The Contrasting Physiological and Subjective Effects of Chewing Gum on Social Stress

Gemma Gray,[1] Christopher Miles,[2] Nigel Wilson,[1] Rebecca Jenks,[1] Martin Cox,[3] and Andrew J. Johnson[1]*

[1]Department of Psychology
Coventry University
Coventry
UK

[2]School of Psychology
Cardiff University
Cardiff
UK

[3]Department of Sports and Bio-molecular Science
Coventry University
Coventry, UK

*Corresponding author

Address for Correspondence:

Department of Psychology

Coventry University

Priory Street

Coventry

CV1 5FB

Tel: +0044 (0)24 7688 8654

Email*: Andrew.Johnson@Coventry.ac.uk

*(*Permission granted to publish email address*)

Acknowledgments

The authors would like to thank Dr. Lara Tucha for her comments on an earlier draft and the later comments from both Prof. Debra Zellner and an anonymous reviewer.

Abstract

Uncertainty exists with respect to the extent to which chewing gum may attenuate stress-induced rises in cortisol secretion (Scholey et al., 2009; Smith, 2010; Johnson et al., 2011). The present study used the Trier Social Stress Task (TSST: Kirschbaum et al., 1993), a task known to elevate cortisol secretion (Kudielka et al., 2004), in order to examine the moderating physiological and subjective effects of chewing gum on social stress. Forty participants completed the TSST either with or without chewing gum. As expected, completion of the TSST elevated both cortisol and subjective stress levels, whilst impairing mood. Although gum moderated the perception of stress, cortisol concentrations were higher following the chewing of gum. The findings are consistent with Smith (2010) who argued that elevations in cortisol following the chewing of gum reflect heightened arousal. The findings suggest that chewing gum only benefits subjective measures of stress. The mechanism remains unclear; however, this may reflect increased cerebral blood flow, cognitive distraction, and/or effects secondary to task facilitation.

Keywords: Chewing gum; social stress; cortisol; subjective stress

Introduction

In a recent study, Sketchley-Kaye, Jenks, Miles & Johnson (2011) examined the moderating effect of chewing gum on both anxiety and mood following exposure to the Trier Social Stress Task (TSST: Kirschbaum, Pirke & Hellhammer, 1993). The task, involving an oral presentation and mental arithmetic test, induced a decrease in both self-rated calmness and contentedness and increases in state-anxiety. Chewing gum acted to moderate this increase in state-anxiety whilst elevating self-rated alertness. This pattern of findings complements an earlier study (Scholey, Haskell, Robertson, Kennedy, Milne & Wetherell, 2009) in which chewing gum moderated the rise in both self-rated stress (see also Smith, 2009a, 2010) and state anxiety, and significantly decreased cortisol concentrations following a cognitive-load stressor.

The reduction in stress levels, both physiologically and subjectively, following the chewing of gum can be interpreted via the mastication-induced changes in cerebral blood flow (e.g. Fang, Li, Lu, Gong & Yew, 2005). Indeed, heightened delivery of both oxygen and glucose to fronto-temporal regions (Onozuka, Fujita, Watanabe, et al., 2002) can act to increase metabolic rate, a post-stress process (in areas BA9 and BA10) associated with a reduction in salivary cortisol concentrations (Kern, Oakes, Stone, McAuliff, Kirschbaum, and Davidson, 2008).

Notwithstanding the above proposed mechanism, in a similar design, Johnson, Jenks, Miles, Albert & Cox (2011) failed to replicate Scholey et al. (2009) in that chewing gum did not attenuate the rise in cortisol. Furthermore, Smith (2010) reported that chewing gum elevated cortisol concentrations under conditions of acute (noise-induced) stress: a finding taken to reflect the heightened alertness/arousal following the chewing of gum (see also Onyper, Carr, Fararr, & Floyd, 2011; and Scholey et al., 2009; Smith, 2009b; Johnson et al., 2011, for alertness effects). These studies suggest a degree of unreliability in respect to the effects of gum on cortisol. One possibility for such unreliability is the diurnal variation in cortisol excretion. For instance, Johnson et al. tested participants in the morning when cortisol levels are typically high (Hucklebridge, Hussain, Evans, Clow, 2005) and such elevation may have masked the effects of chewing and/or the stressful task. Indeed, in Scholey et al. (2009), cortisol levels fell following the stressor when participants were tested in the morning (corroborating the Johnson et al. data). However, since Scholey et al. did not include time of day in their analysis of gum effects, it is unclear the extent to which the reductive effects of chewing gum on cortisol were confined to the afternoon. Similarly, in Smith (2010), despite testing taking place at intervals across the day, time of day was not included as a variable in his analysis. It is, therefore, unclear whether time of day differentially influenced the cortisol excretion. Additionally, Smith (2010) does not report whether there was a main effect of the noise stressor on cortisol excretion. That is, we do not know if the noise was 'physiologically' stressful. If not, then the scenario is quite different to that of Scholey et al., in which the rise in cognitive-load induced cortisol excretion was mediated via the chewing of gum.

The present study examines the extent to which increases in cortisol excretion are moderated by chewing gum with a task known to produce established and reliable effects on cortisol excretion (TSST: Kirschbaum et al., 1993; see also Kudielka, Schommer, Hellhammer, and Kirschbaum, 2004). The presentation and mental arithmetic components of the TSST, in particular, have been shown to increase both cortisol excretion (Kudielka et al., 2004) and state-anxiety (Sketchley-Kaye et al., 2011), and decrease subjective mood state (Kudielka et al., 2004; Sketchley-Kaye et al.). As aforementioned, Sketchley-Kaye et al. (2011) found that chewing gum attenuated the rise in self-rated anxiety following the TSST. In the present study we examine the extent to which this mediating effect of gum following the TSST can be extended to cortisol and self-rated stress.

The TSST comprises a social evaluative stress task where participants deliver a presentation and perform a mental arithmetic task in front of a panel. There are four stages to the task: baseline measures, preparation for the presentation, presentation/mental arithmetic stressor, and post-task recovery. To the extent that chewing gum affects cortisol excretion under conditions of acute physiological stress (Scholey et al., 2009), we predict an interaction between the experimental stage and chewing gum condition. That is, we expect differences between the gum and no gum groups at specific points in the stressor protocol. One might expect increases in stress immediately prior to the TSST (anticipatory stress) and immediately following the TSST. If chewing gum attenuates the rise in cortisol production under conditions of acute stress (Scholey et al., 2009), lower cortisol levels should be reported in the gum group at these stages. Furthermore, since a temporal delay exists in respect to stress exposure and salivary cortisol peak (Kudielka et al., 2004), one might predict differences between the gum and no gum groups following the recovery phase due to a delay in cortisol returning to normal levels. Additionally, if chewing gum moderates the stress induced changes in self-rated stress and mood (e.g. Scholey et al., 2009; Sketchley-Kaye et al., 2011), we predict an interaction between chewing gum and experimental stage such that increases in stress and decreases in mood are both attenuated in the chewing gum condition.

Method

Participants: Forty (20 males, 20 females, mean age = 20 years and 3 months) non-smoking Coventry University Psychology undergraduates participated in exchange for course credit. All participants reported that they were free from both concurrent medication (including the contraceptive pill) and illicit drug use. Participants were instructed to refrain from caffeine, alcohol, and chewing gum on the day of testing and asked to not consume food for up to one hour prior to testing. Participants were assigned at random to either the chewing gum or no chewing gum condition (n=20 per group: chewing gum group comprised 12 males and 8 females, mean age = 20.55 years, SEM = 0.48; no gum group comprised 8 males and 12 females, mean age = 20.00 years, SEM = 0.27). Ethical approval was obtained from the Coventry University Ethics Committee.

Materials: Participants completed both the Bond-Lader Visual Analogue Mood Scale (VAMS: Bond and Lader, 1974), a single-item stress scale (modelled on the scale described by Scholey et al., 2009) and the State-Trait Anxiety Inventory (STAI: Speilberger, Gorsuch, and Lushene, 1969). The Bond-Lader VAMS comprises 16 mood questions, with mood antonyms anchoring either end of a 100mm line. It provides scores for alertness, contentedness, and calmness. Participants are instructed to rate, via a mark on each antonym-paired line, how they are feeling at that moment. On a separate sheet the same single-item scale was used to measure self-rated stress and comprised the single antonym: no stress at all/worst stress imaginable. This single scale was modelled on Scholey et al. (2009) but employed a different antonym. The STAI comprises 40 statements each assessing either state or trait-anxiety. For each statement participants respond on a four-point likert scale indicating the extent to which they agree with each statement.

Salivary samples were obtained through participants placing an Oral Swab (Salimetrics LLC) in their mouth until saturated. Samples were then placed in a conical polypropylene tube and immediately frozen at -20°C. Salivary samples were thawed to room temperature on the day of analysis and centrifuged. Analysis of the samples followed the manufacturer's instructions (Salimetrics LLC).

At three distinct task stages in the study (immediately following baseline measures, immediately prior to the presentation, and at the start of the recovery period), participants in the chewing gum condition were provided with a single pellet of Wrigley's Extra, spearmint-flavoured, sugar-free gum.

Design: A (2x4) mixed design was employed where the first factor is between-participants and refers to chewing gum condition (gum or no gum) and the second factor is within-participants and refers to experimental stage (baseline, pre-TSST, post-TSST, and recovery). The dependent variables measured at each experimental stage were salivary cortisol concentration (µg/dL), self-rated measures of stress, state-anxiety, alertness, contentedness, and calmness.

Procedure: Participants were tested between 15:00hrs and 17:00hrs in order to minimize the possibility of diurnal variations in cortisol excretion masking physiological responsiveness (Hucklebridge et al., 2005). The stressor task was based upon the Trier Social Stress Task (TSST) as described by Kirschbaum et al. (1993); this incorporates a videoed mock interview and mental arithmetic task performed to a panel. Participants were tested individually, with the experimental start time (15:00hr or 16:00hr) counterbalanced across gum conditions.

Participants entered the laboratory and completed the self-rated measures (trait-anxiety was measured at baseline only) and provided a salivary sample. The presentation order of the self-rated measures was counterbalanced with the salivary cortisol sample always taken last. Following completion of the baseline measures, participants were informed that the study required them to participate in a video-recorded presentation to a panel of two psychologists. Participants were informed that the psychologists were experts in both verbal and non-verbal communication. At this juncture participants were given the option to withdraw their participation.

Participants were allotted 10-minutes to prepare for the 5-minute presentation. Participants were required to present an argument in support of their suitability for a graduate position of their choice. Following the preparation phase, self-rated and physiological measures were obtained. Participants made their presentation in a quiet laboratory where two panel members (comprising staff from the Psychology Department at Coventry University) sat behind a desk. The presentation task was again described to the participant and a video camera was positioned to record the participant (although no recording was made).

Participants delivered their 5-minute presentation in a standing position facing the panel. Participants were informed that if their presentation concluded within 5-minutes they were to remain silent until that period had elapsed. If participants finished in less than 5-minutes they received a single verbal prompt of: “is there anything more that you wish to add?” Following the presentation, participants were given a 5-minute subtraction task, in which they were required to repeatedly subtract 7 from a 4-digit number. Participants responded verbally and any errors were corrected verbally (by the panel). If an error was made, the participant was instructed to commence the task again from the original 4-digit starter number. Following this task, participants completed the self-rated and physiological measures.

Participants were given a 10-minute recovery period for which they sat quietly. Following this recovery period the self-rated and physiological measures were taken for a final time. Participants were then debriefed.

Participants in the gum condition received a fresh, single pellet of gum at the start of each of the three task stages, i.e. presentation preparation, presentation, and 10-minute recovery. Participants were requested to chew at a normal rate throughout each of the task stages. At the end of each task stage, participants in the gum condition removed their gum prior to the completion of these measures.

Results

Group Differences

To confirm a null difference in baseline trait anxiety scores between the gum (mean = 38.55; SEM = 2.12) and no-gum (mean = 41.50; SEM = 1.70) groups their scores were compared via an independent samples 2-tailed t-test ($t(38) = 1.08$, $p=0.29$).

Statistics

A 2-way (2x4) mixed ANOVA was employed on all dependent variables with the between-participants factor chewing gum group (gum and no gum) and the within-participants factor experimental stage (baseline, pre-TSST, post-TSST, and post 10-minute recovery).

Effects of Stress Task

The effects of the TSST were assessed by examining the main effect of experimental stage for each of the dependent measures.

Cortisol: Cortisol excretion varied across task-stage, $F(3,144)= 8.35$, $p<0.001$, *partial* $\eta^2=0.18$: mean baseline = 0.39µg/dL (SEM = 0.11), mean pre-TSST = 0.41µg/dL (SEM = 0.09), mean post-TSST = 0.57µg/dL (SEM = 0.07), mean post-recovery = 0.73µg/dL (SEM = 0.09). Post-hoc Bonferonni-corrected comparisons ($p<0.0083$) revealed that cortisol excretion was highest at post-recovery and it differed significantly from baseline ($t(39)=3.34$, $p=0.002$), pre-TSST ($t(39)=3.70$, $p=0.001$), and post-TSST ($t(39)=3.50$, $p=0.001$). The increase in cortisol excretion throughout the task can be taken to reflect the delay in cortsiol elevation following exposure to a stressful stimulus (e.g. Kudielka et al., 2004).

Self-Rated Stress: Subjective stress varied with task stage, $F(3,114)=36.44$, $p<0.001$, *partial* $\eta^2=0.49$: mean baseline = 29.83 (SEM = 3.52), mean pre-TSST = 60.40 (SEM = 3.25), mean post-TSST = 53.85 (SEM = 4.46), mean recovery = 26.57 (SEM = 2.77). Post-hoc Bonferroni-corrected comparisons revealed that, compared to baseline, stress was significantly higher at both the pre-TSST ($t(39)=9.66$, $p<0.001$) and post-TSST stages ($t(39)=4.33$, $p<0.001$). At post-recovery, self-rated stress had returned to initial levels as illustrated by the non-significant difference to baseline ($t<1$). This shows that the task significantly increased self-rated stress but that these effects were acute, and normalised following the recovery phase.

Anxiety and Mood: State-anxiety ($F(3,114)=43.79$, $p<0.001$, *partial* $\eta^2 = 0.54$), contentedness ($F(3,114)= 20.11$, $p<0.001$, *partial* $\eta^2=0.35$), and calmness ($F(3,114)= 36.07$, $p<0.001$, *partial* $\eta^2=0.49$) each varied with experimental stage. For each of these measures post-hoc Bonferroni-corrected comparisons revealed a significant change from baseline to both the pre-TSST and post-TSST stages (i.e. increase in anxiety; decrease in contentedness and calmness). Measures at post-recovery demonstrated that levels had returned to those reported at baseline.

Alertness: The stressor task had no effect on self-rated alertness, $F(3,114)= 1.42$, $p=0.24$, *partial* $\eta^2= 0.04$.

These analyses confirm that the TSST increased participants' perception of both stress and anxiety whilst it decreased mood. Cortisol concentrations increased throughout the task, whilst both self-rated stress and anxiety rose immediately prior and post-presentation, before normalising to baseline levels following the recovery phase. Both contentedness and calmness decreased prior to and after the TSST but increased to baseline levels following the recovery phase. These findings are consistent with the predicted acute change in both mood and stress due to the task.

Effects of Chewing Gum on Stress, Mood, and Anxiety during the Stress Task

The effects of chewing gum with respect to the TSST was explored by examining the main effect of chewing and the interaction between chewing gum and experimental stage (i.e. did chewing gum mediate any changes in stress and mood). Figure 1 displays the effects of chewing gum on the TSST stages for both cortisol and self-rated stress.

Figure 1 about here please

Cortisol: As demonstrated in Figure 1a, baseline cortisol levels were substantially higher (although not significantly, $p=0.21$) for the gum group (0.52µg/dL) compared to the no gum group (0.29µg/dL). To accommodate the disparity in baseline scores a 2x3 ANCOVA was employed, with baseline cortisol scores as the covariate. The main effect of gum condition was significant, $F(1, 37)= 4.17$, $p= 0.05$, *partial* $\eta^2=0.10$, as was the gum condition by experimental stage interaction, $F(2,74)= 4.49$, $p=0.01$, *partial* $\eta^2= 0.11$. Further analysis of this interaction (planned comparisons between gum and no gum at each stage with baseline measures as a covariable) revealed significant differences between the gum and no gum groups to be evident at both post-TSST (adjusted mean cortisol concentration for gum and no gum = 0.67 µg/dL (SEM = 0.08 µg/dL) and 0.45 µg/dL (SEM = 0.08 µg/dL), respectively: $F(1,37)=4.20$, $MSe=0.12$, $p=0.048$) and post recovery stages (adjusted mean cortisol concentration for gum and no gum = 0.89 µg/dL (SEM = 0.11 µg/dL) and 0.56 µg/dL (SEM = 0.11 µg/dL), respectively: $F(1,37)=4.76$, $MSe=0.22$ $p=0.036$). No difference was found pre-TSST ($F<1$). These data suggest that when chewing gum under conditions of stress, cortisol levels are elevated to a greater extent compared to a non-chewing condition.

Self-Rated Stress: The effect of gum on self-rated stress can be seen in Figure 1b. The main effect of chewing gum condition was non-significant, $F(1,38)= 1.81$, $p = 0.19$, *partial* $\eta^2=0.05$. However, the predicted interaction between experimental stage and gum condition was significant, $F(3,114)= 3.48$, $p= 0.02$, *partial* $\eta^2= 0.08$. Further analysis of this interaction (planned t-tests) revealed significant differences between the gum and no gum groups for both post-TSST (mean self-rated stress for gum and no gum = 44.35 (SEM = 6.00) and 63.35 (SEM = 6.00), respectively: $t(38)=2.24$, $p=0.03$) and post-recovery stages (mean self-rated stress for gum and no gum = 20.65 (SEM = 3.73) and 32.50 (SEM = 3.73), respectively: $t(38)=2.25$, $p=0.03$). This indicates that gum moderated the increase in acute subjective stress.

State-Anxiety and Mood: For state-anxiety there was no effect of gum ($F(1,38)= 1.45$, $p= 0.24$, *partial* $\eta^2= 0.04$) nor a gum by stage interaction ($F<1$). For calmness there was no effect of gum nor a gum by stage interaction (both Fs<1). For contentedness there was no effect of gum ($F(1,38)= 1.33$, $p= 0.26$, *partial* $\eta^2= 0.03$) nor a gum by stage interaction ($F(3,114)= 1.40$, $p= 0.25$, *partial* $\eta^2= 0.04$).

Alertness: The main effect of chewing gum approached significance ($F(1,38)= 3.70$, $p= 0.06$, *partial* $\eta^2= 0.09$: mean self-rated alertness for gum and no gum groups = 65.80 (SEM = 2.98) and 57.69 (SEM = 2.98), respectively). There was no effect of experimental stage ($F(3,114)= 1.42$, $p= 0.24$, *partial* $\eta^2= 0.04$) and, importantly, there was no significant interaction between chewing gum and experimental stage ($F(3,114)= 1.59$, $p= 0.20$, *partial* $\eta^2= 0.04$).

Discussion

We employed an established cortisol-elevating task (TSST: Kirschbaum et al., 1993; see also Kudielka et al., 2004) in order to examine the extent to which chewing gum can act to attenuate the rise in stress-induced cortisol concentrations. In line with predictions, completion of the TSST, in comparison to baseline score, produced significant increases in cortisol excretion and this increase was similar to self-rated increases in both stress and anxiety, and decreases in both contentedness and calmness. Although our finding that chewing gum acted to accentuate the cortisol rise is in contrast to Scholey et al. (2009), it is consistent with the data of Smith (2010). Counter intuitively perhaps, and in contrast to the cortisol data, we found that chewing gum attenuated the rise in self-rated stress (consistent with Scholey et al., 2009: see also Smith, 2009a), i.e. participants reported the post TSST and post-recovery task stages as less stressful whilst chewing gum.

The contrasting effects of chewing gum on physiological and subjective measures are curious and suggest that cortisol changes may not always reflect perceived stress (a point mooted by Scholey et al., 2009; see also Johnson et al. 2011, where the stressor produced contrasting effects). It should be noted that the accentuating effect of gum on cortisol excretion cannot be explained by differences in baseline cortisol for the two groups. Specifically, when baseline scores were employed as a covariate, the chewing gum by experimental stage interaction indicated greater cortisol reactivity in the gum group. However, the use of ANCOVA does not mitigate for the possibility that (despite random allocation) participants in the gum group possessed greater stress reactivity. For example, higher trait neuroticism for the gum group would result in greater responsiveness to the stressor (Bolger and Zuckerman, 1995). This may explain the disparity in baseline cortisol: participants in the gum group were experiencing greater anticipatory stress prior to the study commencement. Notwithstanding, it should be noted that trait anxiety did not differ between the groups. A related explanation concerns the disproportionate number of male participants (12) to female participants (8) in the gum group. It has been argued (Kirschbaum, Wüst, & Hellhammer, 1992) that males produce twice as much cortisol under conditions of stress. We tested this proposition via ANOVA with gender and experimental stage as factors. This showed no significant interaction between gender and experimental stage ($F<1$), suggesting equivalent cortisol reactivity in males and females.

The present study provides two curious findings with respect to Sketchley-Kaye et al. (2011). First, in both studies the TSST produced significant increases in self-rated anxiety. However, the increase was moderated by gum in the Sketchley-Kaye et al. study only. Second, the present study failed to replicate the accentuating effect of chewing gum on self-rated alertness found in previous work (e.g. Scholey et al., 2009; Smith 2009b, 2010; Johnson et al., 2011; Sketchley-Kaye et al., 2011). However, speculative post-hoc analysis via independent sample t-test comparisons at each stage of the study revealed some evidence that gum was impacting alertness. No differences were found at baseline (mean alertness for gum and no gum = 65.10 (SEM = 3.20) and 58.40 (SEM = 3.79), respectively, $t(38)=1.52$, $p=0.18$), or pre-TSST (mean alertness for gum and no gum = 63.25 (SEM = 3.84) and 59.60 (SEM = 3.91), respectively, $t<1$). However, alertness was significantly higher in the gum condition post-TSST (mean alertness for gum and no gum = 66.30 (SEM = 4.25) and 52.70 (SEM = 3.54), respectively, $t(38)=2.46$, $p=0.02$), and borderline higher post-recovery (mean alertness for gum and no gum = 68.55 (SEM = 3.08) and 60.05 (SEM = 3.06), respectively, $t(38)=1.96$, $p=0.06$). The observation that alertness effects were at the final sections of the study are consistent with Tucha and Simpson (2011) who reported beneficial effects of chewing gum on the latter stages of a sustained attention task.

In summary, the present study has shown that chewing gum can attenuate the increase in self-rated stress following an acute social stressor task. However, these effects are not mirrored by concomitant changes in cortisol excretion. Indeed, the present data suggest that salivary cortisol concentrations are elevated in the gum group. Considering the contradiction between measures of cortisol and self-rated stress, it may be beneficial for researchers to examine the role of demand characteristics in the subjective assessment of gum effects. The present data do, however, generalise the moderating effects of chewing gum on subjective stress beyond cognitive-load stress (Scholey et al., 2009) to include social-evaluative stress (although it is unclear why such effects are found intermittently, e.g. Johnson et al., 2011; Torney, Johnson, and Miles, 2009). It is therefore, worth considering that social-evaluative stress and cognitive load stress represent qualitatively different experiences. Consequently, gum may have reductive effects for different reasons. Consider for example, the cognitive load stress described by Scholey et al. (2009). Here, gum may improve cognitive performance (e.g. see Smith, 2009b; Wilkinson et al., 2002), reducing stress epiphenomenally. In the present social stressor, the gum may provide a distracting activity that reduces participant focus on the observation process (e.g. Onyper et al., 2011, argued that chewing gum required cognitive resources). Although both speculative explanations, future research is required to disambiguate the mechanisms of stress reduction.

References

Bolger, N. and Zuckerman, A. (1995). A framework for studying personality in stress process. *Journal of Personality and Social Psychology, 69*, 890-902.

Bond, A. and Lader, M. (1974). The use of analogue scales in rating subjective feeling. *British Journal of Medical Psychology, 47(3)*, 211-218.

Fang, M., Li, J.C., Lu, G., Gong, X.Y. and Yew, D.T. (2005). A fMRI study of age-related differential cortical patterns during cued motor movements. *Brain Topography. 17(3)*, 127-137.

Hucklebridge F, Hussain, T, Evans P, Clow A, (2005) The diurnal pattern of the adrenal steroids cortisol and dehydroepiandrosterone (DHEA) in relation to awakening. *Psychoneuroendocrinology, 30(1),* 51-57.

Johnson, A.J., Jenks, R.A., Miles, C., Albert, M., and Cox, M. (2011). Chewing Gum Moderates Multi-Task Induced Shifts in Stress, Mood, and Alertness: A Re-Examination. *Appetite, 56,* 408-411.

Kern, S., Oakes, T.R., Stone, C.K., McAuliff, E.M., Kirschbaum, C., and Davidson, R.J. (2008). Glucose metabolic changes in prefrontal cortex are associated with HPA axis response to psychosocial stressor. *Psychoneurocrinology, 33(4)*, 517-529.

Kirschbaum, C., Pirke, K.M., and Hellhammer, D.H. (1993). The Trier Social Stress Task – a tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology, 28*, 76-81.

Kirschbaum, C., Wüst, S., and Hellhammer, D.H. (1992). Consistent sex difference in cortisol responses to psychological stress. Psychosomatic Medicine, *54*, 648-657.

Kudielka, B.M., Schommer, N.C., Hellhammer, D.H., and Kirschbaum, C. (2004). Acute HPA axis responses, heart rate, and mood changes to psychosocial stress (TSST) in humans at different times of the day. *Psychoneuroendocrinology 29*, 983-992.

Onozuka, M., Fujita, M., Watanabe, K., Hirano, Y., Niwa, M., Nishiyama, K. and Saito, S. (2002). Mapping brain region activity during chewing: A Functional Magnetic Resonance Imaging study. *Journal of Dental Research, 81(11)*, 743-746.

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

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

Sketchley-Kaye, K., Jenks, R.A., Miles, C., and Johnson, A.J. (2011). Chewing gum modified state anxiety and alertness under conditions of social stress. *Nutritional Neuroscience*, *14(6)*, 237-242.

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

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

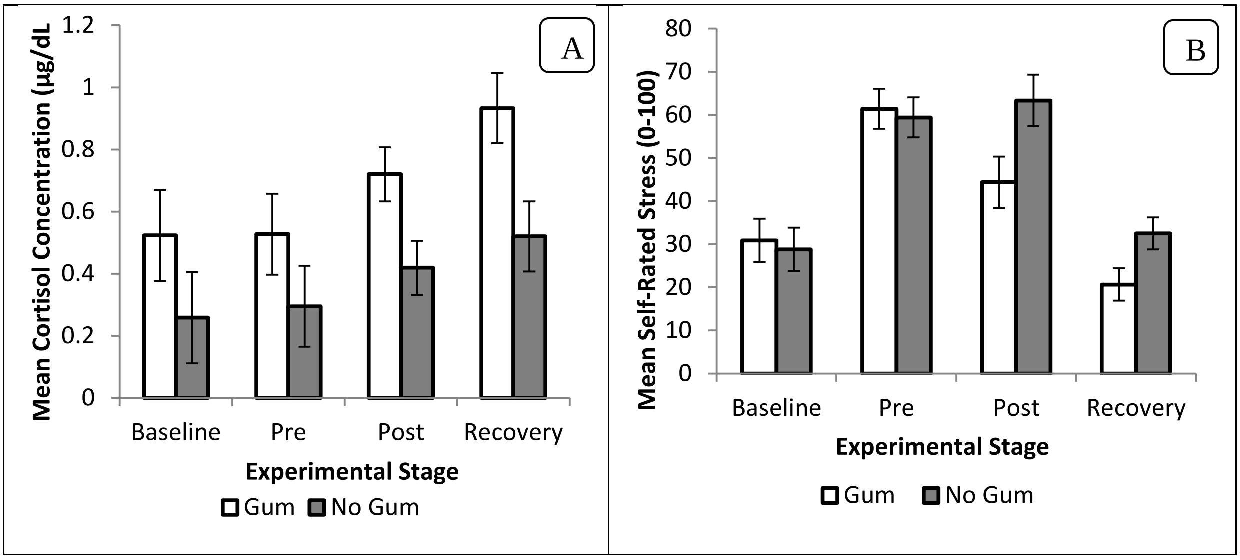
Smith, A. (2010). Effects of chewing gum on cognitive functions, mood and physiology in stressed and non-stressed individuals. *Nutritional Neuroscience, 13(1),* 7-16.

Speilberger, C., Gorsuch, R., Lushene, R.(1969). *The State Trait Anxiety Inventory Manual*. Palo Alto: Consulting Psychologists Press.

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

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

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



<u>Figure 1 (a-b)</u>: Mean measures of cortisol (a) and self-rated stress (b) across the four experimental stages. Errors bars denote +/- SEM.