The physiological experience of the Paced Auditory Serial Addition Task (PASAT): Does the PASAT induce autonomic arousal?

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Abstract

Previous research suggests that the Paced Auditory Serial Attention Task (PASAT) alters mood states, which may induce performance changes and complicate interpretation test scores. In the current design, we examined arousal as one mechanism moderating PASAT performance. It was expected that arousal level would increase during the test, and performance on the test would be related to arousal level. Heart rate and blood pressure (systolic and diastolic) were recorded from 42 healthy adult men during rest and PASAT challenge. Heart rate and blood pressure were significantly higher and stable across the PASAT procedure, while performance scores showed a steady decrease in correct responses. No association of arousal level and performance was found. Although, PASAT induced arousal changes were not significantly related to performance among healthy adults, the observed arousal changes do raise concerns about interpretation of PASAT performance among more sensitive populations and indicate new areas of application of the procedure.

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The Paced Auditory Serial Addition Task (PASAT; Gronwall, 1977), is a widely administered measure of information processing. In this procedure, participants must attend to the auditory presentation of a series of single-digit numbers and respond by saying the sum of

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the number just heard with the number heard immediately prior to that. The task typically involves several testing blocks, where blocks differ in terms of the interval between digit presentation. The PASA T is primarily administered to assess attention, concentration, and general information processing capacity (Cohen, 1993; Gronwall & Wrightson, 1981; van Zomeren & Brouwer, 1994), although there may also be some demands of general intellectual (Deary, Langan, Hepburn, & Frier, 1991; Egan, 1988) and mathematical ability (Chronicle & MacGregor, 1998; Egan, 1988; Sherman, Strauss, & Spellacy, 1997). This procedure has been used to document attentional deficits among patients with traumatic brain injury (Brooks, Fos, Greve, & Hammond, 1999; Cicerone, 1997; Grownwall, 1977; Grownwall & Wrightson, 1981), multiple sclerosis (Snyder, Cappelleri, Archbald, & Fisk, 2001), pain disorder (Sjogren, Thomsen, & Olsen, 2000), and even asthma (Weersink, van Zomeren, Koeter, & Postma, 1997). Given these types of findings, some (e.g., Lezak, 1995) have concluded that the value of the PASA T lies in its ability to very clearly demonstrate even subtle deficits in attention.

Even though the PASA T has been demonstrated to be a sensitive tool for assessing information processing, there have also been persistent complaints that the procedure provides a subjectively unpleasant experience for the individual taking the test. A number of authors have warned that patients and even healthy controls react with aversion to the PASA T procedure (Lezak, 1995; Roman, Edwall, Buchanan, & Patton, 1991; Spreen & Strauss, 1991). Based on these complaints, one study (Holdwick & Wingenfeld, 1999) was designed to specifically assess mood states with PASA T administration. This research demonstrated a significant effect of negative mood induction during the later, more rapid trials of the PASA T procedure. Holdwick and Wingenfeld (p. 282) interpreted these results as indicating that “participants view the PASAT negatively and that the experience of taking the PASAT affected their mood states accordingly.” Based on this and previous reports, it appears that performance of the PASA T imparts some negative mood effects.

The presence of mood effects with the PASA T has drawn the interpretation of performance differences into question. For instance, negative affect may interfere with motivation and cooperation resulting in less than optimal performance on the PASA T (Fos, Greve, South, Mathias, & Benefield, 2000). Also, certain sensitive samples, which are less resilient in their capacity to regulate affect, may experience especially pronounced mood effects on PASA T performance. For example, those already experiencing negative mood states (e.g., mood disorder patients) may be particularly likely to show diminished performance ability on the PASA T (Holdwick & Wingenfeld, 1999; Roman et al., 1991). While these calls for caution assist the clinician in making decisions regarding appropriate application and interpretation of PASA T procedure, research exploring the mechanisms involved in the interaction of mood and PASA T performance has been lacking.

In the current design, we explore autonomic arousal as one possible moderating variable associated with both mood and performance on the PASA T. Physiological arousal plays an important role in a number of prominent theories of emotion (e.g. James-Lange theory, Schacter-Singer theory). For instance, the recognition of the sensation of autonomic arousal in the presence of environmental cues produces measurable changes in mood states (Schachter & Singer, 1962). Also, individuals find low or high arousal disagreeable, while intermediate levels of arousal are inherently pleasant (Eysenck & Eysenck, 1985; Hebb, 1955). Physiological arousal may also play a role in performance ability on information processing tests.
A number of researchers (e.g., Humphreys & Revelle, 1984; Matthews & Deary, 1998) have explored the idea that arousal mediates performance in a curvilinear manner on tasks requiring attentional and memory capacities. In this way, relatively poorer performance occurs under both conditions of low and high arousal, with optimal performance at moderate arousal levels (Yerkes & Dodson, 1908). Because of this convergence of factors relating affect, performance and arousal, we extend the existing literature by exploring the role of autonomic arousal during performance of the PASAT procedure.

This study was designed to determine if changes in autonomic arousal accompany performance of the PASAT and if these changes are related to performance. In order to avoid any confounding effects of clinical impairment with arousability, we sampled normal healthy adults. Based on previous reports regarding mood changes, it is expected that performance of the PASAT will induce significant increases in autonomic arousal. Further, it is expected that the autonomic changes will be negatively related to successful performance on the PASAT.

1. Methods

1.1. Subjects

Forty-two healthy male subjects were recruited from radio and flier advertisements for research volunteers. Exclusion criteria, which approximate those reported in several other autonomic psychophysiological studies (e.g., Al’Absi et al., 1997; Graham, Zeichner, Peacock, & Dishman, 1996), included: (1) hypertension (systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg; Chen, Rennie, Lockinger, & Dosman, 1998); (2) cold or flu symptoms in the seven days preceding testing; (3) previous treatment for any DSM-IV Axis I or II disorder; (4) chronic physical illness affecting the central nervous system; (5) consumption of either prescription or over-the-counter medication within two days of testing; (6) major life event in the past week; (7) cigarette smoking, and (8) ingesting any caffeinated substance or any food in the 5 h preceding scheduled testing.

1.2. Materials

1.2.1. Paced Auditory Serial Attention Test

The Paced Auditory Serial Attention Test (The Psychological Corporation, 1998) is a computerized-format variation of the traditional Paced Auditory Serial Addition Task. The exam requires addition of digit-pairs. Standard administration of the test involves auditory presentation of numbers (1 through 9) in a randomized format. Subjects were instructed to attend and respond with the sum of the number just presented and the number presented immediately prior to that, all the while attending to the next incoming number of the auditory series. For example, when presented with the series of numbers 1, 2, 3, 4, the subject would respond by answering “3,” “5,” and “7” by summing each of the number pairs “1, 2,” “2, 3,” and “3, 4” (Holdwick & Wingenfeld, 1999). There are four trials in the procedure differing in rate of stimulus presentation (2.4, 2.0, 1.6, and 1.2 s inter-stimulus interval) with progressively shorter intervals resulting in increasing intensity of stimulation. Each of the four trials consists of 60 numbers. This testing period is preceded by an approximately 6-min Practice period.
to ensure comprehension of the instructions and some basic achievement with the task prior to the more lengthy and rigorous testing session. The standard Practice procedure required a criterion of five correct responses for randomized digits at the 2.4 presentation rate before actual testing could begin.

1.2.2. DINAMAP MPS

The DINAMAP MPS (1997) Select Portable Monitor© (Dynamic Indirect Non-invasive Automatic Mean Arterial Pressure—Multi-Purpose Square; Critikon; Tampa, FL) was used to record all physiological data. Specifically, measures of heart rate (electrocardiogram: EKG), systolic blood pressure (SBP), and diastolic blood pressure (DBP) were assessed.

DINAMAP MPS modules allow for the continuous recording of heart rate via electrocardiogram using disposable Ag/AgCl electrodes (Trace-It Monitoring Electrodes©, Bio-Detek, Inc; Miami, FL). These EKG leads were applied in the Einthoven’s triangle configuration (Papillo & Shapiro, 1990). The signal was filtered by bandpass set at 0.5 and 40 Hz, with a notch filter set at 60 Hz. Signal detection of the R-wave yielded a beats-per-minute score. Artifact is compensated automatically by the DINAMAP system, which computes heart rate scores based on weighted averages over 10 s intervals. Then a beats-per-minute score is output by the DINAMAP, which is based on ensemble average for 60-s periods. Finally, these 60-s periods were averaged off-line to yield an EKG score for each of the seven separate physiological recording periods.

For blood pressure measurement, a blood pressure cuff (Dura-Cuf©, Critikon; Tampa, FL) was applied to the left arm of each subject, just above the elbow. The DINAMAP system measures systolic and diastolic blood pressure using the oscillometric method (i.e., amplitude of pressure oscillations within the pressure cuff). The DINAMAP applies the oscillometric method by inflating the cuff to a target pressure and step-down deflating. The period between deflation steps is determined by the frequency of matched pulses; when two pulses of equal amplitude are detected, deflation of 8 mmHg occurs. The criterion of two matching pulses before deflation step-down serves as artifact rejection. This procedure offers significant reliability with mercury manometer measurement (Manolio et al., 1988). Blood pressure was assessed at three points during the Baseline period (first minute, fifth minute, and tenth minute of rest). An average was taken of the three measurement points yielding a single Baseline blood pressure score. The same procedure was used during the Recovery period as well. During the PASAT Practice, blood pressure measurement was initiated after the first series of random number trials (i.e., at the outset of trials similar to actual testing). During each of the four PASAT trials, blood pressure measurement was initiated after the 15th stimulus item. This testing schedule allowed sufficient time for the subject time to comprehend the speed of stimulus presentation for that particular trial, while at the same time ensuring that blood pressure measurement would be complete prior to the end of the trial. This procedure yielded an SBP and DBP score for each of the seven separate physiological recording periods.

1.3. Procedure

Upon entry into the study subjects were interviewed regarding their behavioral health history and demographic characteristics.
Each of the subjects experienced seven physiological recording periods: Baseline, PASAT Practice, PASAT 2.4, PASAT 2.0, PASAT 1.6, PASAT 1.2, and Recovery. For the resting Baseline, subjects were asked to sit quietly for 10 min in a light and sound attenuated room. Room temperature was controlled and kept in a “comfortable” range (Anderson, Deuser, & DeNeve, 1995). Following the resting Baseline measure, subjects completed the standard computer administered PASAT Practice session. Upon successful completion of the Practice period, subjects performed each of the standard PASAT trials (2.4, 2.0, 1.6, and 1.2). Finally, subjects began a 10 min resting Recovery session, with instruction identical to the Baseline. Physiological recording was conducted across each of the experimental periods. PASAT performance testing was measured for each of the four trials (i.e., PASAT 2.4, PASAT 2.0, PASAT 1.6, and PASAT 1.2).

1.4. Statistical analyses

All analyses were performed using the SPSS© (Version 10.0) statistical package. The data were examined, and no outliers were obtained. The probability of Type I error was set at .05. Separate analyses of EKG, SBP, DBP, and PASAT performance were conducted using multiple repeated-measures ANOVAs with trial as the within-subjects factor. The Geisser and Greenhouse (1958) conservative $F$ test was used to guard against violations of the sphericity assumption. Type I error rate was controlled during all follow-up comparisons by use of the Bonferroni inequality (Stevens, 1996). Estimates of effect sizes were calculated as Cohen’s $f$ (Cohen, 1993) using $\eta^2/(1 - \eta^2) = \text{Cohen's } f^2$ to determine the magnitude of differences between measurement period. Finally, two-tailed Pearson’s product moment correlations were computed between they primary PASAT performance variables (correct and incorrect responses) and each of the autonomic measures (EKG, SBP, and DBP).

2. Results

2.1. Demographic information

Forty-two healthy males were recruited and included in the analyses. Average age of the group was 25.0 (S.D. = 8.8) and the mean educational level was 14.2 (S.D. = 1.8) years. Mean Body Mass Index (kg/m$^2$) was 24.2 (S.D. = 3.6).

2.2. Physiological recording

2.2.1. Heart rate

Analyses of the heart rate measure (EKG) demonstrated a significant omnibus effect of physiological recording period [Greenhouse-Geisser $F(6, 264) = 8.58, P < .001$, Cohen’s $f = 0.457$, observed Power = 0.997]. There was a significant quadratic function [$F(1, 41) = 26.33, P < .001$, Cohen’s $f = 0.801$] such that EKG increased from Baseline to Practice with maximum heart rate during the four PASAT trials followed by a decline during the resting Recovery period (Fig. 1). Bonferroni-corrected pairwise-comparisons indicated that there were no significant EKG differences between any of the four PASAT trials ($P > .164$),
but during all of the trials EKG output was significantly faster than either Baseline ($P < .001$) or Recovery ($P < .04$) periods. There were no significant differences in heart rate between Baseline, Practice, and Recovery sessions ($P > .05$).

2.2.2. Blood pressure

Separate repeated-measures ANOVAs were conducted for each of the two blood pressure measures (SBP and DBP) with physiological recording period as the within-subject factor (Fig. 2). Because the DINAMAP system relies on automatically adjusting deflection rates for the measurement of systolic (SBP) and diastolic (DBP), there were instances where the blood pressure cuff failed to achieve a reading. This resulted in a loss of five subjects from the blood pressure analyses ($N = 37$ retained).

Analyses of the SBP scores yielded a significant omnibus effect of physiological recording period [Greenhouse-Geisser $F(6, 216) = 13.55$, $P < .001$, Cohen’s $f = 0.624$, observed Power = 1.00]. There was a significant quadratic function [$F(1, 36) = 39.49$, $P < .001$, Cohen’s $f = 1.047$] such that SBP increased from Baseline to Practice periods with maximum SBP during the four PASAT trials followed by decline in SBP during the resting Recovery period. Bonferroni-corrected pairwise-comparisons indicated that there were no significant differences in SBP among any of the four PASAT trials ($P = 1.0$) but during all these PASAT trials SBP was significantly greater than during both the Baseline and Recovery periods ($P < .002$). There was no significant SBP difference between Baseline and Recovery periods ($P = 1.0$). Finally, SBP during the PASAT Practice was significantly higher than during Baseline and Recovery periods ($P < .04$), although not significantly different than any of the PASAT trials ($P > .38$).

Similarly, analyses of DBP revealed a significant pattern of blood pressure change across the physiological recording periods [Greenhouse-Geisser $F(6, 216) = 20.31$, $P < .001$, Cohen’s $f = 0.752$, observed Power = 1.00]. There was a significant quadratic function [$F(1, 41) = 47.38$, $P < .001$, Cohen’s $f = 1.147$] such that DBP increased from Baseline...
to Practice with maximum pressure during the four PASAT trials followed by decline during the resting Recovery period. Bonferroni-corrected pairwise-comparisons indicated that, unlike the other physiological measures, there were significant differences in DBP among the four PASAT trials ($P < .04$). DBP was greatest during the initial trial (i.e., PASAT 2.4), relative to all other PASAT trials as well as Baseline and Recovery. DBP was not significantly different ($P > .17$) across the subsequent PASAT trials (PASAT 2.0, 1.6, and 1.2), although it was greater than during the Baseline and Recovery periods ($P < .001$). Finally, DBP during the PASAT Practice was significantly higher than during Baseline and Recovery periods ($P < .001$), but significantly lower than during the PASAT 2.4 trial ($P < .001$).

2.3. PASAT performance measurement

Separate repeated-measures ANOVAs were conducted across each of the four performance measurement periods (i.e., PASAT 2.4, 2.0, 1.6, and 1.2). The primary dependent variables were the number of correct and incorrect responses. See Figure 3.

There was a significant effect for PASAT trial for the correct responses [Greenhouse-Geisser $F(3, 123) = 82.49$, $P < .001$, Cohen’s $f = 1.419$, observed Power = 1.00]. The nature of
this effect was a significant linear decline \[ F(1, 41) = 140.01, P < .001, \text{Cohen's } f = 1.845 \] in correct responses from the first to the final PASA T trial. There was no effect of PASA T trial for incorrect responses.

2.4. Arousal–performance associations

A series of Pearson’s product moment correlations were computed for the two primary PASA T performance variables (correct and incorrect responses) with EKG, SBP, and DBP for each of the four PASA T trials (Table 1). Only two statistically significant correlations were

Table 1
Pearson product moment correlations of PASAT performance with EKG, SBP, and DBP measures

<table>
<thead>
<tr>
<th>PASAT performance period</th>
<th>PASAT 2.4 Correct</th>
<th>PASAT 2.4 Incorrect</th>
<th>PASAT 2.0 Correct</th>
<th>PASAT 2.0 Incorrect</th>
<th>PASAT 1.6 Correct</th>
<th>PASAT 1.6 Incorrect</th>
<th>PASAT 1.2 Correct</th>
<th>PASAT 1.2 Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>EKG</td>
<td>.10</td>
<td>-.18</td>
<td>-.01</td>
<td>-.28</td>
<td>-.02</td>
<td>-.19</td>
<td>.10</td>
<td>.04</td>
</tr>
<tr>
<td>SBP</td>
<td>.23</td>
<td>-.21</td>
<td>.16</td>
<td>.15</td>
<td>.36*</td>
<td>-.06</td>
<td>.20</td>
<td>.28</td>
</tr>
<tr>
<td>DBP</td>
<td>.08</td>
<td>-.25</td>
<td>.05</td>
<td>-.02</td>
<td>.11</td>
<td>-.11</td>
<td>.10</td>
<td>.35*</td>
</tr>
</tbody>
</table>

* P < .05.
noted. Correct responses and SBP at PASAT period 1.6 was $r = .36$, $P = .022$. Incorrect responses and DBP at PASAT period 1.2 was $r = .34$, $P = .030$. No other correlations were statistically significant (Table 1).

3. Discussion

In the current design we examined autonomic arousal and performance on the PASAT. The main findings were that: (1) there were significant increases in autonomic arousal during performance of the PASAT; and (2) arousal level was unrelated to performance outcome scores on the PASAT. This supported our hypothesis regarding the influence of PASAT performance on autonomic measures of arousal. However, it does not support the hypothesis that physiological arousal is a mechanism by which PASAT induced mood changes relate to performance on the procedure in healthy adults.

As expected, significant increases in heart rate and blood pressure were noted during performance of the PASAT. In particular heart rate and blood pressure were relatively higher during each of the four PASAT testing periods (i.e., 2.4, 2.0, 1.6, 1.2) than during Baseline or Recovery periods. The mechanism for the current results may be accounted for by previous reports (e.g., Catipovic-Veselica et al., 1999) indicating that cognitively demanding procedures alter the myocardial oxygen supply/demand ratio. Changes in this ratio would produce changes in heart rate and blood pressure readings. In this case the PASAT exerts cognitive demand because of the speed and constant updating required of the test, even though it involves a fairly easy and overlearned process for many adults (addition of single-digit numbers).

Somewhat surprisingly, the heart rate and blood pressure readings were relatively constant across the four PASAT testing periods. Although no hypothesis was made regarding differences within task performance, the previous PASAT mood study (Holdwick & Wingenfeld, 1999) suggested that greatest affective changes occur during later trials that have the shortest interval between responses. The relative stability in autonomic output despite the increasing intensity of the PASAT procedure may be accounted for by the process of Transmarginal Inhibition (TMI). TMI is a protective mechanism that suppresses physiological reactivity under highly stimulating conditions, so that arousal levels reach some asymptote rather than continuing to rise with increasing intensity stimulation (Matthews & Deary, 1998). This process is one explanation that would account for the pattern of physiological change observed here, rather than the profile observed in the previous Holdwick and Wingenfeld mood experiment.

The observed autonomic changes appeared to be largely unrelated to performance outcome on the test. While the autonomic variables were relatively stable across the four PASAT periods, correct responses decreased as the procedure progressed. There were no regular patterns within the correlation matrix to suggest a meaningful relationship between autonomic output and PASAT performance. This was contrary to expectations based on earlier work demonstrating a curvilinear relationship between arousal and performance on complex cognitively demanding procedures (e.g., Humphreys & Revelle, 1984; Matthews & Deary, 1998). The divergence of our results with previous reports may be due to differences in the task demands. Humphreys and Revelle used a task similar to the vocabulary portion of the Graduate Record Exam. Performance scores on this task, they postulated, are the result of a trade-off.
between attentional information transfer and memory capacity. The PASAT would appear to be heavily dependent upon attentional information transfer processes, with limited memory requirement because of the brief duration of the retention period. As such, the curvilinear model of arousal–performance may not be appropriate for a task with demands like the PASAT.

Another limitation of the study was that performance within the normal range might have limited expression of any significant arousal–performance relationship. We used a non-clinical sample for this initial study primarily to ensure selection of individuals that would be expected to express a healthy level of physiological reactivity to the task. The problem with this selection procedure is that scores on the PASAT task performance variables occurred in a fairly small range. In fact, there was no significant increase in incorrect responding during the later, more intense, PASAT trials as would be expected with certain clinical groups. Because range restriction results in underestimation of correlations, this sampling criterion may have obscured any meaningful relationship between arousal levels and performance.

While the PASAT produced significant and sustainable increases in autonomic measures of arousal, these changes were unrelated to performance on the PASAT among healthy men. Continued research being conducted by the author (M.S.S.) is exploring these relationships in samples with behavioral pathology that would tend to express a broader range of performance on the PASAT procedure and arousal fluctuation. Further research is needed to adequately explore the inter-relationship between arousal, mood, and performance on the PASAT. This future research may consider experimental manipulation of mood or measurement of state-dependent mood changes concomitant with physiological assessment and PASAT performance.

4. Conclusions

These findings support the notion that autonomic arousal can be reasonably expected to accompany performance of the PASAT, even though increases in autonomic changes do not appear related to performance measures in healthy controls. Even without support for the arousal–PASAT performance relationship, the pattern of arousal induction demonstrated here provides further support for the notion of caution in application of the test as well as offering novel areas of application of the procedure. While the healthy adults were able to tolerate the procedure, care must be taken with sensitive groups who may be more susceptible to the arousal changes that accompany the PASAT experience. For instance, clinical groups that are frustration prone and characterized by hyper-arousability (e.g., post-traumatic stress disorder patients) may be especially susceptible to the effects of the PASAT.

At the same time, the current findings point to an area of novel application of the PASAT. The procedure may be especially useful as an arousal induction procedure. One recent study by our laboratory (Mathias & Stanford, 2003) used the PASAT as an arousal induction technique to explore Eysenck’s (Eysenck & Eysenck, 1985) concept of the role of arousal among impulsive individuals. This procedure has the advantage over previous arousal induction techniques (e.g., swallowing lemon juice or 100 dB noise bursts), because it is of fairly long duration. This longer period of arousal manipulation may allow for more thorough characterization of physiological reactivity.
Induction of arousal may in certain situations be undesirable and undermine interpretation of PASAT performance; however, appreciation of these properties may prove advantageous in addressing questions where a respondent’s arousal profile is the question of interest.

References


