (Smith, 2010) and cerebral blood flow (Hasegawa, Ono, Hori, & Nokubi, 2007; Onozuka et al., 2002; Sesay, Tanaka, Ueno, Lecaroz, & de Beaufort, 2000), as well as EEG and fMRI markers of cortical arousal (Hirano et al., 2008; Morinushi, Masumoto, Kawasaki, & Takigawa, 2000; Takada & Miyamoto, 2004; for a review, see Weijenberg, Scherder, & Lobbezoo, 2011). Improved cerebral blood flow during mastication in particular is thought to be associated with improved cognitive function (Weijenberg et al., 2011).

If chewing gum is indeed associated with increases in arousal and a corresponding shift in cognitive function, it is unclear why many studies find little or no performance advantages of chewing. For instance, Tucha et al. (2004) found that chewing gum was associated with improvements on only one measure (sustained attention) out of 25 or so administered as part of their experiment. Other studies likewise failed to find any effects of gum on memory (Smith, 2009a, 2010), attention (Kohler, Pavy, & Van den Heuvel, 2006; Smith, 2009b; see also Tucha et al., 2010), and learning of lecture material (Allen, Norman, & Katz, 2008). Gum chewing also did not affect performance on a mental rotation task (Nader, Gittler, Waldherr, & Pietschnig, 2010) or the ability to solve anagrams (Torney, Johnson, & Miles, 2009).

It is possible that methodological differences between studies (e.g., differences in study design and task demands, the timing of

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[*] Corresponding author.
E-mail address: sonyper@stlawu.edu (S.V. Onyper).

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measures and the duration of the testing session, as well as the type and brand of chewing gum) can explain some of the discrepancies in findings (e.g., Scholey, 2004a,b). It is also possible that chewing might usurp cognitive resources needed to maintain adequate performance on an attentionally demanding task, as recently suggested by Tucha et al. (2010). Tucha and colleagues found that chewing impaired performance on a task of sustained attention in children with ADHD (who are known to suffer from an inability to remain attentive for prolonged periods of time) and, to a lesser extent, healthy controls, concluding that chewing might act as a distractor task (see also Tänzer, von Fintel, & Eikermann, 2009 and Tucha & Simpson, 2011, for a similar argument).

Notably, studies that provide the strongest support for the claim that chewing gum facilitates cognitive function (and, in particular, episodic and working memory) required that participants began chewing 3 min (Wilkinson et al., 2002) or 15 min (Stephens & Tunney, 2004) *prior* to testing. Similarly, Sakamoto and colleagues (2009) demonstrated that those who chewed gum for 5 min before measurements took place performed faster on a measure of simple reaction time. The evidence provided by these studies offers an intriguing possibility—that the chewing of gum prior to testing "fortifies" one against the effects of interference that might arise when gum is chewed during testing, and in order to observe facilitative effects of gum on performance it must be chewed for a period of time before engaging in cognitively demanding activity. To the best of our knowledge, there is no research that explored this possibility directly; therefore, one of the claims examined in the current study is whether the benefits of gum are more likely to emerge when it is chewed prior to, rather than during, cognitive testing.

We are also interested in exploring the time course of cognitive facilitation due to the chewing of gum. Empirical evidence indicates that heart rate, blood pressure, and cerebral blood flow increase during gum chewing and remain elevated for 15–20 min afterwards (Farella et al., 1999; Hasegawa et al., 2007; Momose et al., 1997; Shinagawa et al., 2004). While these increases are statistically significant, they are moderate in magnitude (e.g., an increase in heart rate of 9–10 heart beats per minute), and low-to-moderate levels of arousal typically benefit memory and cognitive functioning (Revelle & Loftus, 1992). Therefore, if improved performance of participants who chew gum prior to testing is indeed attributable to changes in alertness and arousal, such improvements would coincide with a window of optimal arousal that might reasonably be expected to last from the time chewing has ceased until baseline levels of arousal are re-established, i.e., no more than 15–20 min. On the other hand, if gum is chewed throughout testing, it may result in no improvement in performance, possibly due to interference arising when the attentional demands of completing a cognitive task must be shared with the demands of masticatory processes, particularly early in the testing session (Tänzer et al., 2009; Tucha & Simpson, 2011; see also Tucha et al., 2010).

To summarize, the current experiments investigated whether the cognitive benefits of chewing gum would be greater when gum is chewed prior to testing, and weaken or disappear altogether when gum is chewed during testing. We also examined the time course of the effect of gum chewing on cognitive function, anticipating that the strongest effects would manifest immediately after the cessation of chewing. Participants completed a battery of five tasks representing broad domains of cognition that included tests of episodic and working memory, processing speed, and executive functioning. In Experiments 1a and 1b, participants performed the tasks in two different orders. In either experiment, one group of participants chewed gum *prior* to the battery, while another group did not chew gum at all. In Experiment 2, the order of tasks was counterbalanced across participants, approximately half of whom chewed gum *during* the entire testing session and half served as controls.

Experiments 1a and 1b

The aims of the following two experiments are to test the hypothesis that chewing gum prior to testing will enhance cognitive functioning, and to examine the claim that the performance benefits will be more pronounced earlier in testing—that is, immediately after the gum has been chewed and discarded. Participants in both experiments discarded gum after chewing and immediately before starting the test battery, making our measures of performance free from the potential of any interference/distractor effects due to masticatory processes discussed by Tucha and colleagues (2010), and Tucha & Simpson (2011).

Methods

Participants and design

Eighty St. Lawrence University undergraduates participated in Experiment 1a and 79 different students participated in Experiment 1b in exchange for course credit. The design of each experiment was between-groups: Approximately half of the participants were assigned to the chewing gum condition and half served as controls. Participants were tested in sessions that lasted approximately 35 min. Up to five people were tested in the same session. The study was approved by an ethics review board and all participants provided written informed consent prior to completing the study.

Materials and procedure

Each participant completed a battery of five tasks that measured performance in several cognitive domains. Two tasks provided a measure of episodic memory. In each, participants were shown a different list of 30 words displayed one at a time for 1.5 s with a .25-s break in between. The words were 6–7 letter nouns generated from the MRC Psycholinguistic Database (Coltheart, 1981) with concreteness, familiarity, and image ability ratings of 400–650. The stimuli were projected onto a large screen at the front of a laboratory equipped with personal computers. In the full attention task, the participants were instructed to try to remember the words for a later test. In the divided attention task, participants encoded words while also pressing random keys on the computer keypad. They were required to press a key to each beat of a metronome set at 52 beats per minute, and instructed to make digit sequences as random as possible (i.e., not to enter 1–1–1 or 1–2–3, etc.). A short practice session that familiarized participants with the key entry procedure preceded the encoding phase. After a delay of approximately 3 min during which a different task was performed (see below), the participants were given 2 min to recall the words by writing them down in any order in the booklet provided. The dependent measure was the number of words recalled correctly.

To measure working memory, we used a dot-matrix task involving a visuospatial storage component with a concurrent visuospatial processing load adapted from Miyake and colleagues (2001). A visuospatial working memory task was chosen to minimize interference from other, primarily verbal, tasks included in the battery. Participants viewed sets containing 2–4 matrix equations (see Fig. 1) and verified whether they were true or false. Equations were displayed for 4.5 s during which a response (true or false) was to be made using the 'z' and the forward slash keys of the keyboard. Each equation was succeeded by a 5 × 5 grid shown for 1.5 s with one randomly placed dot inside it, and the grid was followed by a 1-s mask (a black square equal in size to the grid).

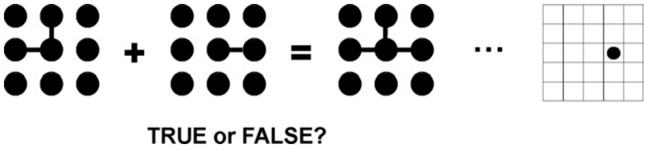

Fig. 1. A sample dot-matrix equation. Participants verified whether each equation was true or false (performing addition or subtraction operations), and then attempted to remember the location of a dot randomly placed inside a 5 × 5 grid. Dot placements were to be marked on an answer grid after viewing a series of 2, 3, or 4 equations/grids. In the figure, the correct response to the equation is *true*.

Participants were instructed to remember the location of the dot in the grid, and indicated the position of all dots in a given set on a blank answer grid after viewing each complete set of equations/grids (the placement of the dots was not duplicated within a given set). Fifteen such sets were completed by each participant: Five sets of 2 equations each were shown first, followed by five sets of 3 equations, and finally five sets of 4 equations. The score was the number of sets completed correctly (max. 15). Two practice sets were completed prior to the start of the main task.

Participants also completed the Symbol Digit Modalities Test (Smith, 1991), by matching digits 1 through 9 to symbols (simple geometric figures) using a reference key. Symbol digit measures perceptual speed of processing, motor speed, as well as visual scanning and tracking ability (Strauss, Sherman, & Spreen, 2006). Following some brief practice, participants were presented with the randomly ordered symbols and instructed to copy down the correct digit under each symbol according to the reference key as quickly and accurately as possible, without skipping any. The dependent measure was the number of digits copied correctly in 90 s.

The fifth task was an animal naming task, a measure of verbal fluency and executive functioning (Gladsjo et al., 1999) during which participants were given 90 s to write down the names of as many animals as possible.

On arrival at the laboratory participants in both experiments were assigned to either a chewing gum or a control condition. In Experiment 1a, half of the participants in the gum condition chewed Wrigley's brand spearmint flavored gum with sugar (approximately 2 g), and half chewed Wrigley's spearmint flavored sugar-free gum.[1] Experiment 1b used Wrigley's doublemint chewing gum. In neither experiment did control participants receive any gum.

At the start of testing those in the chewing gum condition were told that they would complete a battery of cognitive tests, and that one of the goals of the study was to determine whether chewing gum affected the ability to estimate passage of time (this was done as a cover story to minimize demand characteristics). The participants were given a stick of gum and instructed to bite it once every second while keeping track of the time elapsed, using a grid of 600 numbered cells projected onto the screen at the front of the testing room as a visual cue. Participants were timed to a metronome set at 60 beats per minute for the first 10 s of the time estimation task, and then continued in silence until asked to stop, at which point they wrote their estimate in a booklet and discarded the gum. The time interval was always set at 5 min. Those in the control condition were given the same instructions as participants in the chewing gum condition, except that they received no gum. Since estimates of the time interval were part of the cover story rather than of any theoretical interest to the study, they are not discussed further.

Following the 5-min time estimation interval, participants in both experiments completed the cognitive battery. The tasks in Experiment 1a were given as a single block in the following order (duration of each task, including time for instructions/practice, is given in parentheses): Episodic memory encoding of a word list under full attention conditions (2 min), followed by the symbol digit modalities test (3 min), followed by the recall of words (2 min). Next, the participants completed the working memory test (12 min), episodic memory encoding of a different list of words under conditions of divided attention (2 min), followed by the animal naming task (3 min), followed by recall of the second word list (2 min). Participants in Experiment 1b completed the same measures in reverse order (i.e., starting with the episodic memory task under divided attention condition). After completing the performance tasks, participants indicated the frequency with which they typically chewed gum on a scale from 1 (never) to 5 (most of the time).

Results and discussion

One participant in Experiment 1a did not complete the animal naming task as instructed, and a participant in Experiment 1b discontinued participation prior to completing the two final tasks. Thus, their data from those tasks were excluded from analyses.

The Hostelling's Trace multivariate test of the overall effect of chewing gum on performance was significant in both, Experiment 1a, $F(5, 73) = 8.04$, $p < .001$, Hostelling's trace = .55, $\eta^2 = .36$, and Experiment 1b, $F(5, 72) = 3.49$, $p = .007$, Hostelling's trace = .24, $\eta^2 = .20$. Therefore, *t*-tests were used to examine group differences on each performance measure. Table 1 displays mean scores for the chewing gum and control participants, *t* values, and corresponding measures of effect size. Effect sizes are reported as a standardized difference between means (Cohen's *d*). Cohen (1988) characterizes effect sizes of 0.2, 0.5, and 0.8 and above as small, medium, and large, respectively.

Participants who chewed gum prior to completing the battery performed significantly better ($p < .05$) than controls on measures of recall (for words encoded under full attention conditions), working memory, and perceptual speed of processing in Experiment 1a, and on measures of recall (for words encoded under divided attention) and working memory in Experiment 1b. Furthermore, there were no differences between the two groups in the frequency of habitual gum chewing, either in Experiment 1a ($M = 3.08$, $SE = .15$ for the group that chewed gum and $M = 2.83$, $SE = .14$ for controls, $t(798) = 1.21$, $p = .23$) or Experiment 1b (the chewing gum group: $M = 3.20$, $SE = .16$; controls: $M = 2.89$, $SE = .16$; $t(74) = 1.36$, $p = .18$), and entering the frequency of chewing as a covariate into an analysis of variance for group differences on each of the five measures did not alter the statistical conclusions displayed in the table.

An examination of the data shown in the table also reveals that the advantage of chewing gum was particularly evident in the earlier portion of the test battery in both experiments. This would suggest that the benefits of chewing gum on performance may be time-limited. To examine this possibility further, we plotted effect sizes representing standardized differences in mean scores of the chewing gum and control groups as a function of when in the session the task was administered (see Fig. 2). The results indicate that tasks that were closest in time to when gum was chewed manifested a stronger advantage for the gum group than those performed later in the testing session. Across both experiments, all but one task (the animal naming test in Experiment 1b) administered in the first 20 min of testing resulted in enhanced performance of the group that chewed gum prior to completing cognitive measures. Performance of the two groups did not differ significantly on any of the tasks completed at the end of the testing session.

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[1] The decision to include a group that chewed gum with sugar was motivated in part by Stephens and Tunney's (2004) observation that administering a large dose of glucose before chewing gum may augment cognitive effects due to the gum chewing alone. However, no differences between the sugar-free and sugar-added gum groups were found on any of the performance measures (perhaps because the amount of sugar contained in gum was very small), therefore their results were collapsed for all analyses.

Table 1
Means (and standard deviations) of cognitive variables for the group that chewed gum and controls.

Measure	Experiment 1a				Experiment 1b				Experiment 2			
	Gum	Control	*t*-value	Cohen's d	Gum	Control	*t*-value	Cohen's d	Gum	Control	*t*-value	Cohen's d
n	40	40			43	36			33	32		
Recall (full attention encoding)	8.18(3.19)	5.20(2.30)	4.78**	1.07	6.17(2.95)	6.44(1.87)	0.49	−0.11	5.70(2.34)	6.09(2.52)	0.66	−0.16
Symbol digit substitution	60.33(12.06)	54.62(9.24)	2.37*	0.53	57.71(13.24)	57.08(11.28)	0.22	0.05	56.85(9.98)	58.31(7.37)	0.67	−0.17
Working memory	7.10(3.33)	4.70(2.66)	3.56**	0.80	5.95(3.51)	3.94(3.28)	2.61*	0.59	5.06(3.11)	4.63(2.98)	0.58	0.14
Recall (divided attention encoding)	3.60(2.61)	2.98(1.79)	1.25	0.28	4.05(2.20)	3.14(1.72)	2.01*	0.45	3.41 (2.23)	3.45(2.03)	0.08	−0.02
Animal naming	25.15(6.38)	25.23(4.51)	0.07	−0.01	22.56(4.96)	24.25(6.07)	1.36	−0.36	23.73(6.12)	23.50(3.90)	0.18	0.04

Note: Positive values of Cohen's *d* indicate better performance for the group that chewed gum. The order of tasks in Experiment 1a corresponds to the order in which they are given in the table. In Experiment 1b, the order of task administration was reversed. The values for Experiment 2 are collapsed across the two orders of administration which were counterbalanced across participants (no order effects were present for any of the tasks).

* $p < .05$.

** $p < .01$.

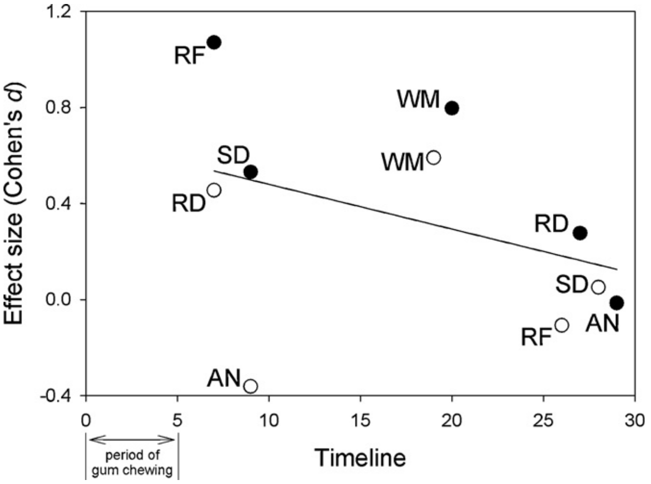

Fig. 2. Association between the time of task administration and the magnitude of the effect of chewing gum on cognitive performance (Cohen's *d*) for Experiments 1a (solid circles) and 1b (open circles). The horizontal axis provides a timeline of administration of cognitive tasks (given as a difference between task start and task completion times), from the time the session commenced (for recall tasks, the plot shows the encoding phase). The solid line represents the best-fit linear regression to effect size estimates from both experiments. *Note:* Participants in the gum group chewed gum during the first 5 min of the testing session. AN = animal naming; RF = recall of list encoded under full attention; RD = recall of list encoded under divided attention; SD = symbol digit substitution task; WM = working memory.

The effects of temporal factors can also be examined by considering differences in recall for words studied under full and divided attention conditions either early or late in the course of testing. There is little reason to expect that the size of group differences in recall on either one of those tasks will vary across the two orders of task administration unless the timing of the test has an impact on the magnitude of the chewing gum advantage. The number of words recalled was examined in a three-way ANOVA with Condition (chewing gum or control), Time of testing (early or late in the session), and Attentional load at encoding (full or divided) as factors. In Experiment 1a, the full-attention memory retrieval took place early in the testing session, and the divided-attention retrieval took place late in testing. In Experiment 1b, the reverse was true. As expected, there were main effects of experimental condition (the group that chewed gum recalled more words, $M = 5.49$, than controls, $M = 4.44$), $F(1,154) = 13.19$, $p < .001$, $\eta^2 = .08$, and attentional load (words studied under full attention were more likely to be remembered, $M = 6.50$ for the full attention and $M = 3.43$ for divided attention encoding conditions), $F(1,154) = 148.50$, $p < .001$, $\eta^2 = .49$, and a time of testing by condition interaction, $F(1,154) = 6.68$, $p = .01$, $\eta^2 = .04$. More importantly, there was also a three-way interaction between condition, attentional load, and time of testing, $F(1,154) = 12.21$, $p = .001$, $\eta^2 = .07$. As shown in Fig. 3, this interaction indicates that the magnitude of the effect of chewing gum on recall varied with the timing of the test and also depended on the resource availability at encoding—while early testing led to a greater advantage of the chewing gum group under conditions of divided attention ($d = 0.45$), this advantage was more than twice as large when full attention was given to the encoding task ($d = 1.07$). These results also suggest that the benefits of gum chewing may be less pronounced with increased task load.

Experiment 2

As indicated earlier, a number of research studies have failed to reveal a cognitive advantage to gum chewing. The vast majority of

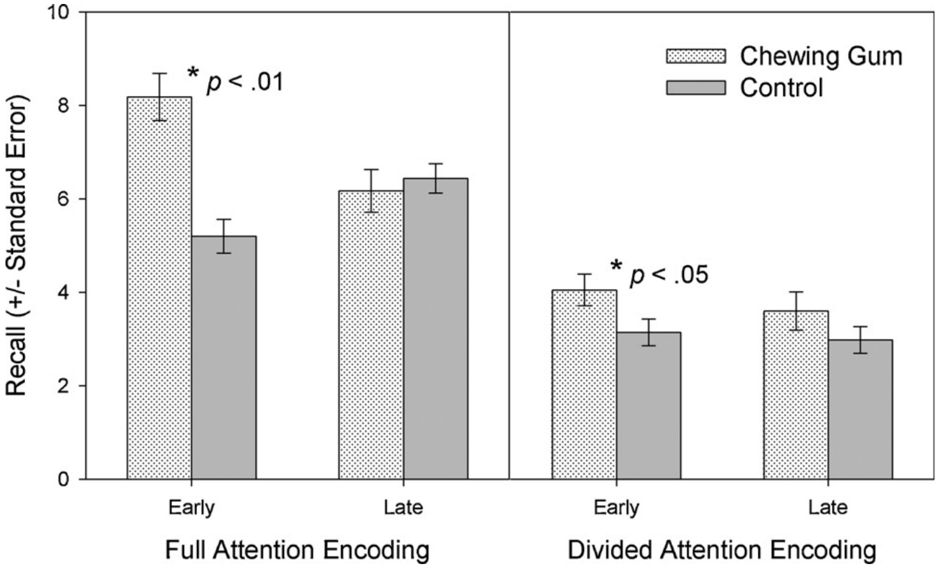

Fig. 3. The effects of full and divided attention at encoding on free recall performance early and late in the testing session. The magnitude of the effect of chewing gum on recall varied with the timing of the test but also depended on resource availability at encoding. Completing the task early in the session produced a chewing gum advantage for lists encoded under full and divided attention conditions. The effect was stronger, however, in the full attention condition. Performance of the chewing gum and control groups did not differ when the task was administered late in the testing session regardless of resource availability at encoding.

these studies used a procedure in which gum was chewed throughout testing with the rate of chewing under participant control. The reasons for a lack of an effect are not clear, but may include dual-task interference resulting from concurrent mastication (e.g., Tucha et al., 2010; Tucha & Simpson, 2011). The current experiment adopts a procedure similar to those studies, with the expectation that few (if any) of the cognitive advantages of gum chewing seen in the preceding two experiments will be manifested here. As an additional goal, we examine whether the testing order effects seen in Experiments 1a and 1b and observed for measures of attention by Tänzer and colleagues (2009) and Tucha and Simpson (2011) occur for tasks included in the current experiment.

Methods

The participants were 65 St. Lawrence University undergraduates who did not participate in the previous two experiments. They were tested in sessions lasting approximately 30 min in groups of up to five in the same session. Upon arriving at the laboratory and signing informed consent, the participants completed the same cognitive battery as in Experiments 1a and 1b (minus the time estimation task). Approximately half of the participants ($N = 33$) were assigned to the condition in which Wrigley's doublemint gum was chewed throughout the entire testing session, and the rest were controls that did not receive chewing gum during the experiment. To make this experiment comparable to previous studies, the group that chewed gum did so naturally—that is, without a metronome-imposed rhythm. The order of tasks was counterbalanced within each condition; the duration of each task was the same as in the earlier experiments.

Results and discussion

Table 1 presents descriptive statistics, t-values, and effect sizes for the five cognitive tasks. The multivariate test of the overall effect of gum chewing on cognitive performance was not significant, $F < 1$. In addition, none of the t-tests between the chewing gum and the control groups were statistically significant. Furthermore, analyses of variance with condition and order of testing as factors revealed no main effects or interactions for any of the individual measures, indicating that there are no order effects on task performance. In other words, our results are consistent with previous research that fails to find cognitive benefits of chewing when gum is chewed concurrently with testing.

General discussion

The current series of experiments evaluated two hypotheses regarding the relationship between chewing gum and cognitive function. First, we hypothesized that participants that chewed gum for 5 min prior to engaging in cognitive testing would outperform those that did not chew gum. This prediction was guided by an examination of literature that revealed that chewing gum was more likely to benefit cognitive function when chewing commenced for at least several minutes prior to engaging in mental activity, but that little or no improvement would be seen if gum were chewed solely during cognitive tests. Second, we predicted that if cognitive advantages of chewing gum were obtained, they would be most evident soon after chewing. This hypothesis was based on the assumption that heightened arousal associated with masticatory processes may be responsible for enhanced cognitive performance, and that this arousal would gradually diminish after cessation of chewing.

The results provide strong evidence that chewing gum is associated with an overall increase in cognitive functioning, particularly working memory, episodic memory, and perceptual speed of processing, but only when chewing takes place prior to cognitive testing. The benefits, furthermore, appear to be of limited duration. In both Experiments 1a and 1b, five of the six tasks initiated in the first half of the 30-min battery resulted in statistically significant increases in performance of participants who chewed gum (see Fig. 2). Performance on tasks that were completed toward the end of the testing session, however, did not differ between the gum and the control groups in either experiment. Notably, the advantages associated with the chewing of gum disappeared altogether when it was chewed throughout the entire 30-min period of testing in Experiment 2. This outcome contrasts with the findings of Tänzer et al. (2009) and Tucha and

Simpson (2011) who found that performance increases on a task of sustained attention associated with chewing gum emerge later in testing, although none of our tasks were measures of attention.

The precise mechanisms associated with increases in performance due to gum chewing are not well understood. Stephens and Tunney (2004), for instance, suggested that enhanced delivery of glucose to the brain as a result of insulin secretion during mastication was responsible for the improved performance of participants who chewed gum. They found that participants who started to chew prior to testing performed as well as those that did not chew gum but ingested a glucose-enriched drink on several tests of episodic and working memory, and a measure of attention and processing speed. It is also possible, however, that the outcome observed by Stephens and Tunney can be explained by a more generalized increase in metabolic demands as a result of mastication, leading to elevated arousal. Arousal theory (Sanders, 1986; Yerkes & Dodson, 1908) holds that moderate arousal would typically be optimal for performing a variety of cognitive tasks, although task complexity mediates this effect (e.g., Revelle & Loftus, 1992). Mastication leads to low-to-moderate increases in arousal and alertness as shown by physiological and behavioral measures (Weijenberg et al., 2011), and there is evidence that elevated levels of arousal persist for a period of time after the cessation of chewing. For instance, Shinagawa et al. (2004) observed that the chewing of gum for 5 min led to a 25% increase in blood flow in several cortical regions that peaked 10 min after gum was discarded and returned to baseline levels after 20 min. Others observed that heart rate (Farella et al., 1999; Hasegawa et al., 2007) and blood oxygenation levels (Kamiya et al., 2010; Momose et al., 1997) would peak during chewing but also remain elevated afterwards. Thus, if arousal reaches levels conducive to enhanced cognitive function while gum is chewed and remains within the "optimal window" for 15–20 min following chewing, then improved performance on tasks susceptible to arousal-related benefits should emerge. Even though no arousal measures were collected in the current study, the results of the first two experiments are consistent with this possibility.

Conversely, if levels of arousal fall outside of the optimal window, no performance increments would be expected, which may explain the null effect observed for participants that chewed gum during cognitive testing in the final experiment. We would argue, however, that such an explanation is not sufficient by itself to account for Experiment 2 results. One reason is that several recent studies demonstrated that chewing gum can interfere with performance of attentionally demanding tasks (Tänzer et al., 2009; Tucha et al., 2010; Tucha & Simpson, 2011; see also Miles & Johnson, 2007). In addition, the naturalistic pattern of chewing in studies that find positive effects of gum on cognitive performance does not appear very different from the studies that find no such effects, although more reliable benefits seem to emerge mainly when participants start chewing gum prior to testing (e.g., Stephens & Tunney, 2004; Wilkinson et al., 2002).

It is also possible that in situations where gum chewing occurs during cognitive testing potential performance benefits due to chewing-induced arousal are masked by the distracting nature of the chewing task. One source of insight into this possibility comes from studies of exercise and cognitive function. For instance, exercise is known to heighten sympathetic nervous activity, increasing physical arousal. Nonetheless, a recent meta-analysis concluded that cognitive performance is typically reduced during short (i.e., 20 min or less) periods of exercise but improves immediately thereafter (Lambourne & Tomporowski, 2010). Cognitive function, which relies on a limited pool of metabolic resources, is thought to be compromised when those resources are directed toward meeting the more immediate demands of exercise. Once exercise is concluded, however, gradual metabolic recovery coupled with declining – yet still elevated compared to baseline – levels of arousal results in facilitation of cognitive performance. Interestingly, forms of exercise that are less physically and attentionally demanding (such as pedaling a stationary bike versus running on a treadmill) result in little cognitive impairment during physical activity as well as greater cognitive enhancement afterwards (Lambourne & Tomporowski, 2010). If we consider that chewing gum leads to cardiovascular and neurophysiological changes similar to those that occur during mild to moderate exercise (Hasegawa et al., 2009; Weijenberg et al., 2011), then the results of our experiments would be directly comparable to those reported by Lambourne and Tomporowski (2010).

The possibility of shared resources is supported by the findings that mastication activates many of the same areas of the brain as mental activity (Weijenberg et al., 2011). It is also consistent with our own observation of a reduced chewing gum advantage in recall when information is encoded under increased task load conditions (Fig. 3), although we must note that this reduction may also be due to a possible floor effect in the recall scores of words in the divided attention condition. Thus, we propose that the arousal-mediated explanation of the chewing gum advantage is incomplete without also considering the potential detrimental effects of the processes involved in the chewing of gum on maintaining optimal cognitive functionality. This *dual-mechanism theory* has the potential to unite the discrepant findings observed among studies that use different experimental procedure and stimulus materials, although it may not readily account for all of existing findings, such as the late emergence of the attentional benefits observed in the Tänzer et al. (2009) and Tucha and Simpson (2011) studies.

One notable limitation of the current study is the absence of measures of physiological arousal, which makes our conclusions regarding the role of arousal in modulating the cognitive advantages of gum chewing speculative. Direct measures of arousal coupled with careful controls will be necessary to establish whether performance increases for participants who chew gum are due to arousal or some other factor, especially because most of the studies to date have provided evidence that is correlational in nature. For instance, while chewing could result in increased cerebral blood flow thus enhancing performance, elevated blood flow may also be the outcome of greater resource demand necessitated by the need to control chewing and perform cognitive operations concurrently. Degree of interference or dual-tasking is another factor that must be operationalized and controlled in subsequent studies. Future research incorporating controls that attain levels of arousal comparable to those induced by the chewing of gum (yet achieved via other means, such as exercise or a cold pressor test) would provide a more direct validation of the arousal mediation hypothesis and yield a clearer picture of the mechanisms responsible for performance benefits associated with the chewing of gum.

One of the differences between the current study and previous research concerns the rate of gum chewing. Participants in Experiments 1a and 1b were instructed to chew rhythmically, in time to a metronome, whereas past studies have typically allowed participants to set their own pace of chewing, which was also the case in Experiment 2. While it is possible that at least some of the observed differences in outcomes of the first two experiments and the final experiment may have been due to a discrepancy in chewing instructions, it should be emphasized that in Experiments 1a and 1b participants assigned to the gum condition did not chew gum during cognitive testing (but rather prior to testing, which should eliminate any confounding influences of the act of chewing itself on cognitive measures), while those in Experiment 2 did. It is also unlikely that the rate of chewing is more important than the act of chewing itself, since in previous studies that observed a cognitive advantage of gum that was chewed prior to testing the rate of chewing was uncontrolled (e.g., Sakamoto et al., 2009; Stephens & Tunney, 2004; Wilkinson et al., 2002). Nonetheless, a direct examination of the effects of the manner in which gum is chewed (rhythmically or naturally) is necessary to fully resolve this question.

It is also possible that the cognitive effects of gum chewing observed in our study are confounded with flavor—for instance, there is evidence that some flavors lead to an amplification of cognitive effects, even in the absence of chewing (Zoladz & Raudenbush, 2005; see also Johnson & Miles, 2008). On the other hand, studies (e.g., Sakamoto et al., 2009) also reveal performance improvements after participants chew flavorless gumbase, suggesting that the presence of gum itself is sufficient to induce changes in cognitive functioning.

Finally, even though the performance benefits seen in our results apply to several types of cognitive processing – in particular, working memory, episodic memory, and processing speed – we stop short of making a claim that the benefits of gum chewing are domain-general. For instance, those who chewed gum prior to the test battery did not show a performance advantage on the animal naming task, a measure of verbal fluency typically associated with executive functions. Others (e.g., Stephens & Tunney, 2004) also failed to demonstrate the effects of chewing on verbal fluency. Measures of fluency are often thought to reflect prefrontal functioning, specifically in the dorsolateral region (Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998). While we know relatively little about the causes of performance variation among different cognitive measures due to gum chewing, there is evidence that the effects of chewing on the brain are selective, rather than general, and that they do not typically lead to differential activation of dorsolateral prefrontal cortex (Kamiya et al., 2010; Momose et al., 1997; Onozuka et al., 2002; but see Takada & Miyamoto, 2004).

In summary, the current study demonstrates that the discrepancies in research findings of the burgeoning literature on the effect of gum chewing on cognitive function can be attributed to the timing of chewing. Clear performance advantages emerge when gum is chewed prior to (but not during) cognitive testing, although the benefits persist only for the first 15–20 min of the testing session. Our findings also suggest that the benefits of gum chewing extend only to some cognitive domains. A dual-process mechanism is proposed to account for the presence of the chewing gum advantage when gum is chewed prior to engagement in demanding cognitive processing, and its elimination when gum is chewed during mental activity. Mastication-induced arousal is postulated as the potential mechanism to explain the time-limited nature of performance enhancement, and interference due to a sharing of metabolic resources by cognitive and masticatory processes is thought to explain why performance may not increase or even decline. Additional tests of the dual-process theory of the chewing gum advantage are necessary to delineate both its generality and limitations, and further studies are needed to provide a more complete picture of the relationship between physiological changes and cognitive functioning due to the chewing of gum.

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