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The effect of increased parasympathetic activity on perceived duration

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Running head: PSNS and timing

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Abstract

Theories of human temporal perception suggest that changes in physiological arousal distort the perceived duration of events. Behavioural manipulations of sympathetic nervous system (SNS) activity support this suggestion, however the effects of behavioural manipulations of parasympathetic (PSNS) activity on time perception are unclear. The current study examined the effect of a paced respiration exercise known to increase PSNS activity on sub-second duration estimates. Participants estimated the duration of negatively and neutrally valenced images following a period of normal and paced breathing. PSNS and SNS activity were indexed by high-frequency heart-rate variability and pre-ejection period respectively. Paced breathing increased PSNS activity and reduced the perceived duration of the negative and neutrally valenced stimuli relative to normal breathing. The results show that manipulations of PSNS activity can distort time in the absence of a change in SNS activity. They also suggest that activities which increase PSNS activity may be effective in reducing the perceived duration of short events.

Introduction

A veridical perception of time is critical to survival and success (Lake, 2016; Ogden, Henderson, McGlone & Richter, 2019). Objectively time passes at a constant unchanging rate. Subjectively, however, our perception of time is altered by our activities and emotional state (see Lake, 2016 and Wearden O'Donoghue, Ogden, & Montgomery, 2014 for discussion). Perhaps the most often reported example of distortion to time is the subjective lengthening of the perceived duration of negatively valenced stimuli relative to neutrally valenced stimuli presented for the same duration of time (see Droit-Volet & Meck, 2007 and Lake, 2016 for reviews). For example, subjectively, angry faces last for longer than neutral faces (Droit-Volet, Brunot & Niedenthal, 2004), negatively valenced IAPS images (Gil & Droit-Volet, 2012) and IADS (Mella, Conty & Pouthas, 2011) last for longer than neutrally valenced ones and pain lasts for longer than non-painful touch (Fayolle, Gil & Droit-Volet, 2015; Ogden, Moore, Redfern & McGlone, 2014). Clinical groups also display temporal distortions when in the presence of triggering stimuli (Bar-Haim, Kerem, Lamy & Zakay, 2010, Watts & Sharrock, 1984, Yoo & Lee, 2015). For example, people with arachnophobia overestimate the duration of the presence of spiders relative to control participants (Watts & Sharrock, 1984) and people with anxiety over-estimate the duration of threatening stimuli relative to non-anxious controls (Bar-Haim et al., 2010). These latter findings led Bar-Haim et al., (2010) to suggest that, in anxious groups, temporal distortions may contribute to the maintenance of anxiety.

The emotional valence of an event appears to influence the direction in which time is distorted. Positively valenced stimuli, for example, are often reported as being perceived as shorted than neutrally valenced stimuli of the same duration (e.g. Droit-Volet, Bigand, Ramos & Bueno, 2010; Smith, McIver, Di Nella & Crease, 2011). However, it should be noted that this effect is not universal and recent studies have failed to demonstrate any distortion to the duration of positively valenced stimuli (van Hedger et al., 2017, Ogden et al., 2019). Furthermore, within an emotional valence, discrete emotional categories appear to have differing capacities to distort duration. For example, for negatively valenced stimuli, those evoking shame appear to subjectively shorten perceived duration (Gil & Droit-Volet, 2011) whereas those evoking fear and disgust lengthen perceived duration (Gil & Droit-Volet, 2012). Indeed the extent to which a negatively valenced stimulus evokes subjective lengthening appears to be determined by its capacity to induce arousal, with images of sadness, which evoke low arousal, producing smaller lengthening effects than fear inducing stimuli, which evoke high arousal (Gil & Droit-Volet, 2012). The capacity of an emotional stimulus to distort time is also in part dependant on the extent to which the displayed emotion can be embodied and empathised. Increased empathy is associated with greater temporal distortions (Mondillon, Niedenthal, Gil & Droit-Volet, 2007) however when emotion embodiment is prevented distortions to time are attenuated or absent (Effron, Niedenthal, Gil & Droit-Volet, 2006).

Theories of time perception suggest that distortions occur due to changes in physiological arousal which in turn affect the processing of duration. Scalar Expectancy Theory (SET: Gibbon, Church & Meck, 1984), the dominant cognitive model of timing, proposes that there is an internal clock which is used to judge duration. Physiological arousal influences the speed at which the pacemaker of this internal clock emits output. Increases in arousal increase pacemaker rate leading to greater accumulation resulting in longer perceptions of duration. Decreases in arousal reduce pacemaker rate leading to less accumulation and shorter perceptions of duration (Gil & Droit-Volet, 2012; Penton-Voak, Edwards, Percival &Wearden, 1996).

In neuro-biological models such as the Striatal Beat Frequency Model (SBF: Matell & Meck, 2004), time is processed through the oscillatory patterns of cortical neurons, which are in turn detected by spiny striatal neurons. Specific oscillatory patterns are therefore associated with specific durations. In SBF, temporal distortions occur because arousal influences dopamine levels in the cortex (e.g. Darvas, Fadok, Palmiter, 2011) which in turn alters the firing rate of cortical projections to the striatum and the rate of the cortical oscillators (Cheng, Tipples, Narayanan & Meck, 2016). Increases in dopamine increase firing and oscillation rate, resulting in longer perceptions of time, whereas decreases in dopamine slow the firing and oscillation rate resulting in shorter perceptions of time.

In Craig's (2009) homeostatic model of timing, distortions to time occur because of the dual role of the anterior insula cortex (AIC) in time perception (Livesey, Wall & Smith, 2007) and homeostatic regulation (Craig, 2002). Craig (2009) proposes that when judging duration in state of heightened negative emotion, there is an increase in sympathetic nervous system (SNS) activity accompanied by an increase in right side AIC activity. The combined effect of AIC activity during temporal perception and right side AIC activation due to threat and SNS activation therefore results in subjective lengthening of the perceived duration of events. However, when judging duration in a relaxed situation, there is an increase in parasympathetic nervous system (PSNS) activity accompanied by an increase in left side AIC activation. This combination of activation results in a contraction of time and hence subjectively shortened perceptions of duration. Functional asymmetry in the AIC and the associated changes in SNS and PSNS activation are therefore causal to the lengthening and shortening of time in this model.

Although theoretical models of time perception and experimental studies of distortions to time (e.g. Gil & Droit-Volet, 2012) often discuss arousal as a causal mechanism in duration distortions, until recently, *arousal* had been poorly defined within experimental manipulations of temporal perception (Lake, 2016). Recent studies have however focused on establishing the effects of changes in the activity of the autonomic nervous system on duration perception, to understand the underlying causes of temporal distortions (van Hedger, Necka, Barakzai, & Norman, 2017; Piovesan, Mirams, Poole, Moore & Ogden, 2018; Ogden, Henderson, Richter & McGlone, 2019). Van Hedger et al. (2017), Piovesan et al. (2018) and Ogden et al. (2019) defined physiological arousal as the activity of the sympathetic nervous system and parasympathetic nervous system activity. SNS reactivity increases in response to stress whereas PSNS reactivity increases with rest and relaxation. Van Hedger et al. (2017), Piovesan et al. (2018) and Ogden et al. (2019) tested whether changes in SNS and PSNS were causal in the experience of emotional distortions to time. Together, their studies demonstrated that SNS reactivity evoked by a social stressor (van Hedger et al., 2017), experimental pain (Piovesan et al., 2018) and highly arousing negatively valenced IAPS images (Ogden et al., 2019) was predictive of the subjective lengthening of the perceived duration of these negatively valenced stimuli. Consistent with the predictions of SET, SBF and Craig's homeostatic model of timing, increases in SNS reactivity therefore appear to be causal in the subjective lengthening of the perceived duration of highly arousing negatively valenced stimuli.

Whilst the role of SNS activity in distortions to time is now established, the effect of PSNS activity change on temporal experience is unclear. This is in part because, to date, studies have focused on behavioural manipulations of SNS activity rather than manipulations of PSNS activity. When studies have used manipulations known to affect PSNS activity, direct measures of PSNS have not been taken (e.g. Droit-Volet, Chaulet & Dambrun, 2018). Furthermore, when studies have taken measures which are indicative of PSNS activity, they have focused on the effect of resting state cardiac activity on the accuracy of duration perception rather than specific manipulation of PSNS activity itself (e.g. Cellini, Mioni, Levorato, Grondin & Stablum, 2015; Fung, Crone, Bode & Murawski, 2017; Meissner & Wittmann, 2011; Pollatos, Yeldesbay, Pikovsky & Rosenblum, 2014). These studies have also produced mixed results, with some studies reporting that greater vagal tone is associated with more accurate duration perception (e.g. Cellini et al., 2015; Pollatos et al., 2014), but others reporting no association (Fung et al., 2017).

If, as suggested by theories of time perception, *changes* in physiological arousal are a causal factor in distortions to time, then it is plausible that behavioural manipulations which alter PSNS activity may distort time. Paced breathing at a low frequency (less than 10 breaths per minute) has been shown to be effective in increasing PSNS activity (Sakakibara, Takeuchi, & Hayano, 1994; Tsai, Kuo, Lee, & Yang, 2015; Wu & Lo, 2008) and is associated with greater relaxation and lower levels of stress, indicating a reduction in arousal (e.g. Nardi, Freire & Win, 2009; Yackle et al., 2017). Because of these effects, Craig (2009) specifically suggested that paced breathing may cause time contraction, shortening the perceived duration of events. Slow, paced breathing thus seems to constitute a valid means to behaviourally manipulate PSNS activity to establish its effect on time perception.

The current study

This study tested the effect of a paced respiration exercise known to increase PSNS activity (Bernardi et al., 1989; Bernardi, Porta, Gabutti, Spicuzza & Sleight, 2001; Sakakibara et al., 1994; Tsai et al., 2015; Wu & Lo, 2008) on the perceived duration of sub-second negative and neutral stimuli. Participants were asked to complete four duration judgment tasks. Two of the tasks, one with neutral stimuli and one with high arousal negative stimuli, were preceded by a story listening task during which participants breathed at their normal rate. The two remaining tasks, one with neutral stimuli and one with high arousal negative stimuli, were preceded by a paced breathing exercise in which participants were guided to breathe at a rate of six breaths per minute. Sub-second verbal estimation was selected as the task to be consistent with the methodologies employed in psychophysiological studies which have directly manipulated SNS activity (e.g. Piovesan et al., 2018; Ogden et al., 2019) and with behavioural studies demonstrating the effect of emotional arousal on perceived duration (e.g. Gil & Droit-Volet, 2012). It is also widely used in the field in general, being employed to understand modality differences in timing (e.g. Wearden, Todd & Jones, 2006), the relationship between timing and general cognition (Ogden, Wearden & Montgomery, 2014) and the effects of clinical conditions on time perception (Wearden et al., 2009) (see also

Wearden, 2015 for discussion). Throughout all tasks, PSNS activity was indexed by high frequency heart rate variability (HF-HRV) and SNS activity was indexed by pre-ejection period (PEP). The difference in PSNS activity, SNS activity and estimates during the four tasks were compared to establish whether the paced breathing exercise shortened perceived duration relative to the control listening task.

It was expected that PSNS activity would be greater in the paced breathing condition than the normal breathing condition. SNS activity was not expected to be affected by the breathing manipulation but was assessed to capture a comprehensive picture of physiological (autonomic) arousal. Duration estimates were expected to be longer for the neutral stimuli than the negative stimuli. Critically, duration estimates for both the negative and the neutrally valenced stimuli were expected to be shorter following paced breathing than following normal breathing.

Method

Participants: Thirty participants, with no known cardiac pathology, were recruited through volunteer sampling from Liverpool John Moores University and the general population. Participants were aged 19 to 35 (M=25.30, SD=3.63) with 18 females. Sample size for this study was similar to that used in previous research examining the effect of paced breathing on PSNS activity (Bernardi et al., 1989, Sakakibara et al., 1994). A power analysis indicated that a sample of 30 would detect a medium effective size (f = .27) with an alpha of 0.05 and power of 0.80.

Design: A within-subjects design with two independent variables (IVs). The first IV was breathing instruction: normal breathing and paced breathing. The second IV was image valence: neutral and high arousal negative. There were three dependant variables; mean duration estimates (ms), high frequency heart rate variability (HF-HRV) and pre-ejection period (PEP).

Materials and apparatus:

Physiological recording: A medis Cardioscreen 1000 sampled electrocardiogram (ECG) and impedance cardiogram (ICG) signals at a sampling rate of 1000 Hz to determine pre-ejection period (PEP) and high frequency heart rate variability (HF-HRV). The Cardioscreen 1000 impedance cardiograph electrodes were connected to the base of the participant’s neck and to the middle axillary lines at the level of the xiphoid on both the right and left sides, the earlobe electrode was connected to the left earlobe. PSNS arousal was indexed by respiration-centred heart-rate variability (HRV), the change in the time between consecutive heart beats that is associated with respiratory activity. Increases in PSNS activity lead to a more pronounced difference between the shorter inter-beat intervals associated with inspiration and the longer inter-beat intervals associated with expiration, and thus result in a higher HRV (Berntson et al., 1997). SNS arousal was indexed by PEP. PEP refers to the period between the electrical innervation of the left ventricle (Q wave of the ECG) and the opening of the aortic valve (B notch), and is a direct indicator of the force with which the heart contracts. Given that sympathetic impact on the heart is the main determinant of myocardial contraction force, PEP shortening indicates under certain conditions (that is, no parallel increases in cardiac preload or decreases in cardiac afterload) an increase in sympathetic activity. Amongst the available non-invasive indicators of SNS impact on the heart, PEP constitutes the most valid one (Berntson et al., 1997; Sherwood, Dolan & Light, 1990). A V100 blood pressure monitor assessed participants systolic and diastolic blood pressure to control for afterload effects on PEP (Sherwood, Dolan & Light, 1990).

Time estimation task: Participants were instructed to estimate, in milliseconds, the presentation duration of images presented on a computer screen. All stimuli were presented on a 32 inch monitor. Participants used the keyboard to enter all responses. The experiment structure was written in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) which paced all experimental events.

Stimuli selection: Stimuli were selected from the IAPS (Lang, Bradley & Cuthbert, 1997). Two categories of images were selected: high arousal negative and neutral. The images were selected according to IAPS standard ratings for arousal and for valence using the following criteria: High arousal negative images (valence 1.50 – 2.50, arousal 6.00 – 7.50) and neutral (valence 4.00 - 5.00, arousal 1.50 – 3.00). Six images were selected for each condition (see Table 1 for image numbers). These criteria were informed by that used in Angrilli, Cherubini, Pavese & Manfredini (1997) and Gil & Droit-Volet, (2012). Table 2 shows the mean valence and arousal scores for each condition taken from the IAPS manual (Lang et al., 1997).

Table 1: IAPS image numbers

Negative	*Neutral*

3110	7010
3120	7050
9050	7060
9405	7150
9410	7175
9921	7031

Table 2. Valence and arousal means and standard deviations for image levels

Image type	*Valence M*	*Valence SD*	*Arousal M*	*Arousal SD*
Negative	*1.69*	*0.27*	*6.76*	*0.47*
Neutral	*4.75*	*0.18*	*2.22*	*0.47*

Procedure: The basic experimental procedure was as follows; cardiac monitors were attached to the participant. Participants then completed a three minute baseline cardiac recording task in which participants listened to the Wonderful Wizard of Oz and physiological recordings were taken throughout. Participants then completed four time estimation tasks: 1) normal breathing neutral images, 2) normal breathing negative images, 3) paced breathing neutral images, 4) paced breathing negative images. Normal breathing tasks were always completed before paced breathing tasks. The order of the negative and neutral tasks was randomised across participants. Participants were offered the opportunity to take breaks between each condition if desired.

In the normal breathing tasks, participants listened to a six minute audio book (The Jungle Book or Alice in Wonderland) prior to each time estimation task. In the paced breathing tasks, before each time estimation task, participants were presented with a six minute video of a circle expanding and contracting at a rate 0.10Hz. Participants were instructed to inhale during circle expansion and exhale during circle contraction. This type of exercise has previously been shown to be effective in selectively increasing PSNS activity (Bernardi et al., 1989 and Bernardi et al., 2001) reflecting an uncoupled mode of autonomic control in which SNS and PSNS do not covary (Berntson et al., 1991). Participants were then instructed to maintain this breathing rate during the subsequent time estimation task.

Following the paced/normal breathing exercise participants completed 21 time estimation trials. At the start of the time estimation task participants were instructed that they would see a series of images on the screen and that their task was to estimate, in milliseconds, how long each image was presented. At the beginning of each trial participants were prompted to press the space bar to begin, followed by a inter stimulus interval (ISI) of either 1000 or 1500ms, selected randomly by the experimental program. An image was then presented for a duration of either 200, 300, 400, 500, 600, 700, or 800ms, followed by a 500ms ISI. Participants were then instructed to type their estimate of how long the image was presented on the screen for. They were informed their estimation could be anywhere between 50 and 1000ms and participant were reminded that 1000ms was equal to one second. In the neutral tasks, all images were neutrally valenced images taken from the IAPS. In the high arousal negative tasks all images were high arousal negatively valenced images from the IAPS. Following the first 21 trials, there was a two minute break. In the paced breathing conditions participants were re-presented with the video of the expanding and contracting circle and instructed to maintain this breathing rate during this break and the subsequent time estimation task. In the normal breathing conditions participants listened to a further two minutes of the audio book. Participants then completed a further 21 trials of the time estimation task. There were therefore a total of 42 trials in each of the four tasks. Trial order was randomised for each participant. No performance feedback was given. Each time estimation task took approximately seven minutes. Physiological recordings were taken throughout.

Physiological measures: R-peaks, characteristic graphical deflections that reflect depolarization on the right and left heart ventricles and that are associated with the contraction of the heart, were detected in the ECG signal using a modified Pan-Tomkins peak detection algorithm. The ICG signal was differentiated and the resulting dZ/dt signal was filtered with a low-pass Butterworth filter with a corner frequency of 50 Hz. The filtered dZ/dt signal and the detected r-peaks were used to create dZ/dt ensemble averages over intervals of 1 minute (Kelsey & Guethlein, 1990). PEP was scored as interval between R-onset and the B-point using the guidelines of the Society for Psychophysiological Research (Sherwood, Allen, Fahrenberg, Kelsey, Lovallo, & van Doornen, 1990). Drawing on the detected r-peaks, inter-beat-intervals (IBIs) were extracted and used—after deleting ectopic beats (Lippman, Stein, & Lerman, 1994), removing slow trends using smoothness priors and resampling at 4 Hz to compute heart rate variability using Fast Fourier Transform (window length was 256 samples; window overlap 50%). In particular, the 10-Hz frequency band centred around the individual participant's respiration frequency, which was determined as peak-frequency in the frequency range from 0.04 Hz to 0.40 Hz of an FFT power spectrum of the ICG Z signal (de Geus, Willemsen, Klavier, & van Doornen, 1995; Ernst, Litvack, Lozano, Cacioppo, & Berntson, 1999) was used as our estimate of respiratory sinus arrhythmia. These calculations were conducted on the baseline data and the data from the four time estimation tasks. Change in HF-HRV and PEP from the baseline recording to the four time estimation tasks were calculated to provide change scores of PSNS and SNS activity in the four tasks.

Results

Data from one participant was excluded because they produced the same estimate for all stimuli in one condition. We therefore report data from 29 participants.

Table 3: Mean baseline corrected HF-HRV and PEP as a function of condition

Condition	*Valence*	*Mean HF-HRV*	*SD HF-HRV*	*Mean PEP*	*SD PEP*
Normal Breathing	*Neutral*	-0.01	0.26	0.23	5.05
	Negative	-0.04	0.25	0.20	4.20
Paced breathing	*Neutral*	0.24	0.46	0.61	5.07
	Negative	0.20	0.49	1.32	5.48

HF-HRV: To assess the effect of stimulus valence (neutral or negative) and breathing instruction (paced vs normal) on PSNS activity a repeated measures ANOVA was conducted on mean baseline corrected HF-HRV for each condition. It showed a significant effect of breathing instruction $F(1, 28) = 5.68$, $p = .02$, $\eta_p^2 = .17$ suggesting an increase in PSNS activity in the paced breathing condition relative to normal breathing condition. There was no significant effect of stimulus valence $F(1, 28) = 1.52$, $p = .23$, $\eta_p^2 = .05$ and no significant interaction between stimulus valence and breathing instruction $F(1, 28) = .03$, $p = .86$ $\eta_p^2 = .001$.

PEP: To assess the effect of stimulus valence (neutral or negative) and breathing instruction (paced vs normal) on baseline corrected SNS activity a repeated measures ANOVA was conducted on PEP values. It showed no significant effects of breathing instruction $F(1, 28) =$

.50, $p = .49$, $\eta_p^2 = .02$ or stimulus valence $F(1, 28) = .84$, $p = .37$, $\eta_p^2 = .03$. There was also no significant interaction between stimulus valence and breathing instruction $F(1, 28) = .85$, $p = .37$, $\eta_p^2 = .03$.

Time estimates:

Figure 1: Mean time estimates plotted against the standard duration for the normal and paced breathing conditions and negative and neutral stimuli.

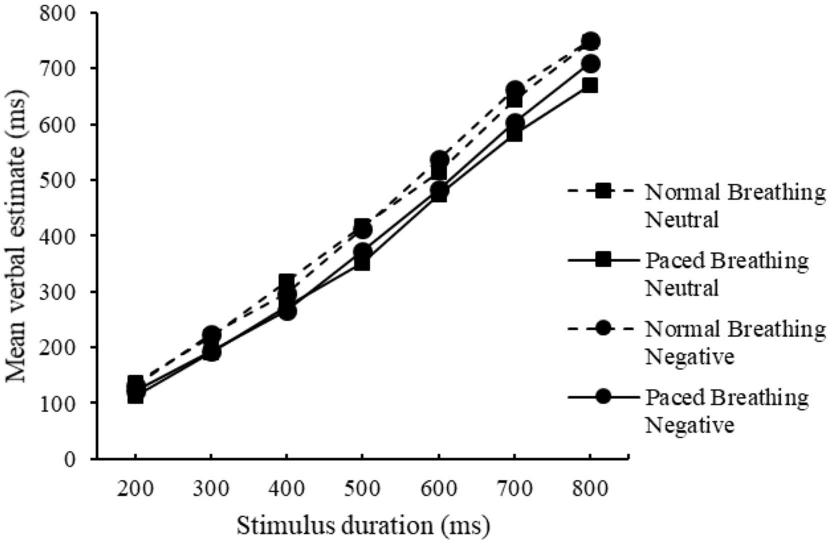


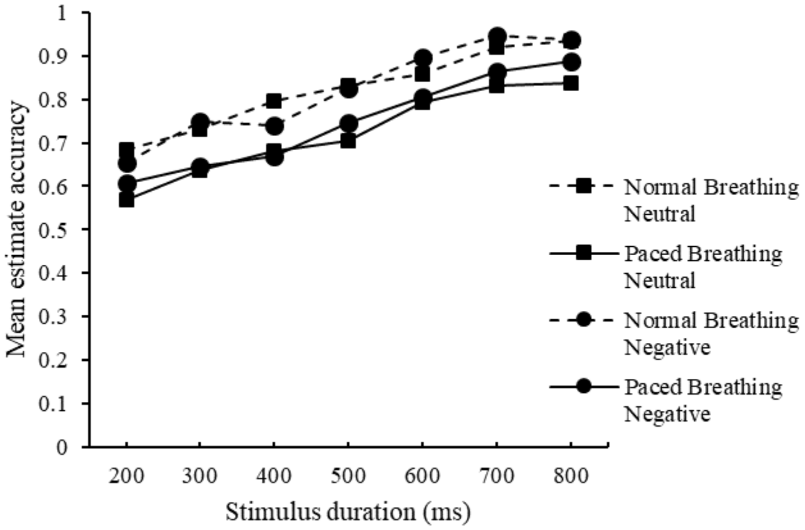
Figure 1 shows mean time estimates plotted against the standard duration. Examination of Figure 1 suggests that for both neutral and negatively valenced stimuli, estimates were shorter following paced breathing than following normal breathing. This was confirmed by statistical analysis.

A repeated measures ANOVA with within subjects factors of breathing instruction (normal vs control), stimulus valence (neutral vs negative), and stimulus duration (200, 300, 400, 500, 600, 700 and 800ms) showed significant effects of breathing instruction $F(1, 28) = 11.63$, $p = .002$, $\eta_p^2 = .29$ and stimulus duration $F(6, 168) = 404.73$, $p < .001$, $\eta_p^2 = .94$. Estimates were significantly shorter in the paced breathing conditions than the normal breathing condition. There was no significant effect of valence $F(1, 28) = .91$, $p = .35$, $\eta_p^2 = .03$ and no significant interaction between breathing condition and valence $F(1, 28) = .51$, $p = .48$, $\eta_p^2 = .02$, valence and duration $F(6, 168) = .94$, $p = .44$, $\eta_p^2 = .03$, breathing instruction and duration $F(6, 168) = 1.67$, $p = .13$, $\eta_p^2 = .06$ or breathing instruction, valence and duration $F(6, 168) = .48$, $p = .83$, $\eta_p^2 = .02$.

To establish the relationship between ANS reactivity and time perception the following scored were calculated: ‘Change in HF-HRV’ was calculated by deducting average baseline corrected HF-HRV scores for paced breathing from average baseline HF-HRV scores for normal breathing. ‘Change in time estimates’ was calculated by deducting the average mean time estimates for paced breathing from the average mean time estimates for normal breathing. ‘Change in PEP’ was calculated by deducting average baseline corrected PEP scores for paced breathing from average baseline PEP scores for normal breathing. Data was collapsed across the negative and neutral valence conditions for this analysis. There was no significant relationship between HF-HRV change and estimate change $r(28) = -.13$, $p = .49$. There was also no significant relationship between PEP and estimate change $r(28) = -.17$, $p = .37$.

Time estimate accuracy

Figure 2: Estimate accuracy plotted against stimulus duration for the normal and paced breathing conditions and negative and neutral stimuli.



The accuracy of estimates was calculated for each duration in each condition by dividing the estimate by the stimulus presentation duration. Using this method, an accuracy score of 1 indicated veridical timing, a score of below 1 indicates underestimation of duration and a score of above one indicates and overestimation of duration. Figure 2 shows mean accuracy as a function of breathing instruction and stimulus valence. Examination of Figure 2 suggests that accuracy was greater in the normal breathing conditions than the paced breathing conditions. This suggestion was confirmed by statistical analysis.

A repeated measures ANOVA with within subjects factors of breathing instruction (normal vs control), stimulus valence (neutral vs negative), and stimulus duration (200, 300, 400, 500, 600, 700 and 800ms) showed significant effects of breathing instruction $F(1, 28) = 10.22$, $p = .003$, $\eta_p^2 = .27$ and stimulus duration $F(6, 168) = 14.70$, $p < .001$, $\eta_p^2 = .34$. Estimates were significantly shorter in the paced breathing conditions than the normal breathing condition. There was no significant effect of valence $F(1, 28) = .43$, $p = .51$, $\eta_p^2 = .02$ and no significant interactions between breathing condition and valence $F(1, 28) = .61$, $p = .44$, $\eta_p^2 = .02$, valence and duration $F(6, 168) = .76$, $p = .61$, $\eta_p^2 = .03$, breathing instruction and duration $F(6, 168) = .18$, $p = .98$, $\eta_p^2 = .006$ or breathing instruction, valence and duration $F(6, 168) = .55$, $p = .77$, $\eta_p^2 = .02$.

The relationship between change in estimate accuracy from normal to paced breathing and change in PSNS and SNS was tested. There was no significant relationship between HF-HRV change and estimate change $r(28) = -.05$, $p = .80$. There was also no significant relationship between PEP and estimate change $r(28) = .21$, $p = .27$.

Discussion

This study tested whether a paced respiration exercise known to increase PSNS activity (Bernardi et al., 1989; Bernardi, Porta, Gabutti, Spicuzza & Sleight, 2001; Sakakibara et al., 1994; Tsai et al., 2015; Wu & Lo, 2008) would reduce the perceived duration of negative and neutral events. The results showed that PSNS activity was significantly greater in the paced breathing condition than in the normal breathing condition. This replicates previous findings that a respiration rate of six breaths per minute is effective in increasing PSNS activity (Bernardi et al., 1989; Bernadi et al., 2001 Sakakibara et al., 1994; Tsai et al., 2015; Wu & Lo, 2008). SNS activity was unaffected by the breathing manipulation. Estimates for both the negative and the neutral stimuli were significantly shorter following paced respiration than normal respiration. This supports the hypothesis that increasing PSNS activity would shorten the perceived duration of events. Furthermore, the findings confirm Craig's (2009) suggestions that paced respiration would be an effective way to reduce the perceived duration of events. Interestingly estimates were also less accurate, due to greater underestimation, following paced than normal breathing suggesting that increasing PSNS activity has a negative effect on timing acuity.

The finding that increasing PSNS activity is associated with a reduction in perceived time is consistent with the predictions of models of time perception such as SET (Gibbon et al., 1984), SBF (Matell & Meck, 2004) and Craig's (2009) homeostatic model of timing. These models suggest that changes in physiological arousal affect the way in which duration is processed through changes in pacemaker rate (see Gil & Droit-Volet, 2012; Penton-Voak, et al., 1996 for discussion), neural oscillation rate (see Cheng et al., 2016 for discussion) or AIC activity (Craig, 2009). As a result of these changes, increases in SNS activity are believed to be associated with a lengthening of perceived duration whereas decreases in arousal and increases is PSNS activity are associated with a relative shortening of perceived duration. Our findings are therefore consistent with the suggestion that a reduction in arousal, characterised by an increase in PSNS activity, can reduce the perceived duration of sub-second events.

The findings may also be compatible with more recently developed channel-based models of duration perception (see Heron et al., 2012 for discussion). In a channel-based system of duration processing, duration is processed by neural channels which respond selectively and specifically to a small range of stimulus durations. The idea of channel-based duration processing is based on similar finding from vision and audition, for example, the existence of selectively responding neural channels for particular orientations of stimuli or pitches of tones. The basic principles of a channel-based system of duration processing are supported by evidence of neurons which selectively respond to specific durations (Hayashi et al., 2015) and recent evidence of sensory adaptation of duration which elicited both lengthening and shortenings of subjective duration (see Heron et al., 2012 for examples although also see Curran, Benton, Harris, Hibbard & Beattie, 2016). However, it is also acknowledged that perceived duration is likely to be dependent on a wide range of cognitive factors in addition to channel activation (Maarseveen, Paffen, Verstraten & Hogenboom 2019, van Wassenhove, 2009).

Heron et al., (2012) suggest that channel-based models can explain some non-emotional distortions to time, e.g. the subjective lengthening of perceived duration which occurs following repetitive pre-stimulation (see Penton-Voak et al., 1996 for discussion of this effect). However, to our knowledge, channel-based models of time perception have not been applied to emotional distortions of time. One way in which subjective lengthenings, and particularly shortenings of duration, can be explained in a channel-based model is by changes in the onset and offset latency within which channels are activated and deactivated at stimulus onset and offset (see Heron et al., 2011 and Maarseveen, Paffen, Verstraten & Hogendoom 2019). To accommodate the effects of increases in SNS and PSNS activity reported in this and other papers we therefore *speculate* that one way in which changes in physiological arousal may influence a channel-based model of time perception is by increasing and decreasing the onset and offset latency of channel activation. Alternatively, it is possible that increased PSNS activity supresses the responding of duration coding neurons, leading to shorter perceptions of duration (see Curran et al., 2016 for discussion). However, we also acknowledge that arousal may affect the subsequent stages in a channel-duration processing model. As these suggestions are purely speculative, we encourage future research to test the effects of changes in physiological arousal on the predictions of a channel-based model of duration processing.

In the current study, although the paced breathing manipulation increased PSNS activity, consistent with an increase in relaxation, SNS activity was unaffected by the breathing manipulation. This replicates previous findings showing that that paced respiration can increase PSNS activity in the absence of a change in SNS activity, supporting suggestions that reduced respiration rate has a direct effect on the PSNS (e.g. Sakakibara et al., 1994; Tsai et al., 2015; Wu & Lo, 2008). One might wonder whether the absence of effects on SNS might be due to our SNS measure not being sensitive enough and whether another indicator of SNS activity might have found an effect of the breathing manipulation. However, we consider this to be unlikely. First, some of the most frequently used non-invasive measures of SNS activity like changes in pupil diameter or skin conductance level do not depend on the sympathetic outflow to the heart and are thus necessarily less valid indicators of myocardial SNS activity than PEP. Second, measures like T-wave amplitude (Furedy & Heslegrave, 1983) or high-frequency heart rate variability (Lombardi et al., 1987), which were promoted as indicators of myocardial SNS activity some years ago, are no longer considered to be indicators of myocardial SNS activity that are as specific as PEP (Berntson et al., 1997; van Lien et al., 2015). The current study's results therefore demonstrate that temporal distortions can occur in the absence of a change in SNS activity, suggesting that changes in PSNS activity may have the capacity to affect time perception independently of changes in SNS activity. Furthermore, the subjective shortening of duration observed in this study following the paced breathing exercise suggests that a reduction in SNS is not necessarily itself required for a reduction in perceived duration. Instead, activities which act solely by increasing PSNS activity appear effective in shortening perceived time.

Studies in which SNS activity is manipulated consistently show that the SNS activity evoked by a manipulation is directly related to the extent to which the manipulation distorts duration, with larger changes in SNS activity being associated with larger distortions to time (e.g. van Hedger et al., 2017; Ogden et al., 2019; Piovesan et al., 2018). This has been taken as evidence that SNS activity has a direct effect on time perception. In the current study however, although the behavioural manipulation of PSNS activity shortened the perceived duration of events, the change in PSNS activity as a result of the manipulation was not directly related to changes in duration perception. This raises the possibility that PSNS activity is not itself directly related to distortions to time, but instead mediates our experience of time via other mechanisms. For example, it is possible that changes in attention and working memory function due to increased vagal tone (see Hansen, Johnsen & Thayer, 2003 for of the effect of PSNS activity on cognition) act as a mechanism for the PSNS to affect time perception because perceived time is influenced by these general cognitive resources (Matthews & Meck, 2016). However, it is also possible that the correlational analysis performed in this study failed to reach significance because of a lack of power.

A further explanation for the absence of a direct relationship between PSNS activity and temporal distortions is that it was the breathing exercise itself, rather than its associated change in PSNS activity which affects duration processing. However, previous research examining the effects of altered breathing rate on perceived duration does not show consistent shortening effects. For example, Schaefer & Gilliand (1938) observed no clear relationship between breath rate and perceived duration. Conversely, Schwartz, Winkler and Sedlmeier (2013) observed increases in perceived duration when participants were instructed to hold their breath for as long as possible whilst completing temporal tasks. Although, in Schwartz et al., (2013), breath holding reduced heartrate, it also increased arousal and was therefore perhaps unlikely in itself to affect time perception. It would therefore seem that breathing manipulations themselves do not consistently reduce the perceived duration of events. This suggests that, in the current study, the change in PSNS activity, rather than the change in breathing rate, was critical to the shortening of perceived duration observed. The selection of breathing techniques known to specifically increase PSNS activity, rather than altering heart-rate per-se, is therefore critical for reducing the perceived duration of events.

Evidence that increased PSNS is associated with a shortening of perceived time suggests that changes in PSNS activity may be the mechanism by which relaxation shortens perceived duration. Relaxation training (Droit-Volet, Fanget & Dambrun, 2015), some specific variants of mindfulness meditation (see Droit-Volet et al., 2018 for discussion) and pleasant touch (Ogden, Moore, Redfern & McGlone, 2015) have been shown to shorten the perceived duration of events. Relaxation training, such as that delivered by Droit-Volet et al., (2015) increases PSNS activity (Sakaibara et al., 1994). Similarly, CT afferent activating pleasant touch, such as that delivered in Ogden et al., (2015), has been suggested to increase relaxation and PSNS activity (Pawling, Cannnon, McGlone & Walker, 2017). It is therefore possible that the increase in PSNS activity brought about by these activities contributed to the shortenings of perceived duration observed. Future research should test the effect of changes in PSNS activity on time perception during these types of relaxation activities.

Whilst the current study offers initial evidence that direct manipulations of PSNS activity have the capacity to shorten the perceived duration of events, this conclusion is limited to timing in the sub-second range. Sub and supra-second timing are thought to depend on different neural networks (Lewis & Miall, 2003a) with the timing of longer durations (i.e multiple seconds) being more dependent on attention and working memory resources than that of short (sub-second) durations (Lewis & Miall, 2003b). Because of these differences, it is possible that changes in PSNS activity may have different effects on the timing of longer and shorter events. Future research should therefore aim to clarify the role of the autonomic nervous system in emotional distortions to time across a range of durations and in real world scenarios.

It is noteworthy that, in the current study, we did not observe longer estimates for the high arousal negative stimuli than the neutral stimuli. This was unexpected given consistent previous demonstration that negative stimuli are perceived as longer than neutral stimuli of the same duration (see Droit-Volet & Meck, 2009, Lake 2016 for review and discussion). One possible explanation for this null result is that the block based design of the current tasks, in which neutral and high arousal negative were presented in different tasks, removed the contrast between stimuli on a trial by trial basis required to elicit the lengthening's observed in previous studies. This argument was used by Piovesan et al., (2018) to explain the absence of a lengthening effect of pain on time estimates in experiment 2 of their paper and is based on Matthews, Stewart & Wearden's (2011) demonstration that contrast, rather than absolute stimulus intensity, is determinant of perceived duration. This suggestion was recently supported by Grommet, Hemmes & Brown (2019) who directly manipulated whether emotional contrast was present or absent within tasks. Emotional distortions to time were only observed when neutral and emotional stimuli occurred within the same task. In tasks in which emotional and neutral stimuli were presented separately no emotional distortions were observed. The findings of this experiment therefore add to the growing body of evidence that trial-by-trial variations in contrast appear necessary for emotional distortions to time to occur.

Limitations

In the current study, the normal breathing conditions were always performed before the paced breathing conditions. This was order was used to ensure that there were no carryover effects of PSNS change as a result of paced breathing from one condition to another and to ensure that breathing during the normal breathing condition was not altered by an increased attention to breath as a result of the paced breathing instruction. The lack of counterbalancing of the paced and normal breathing conditions prevents the conclusion that the paced breathing exercise itself caused the effects observed. We therefore acknowledge that it is possible that an increase in relaxation across the experiment, perhaps due to increased familiarity, may have contributed to the increase in PSNS activity observed.

When selecting the IAPS images for use as stimuli, we did not control for differences in image luminance, complexity or spatial frequency. This is not uncommon, other studies examining emotional distortions to time using the IAPS as stimuli have not controlled for these factors (e.g. Gil & Droit-Volet, 2012; Ogden et al., 2019, van Hedger et al., 2017). It is therefore possible that differences in the physical properties of the stimulus in the high arousal negative and neutral conditions contribute to distortions to time. However, it should be noted that the consistent observation of emotional distortions to time when using facial stimuli (e.g. Droit-Volet, 2004) and somatosensory stimulation (e.g. Fayolle et al., 2015; Piovesan et al., 2018), which ensure a high degree of similarity in spatial configuration, luminance and content across conditions, suggests that differences in these properties are not the primary driver of emotional distortions to time.

Conclusion

The findings of this study show that a paced respiration rate which induces an increase in PSNS activity is effective in reducing the perceived duration of negative and neutrally valenced stimuli. This shortening occurs in the absence of a reduction in SNS activity suggesting that activities or interventions, which influence PSNS activity, may offer a mechanism by which people can subjectively shorten the duration of very short unpleasant events that they experience. Future research should now aim to establish the extent to which these shortening effects can be replicated with longer duration ranges in more ecologically valid paradigms.

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