Individual differences in sensory integration predict differences in time perception and individual levels of schizotypy

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Abstract

To interact functionally with our environment, our perception must locate events in time, including discerning whether sensory events are simultaneous. The Temporal Binding Window (TBW; the time window within which two stimuli tend to be integrated into one event) has been shown to relate to individual differences in perception, including schizotypy, but the relationship with subjective estimates of duration is unclear. We compare individual TBWs with individual differences in the filled duration illusion, exploiting differences in perception between empty and filled durations (the latter typically being perceived as longer). Schizotypy has been related to both these measures and is included to explore a potential link between these tasks and enduring perceptual differences. Results suggest that individuals with a narrower TBW make longer estimates for empty durations and demonstrate less variability in both conditions. Exploratory analysis of schizotypy data suggests a relationship with the TBW but is inconclusive regarding time perception.

Keywords:

- audiovisual integration
- temporal processing
- filled duration illusion
- schizotypy
- time perception
- verbal estimation
- simultaneity judgments

1. Introduction

Substantial research has shown that individual differences in how we process events in time relates to differences in subjective perception, both momentary (e.g. Cecere, Rees, & Romei, 2015; Costantini et al., 2016; Samaha & Postle, 2015; Stevenson, Zemtsov, & Wallace, 2012) and long term (e.g. Ferri et al., 2017; Foucher, Lacambre, Pham, Giersch, & Elliott, 2007; Meissner & Wittmann, 2011; Scarpina et al., 2016). However, there have been relatively few studies examining whether, and how, temporal processing relates to explicit judgements of duration. In this research, we aim to examine how the natural variances between individual perceptual systems combine with systematic differences in stimuli in producing subjective time estimates.

It is well established that both the nature of the task and the characteristics of the stimuli, such as duration, complexity and intensity, influence experimental timing judgements (Block & Zakay, 1997; Matthews, Stewart, & Wearden, 2011; Zakay & Block, 1997). There is also evidence of significant differences in timing related to particular groups and characteristics. Older people tend to make shorter time estimations (Carrasco, Bernal, & Redolat, 2001) and children tend to have more variable timing than adults (Block, Zakay, & Hancock, 1999; Droit-Volet, 2013) although this is difficult to separate from attention and working memory processes (Droit-Volet, 2013), which have also been shown to influence timing (Ogden, MacKenzie-Phelan, Mongtomery, Fisk, & Wearden, 2019; Ogden, Samuels, Simmons, Wearden, & Montgomery, 2017; Ogden, Wearden, & Montgomery, 2014). Some studies have also found a gender difference but this appears to be minor and task dependent (Block, Hancock, & Zakay, 2000; Espinosa-Fernández, Miró, Cano, & Buela-Casal, 2003).

With regards to clinical conditions, impaired timing performance has been found in individuals with Parkinson's disease (Allman and Meck, 2011) although some evidence suggests such differences are small and task dependent, and may be exaggerated when a motor component is involved (Wearden et al., 2008). Further differences in timing have been found in relation to other conditions including autism (M. Allman & Falter, 2015; Falter, Noreika, Wearden, & Bailey, 2012) and schizophrenia (Lee, Dixon, Spence, & Woodruff, 2006). Traits of schizophrenia can be measured within the general population (schizotypy). Reed and Randell (2014), utilising the O-LIFE schizotypy scale (Mason, Linney, & Claridge, 2005), found that people scoring highly on the Unusual Experiences subscale, which relates to the positive aspects of schizotypy (characterised by perceptual aberrations, magical thinking, and hallucinations) seemed to judge less time had passed, relative to low scorers on that scale. Research has also linked interoception (sensitivity to internal signals from the body) to timing (Meissner & Wittmann, 2011), showing that individual variation in other types of perception can influence subjective timing. Craig's (2009) model associates timing with the processing of interoception in the insula cortex, however there is also evidence that some aspects of timing are embedded within other sensory systems (Bueti, Bahrami, & Walsh, 2008; Gamache & Grondin, 2010).

The aim of the current study is to test the possibility that our judgments of duration are also influenced by the rate at which we sample the world through our senses. The Temporal Binding Window (TBW) refers to the range of stimulus offset asynchronies within which discrete sensory events are in some way integrated with the effect of altering responses (Stevenson & Wallace, 2013), most simply a bleep and a flash occurring within the temporal window are more likely to be seen as simultaneous. A wider temporal binding window has been associated with differences in subjective perception over a number of timescales. Considering very short-term (e.g. ~100ms) differences, there is evidence that individual occipital alpha peak frequencies in the Electroencephalogram (EEG) relate to the timing of visual (Samaha & Postle, 2015) and audio-visual (Cecere et al., 2015) integration, suggesting that the intrinsic timing of individual sensory systems may lead to differences in subjective perception. In a less transitory example, the window within which individuals classify two stimuli from different sensory modalities (in this case tactile and auditory) as occurring synchronously, positively relates to the degree to which they are susceptible to the rubber hand illusion (Costantini et al., 2016).

Considering enduring differences, the TBW also relates to some neurodevelopmental conditions that include perceptual differences, such as autism spectrum disorders (Baum, Stevenson, & Wallace, 2015; Foss-Feig et al., 2010; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011), dyslexia (Hairston, Burdette, Flowers, Wood, & Wallace, 2005; Wallace & Stevenson, 2014) and schizophrenia (Foucher et al., 2007; Giersch et al., 2008; Thakkar, Nichols, McIntosh, & Park, 2011). In the case of schizophrenia, temporal integration has also been found to relate to measures of schizotypy in the general population (Ferri et al., 2017; Ferri, Venskus, Fotia, Cooke, & Romei, 2018). Temporal binding also appears to vary over development, with infants having a wider window than adults (Lewkowicz, 1996) and differences persisting into adolescence (Hillock-Dunn & Wallace, 2012; Hillock, Powers, & Wallace, 2011). Collectively, these findings suggest that individual differences in temporal integration relate to a number of differences in wider perception that persist over time.

Based on the above, we use the temporal binding window as a measure of individual differences in integration that, in relating to a variety of other conditions and measures, appears to be indicative of wider and more enduring differences in perceptual experience. As there is reason to think of human perception as being derived from a stream of discrete, temporally bounded, sensory samples (VanRullen & Koch, 2003) then differences in the TBW may be indicative of individual differences in the fundamental timing of perception.

This investigation uses a variation on the Simultaneity Judgement (SJ) task (Zampini, Guest, Shore, & Spence, 2005) to provide an estimate of the TBW. Typically this task presents a brief visual stimulus with an auditory beep at a range of offsets; it can then be estimated, via fitting two sigmoid functions, at what point the individual perceives simultaneity and at what point the visual and auditory stimuli are no longer perceived as simultaneous the majority of the time. However asymmetries in data from this task are common and evidence has suggested that the two sides of the curve (by convention the right side is visual leading and the left auditory leading) differ in both behavioural and neural terms (Cecere, Gross, & Thut, 2016; Cecere, Gross, Willis, & Thut, 2017) and that the right side specifically relates to other illusions (that are in themselves used to measure the TBW) such as the McGurk effect and flash-beep illusion (Stevenson et al., 2012). In this case we only measure the temporal binding window for the right (visual leading) side, allowing more trials and smaller differences between the offsets.

To compare the TBW to timing judgements this study uses a novel measure in exploiting the filled duration illusion as an indicator of individual differences. The filled duration illusion is a robust and well supported effect whereby intervals “filled” with stimuli (often sound) are routinely estimated as longer than those where only the beginning and the end of the target duration are signalled (Thomas & Brown, 1974; Wearden, Norton, Martin, & Montford-Bebb, 2007). Filled durations have also been found to be less variable than unfilled ones in some experiments (Rammsayer & Lima, 1991; Wearden et al., 2007). While filled intervals can be filled by a continuous tone (e.g. Wearden et al., 2007) the effect is also found when the interval is filled with a series of tones, or events in other modalities, and the size of the effect varies in accordance with the number and distribution of these (Buffardi, 1971; Foley, Michaluk, & Thomas, 2004; Horr & Di Luca, 2015; Schiffman & Bobko, 1977). It has also been found that applying a click train prior to the timed stimulus increases estimates in both conditions (Wearden et al., 2007). Plourde, Gamache, and Grondin (2008) found that the effect is still found even when they split the filled and unfilled durations over separate sessions, so there is no direct comparison. Notably some results seem to show that the effect is not reliable when the two conditions are split between groups (Droit-Volet, 2008; Robertson & Gomez, 1980). From this we might suggest that the effect is relatively stable within individuals but not necessarily between them, and so might be a good indicator of individual differences.

We propose to use the filled duration illusion as a novel measure of individual difference where a participant's timing score is based on the comparison of their estimate of the duration of a stimulus to their own timing of an empty duration of the same length. An additional advantage of this method is that it allows further analysis as to whether any relationship identified is driven by the empty duration, which might be more indicative of an individual's baseline timing (e.g. timing that is relatively uninfluenced by stimulus characteristics), or the filled duration which would suggest the relationship is more specific to how a stimulus is processed (given that typically this condition varies depending on the timed stimulus). Systematic individual differences in both conditions (rather than in the difference between them) would indicate a general difference in the underlying mechanism of timing between individuals.

As noted above, schizophrenia and schizotypy have been associated with altered temporal binding (Ferri et al., 2017; Foucher et al., 2007; Giersch et al., 2008; Thakkar et al., 2011). Altered timing (including perceived duration and variability), on temporal bisection tasks, has also been associated with schizophrenia (Lee et al., 2009) and schizotypy (Lee et al., 2006; Reed & Randell, 2014). In this case schizotypy was measured via the O-LIFE scale (Mason et al., 2005), as used by Reed and Randell (2014), as a way of potentially relating temporal processing to more enduring individual differences in perception in behaviour. In particular, and in line with the above findings, a relationship is expected with the Unusual Experiences subscale, which represents positive schizotypal traits including differences in perception. Measuring schizotypy also helps to begin to disassociate whether any relationship between the measures is direct or mediated by schizotypy.

The primary aim of this study is to test whether any relationship exists between integration and timing. As people with wider TBWs appear to be more susceptible to sensory illusions we posit the a-priori hypothesis that TBW width will relate positively to the size of the filled duration illusion. This corresponds with developmental studies where separate findings show that children have a wider TBW (Hillock-Dunn & Wallace, 2012; Wang, Datta, & Sussman, 2005) and a larger filled duration effect (Droit-Volet, 2008) compared to adults. If this is driven by changes in the filled slope, this suggests differences in how the stimulus is processed, while if driven by changes in the empty slope, this implies baseline differences associated with rate of integration. As several of the studies above have found individual differences also relate to variability in timing, and filled intervals have been found to be less variable, we will also seek a relationship between the TBW and variability in timing responses.

Secondarily we propose an exploratory analysis as schizotypy scores have been previously associated with both timing (Lee et al., 2006; Reed & Randell, 2014) and temporal integration (Ferri et al., 2017). It is hypothesised that schizotypy scores will relate to both of the primary measures (time estimations and simultaneity judgement) thus associating these measures with long term perceptual differences as well as transitory ones.

2. Methods

2.1 Participants

A statistical power analysis was performed, for sample size estimation, initially to find an appropriate sample size for our primary comparison between temporal binding and estimations. This was based on data from Rammsayer and Brandler (2007), which, while being a very different design of study, does include some correlations (N=100) between a measure of temporal integration (the temporal order judgement) and timing tasks (Duration Discrimination and Temporal Generalisation), which might therefore produce similar effect sizes to the hypothesised relationship. The strength of 5 relevant correlations varied between 0.30 and 0.47, so conservatively we set the effect size for the calculation to 0.35. With alpha = .05 and power = 0.80, the projected sample size needed with this effect size was calculated at N=49 using GPower 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009; Faul, Erdfelder, Lang, & Buchner, 2007). However, as we wished to include an exploratory analysis into relationships with schizotypy we doubled this to aim for approximately 100 participants.

102 participants were tested in groups (separate individual booths). All participants were paid volunteers. Two were removed prior to any analysis due to missing data (due to a technical issue and a non-completion). Of the remaining 100, 63 were female (1 unspecified), 92 were right-handed and the mean age was 23 years (SD=7.89).

2.2 Procedure

Participants performed all tasks in batches of up to 30 individuals. Each was in an individual booth within a larger room and wore sound cancelling headphones. They were instructed to sit upright, facing the screen. The experimental protocol was presented using psychophysics toolbox (Brainard & Vision, 1997; Kleiner et al., 2007; Pelli, 1997) in Matlab^{TM} 2014a (TheMathworks, Inc., Natick, MA, USA).

The experiment consisted of a timing task and the simultaneity judgement task, which were counterbalanced in terms of order and separated in each case by completion of the O-LIFE Schizotypy questionnaire (Mason et al., 2005), which also served as a buffer to minimise any effect of one task upon the other. For both the simultaneity and timing tasks, the order of stimuli was pseudo-randomised via a random permutation function seeded to the participant number. The procedure lasted approximately 40 minutes, depending on the individual.

2.3 Simultaneity judgement

Participants were presented with two-alternative, forced-choice simultaneity-judgment tasks where they were presented first with a fixation cross (8x8mm/30pixels) for 664ms (40 frames). The visual stimulus was a white ring (50 pixels/132mm diameter) circumscribing the fixation cross for 30ms and this was simultaneous with, or preceding, a tone of 3520 Hz for 30ms duration; the following Stimulus Onset Asynchronies (SOAs) were used: 25, 50, 75, 100, 125 , 150, 175, 200, 225, 250, 275, 300, 325, 350, 375, 400 (see figure 1). The options “simultaneous” and “non-simultaneous” (these terms having been clarified in on-screen instructions) were continually on the screen at the bottom left and right corners (the sides counter-balanced between blocks); participants selected one of these via the left and right ctrl keys (having been instructed to use one index finger for each). The next trial was initiated once a response was given. Regular breaks were incorporated into the task which consisted in total of 1 block of 1 set of 8 intervals (25,75,125,175,225,275,325,375) for training, followed 2 blocks each of 16 sets of 17 intervals; resulting in 32 repetitions at each level and 544 trials in total.

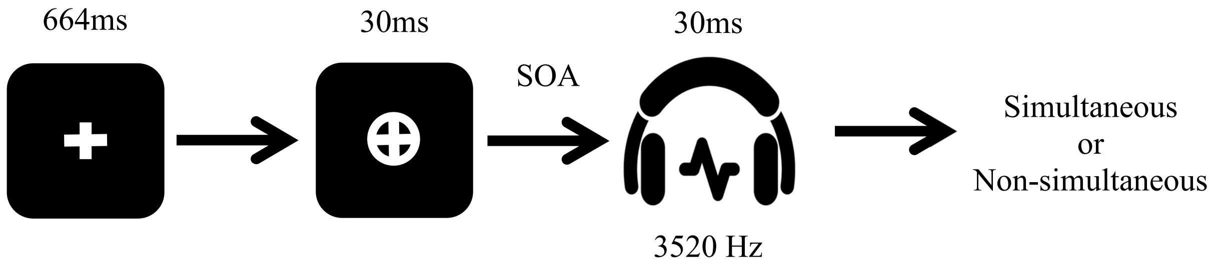

Figure 1: Schematic representation of the Simultaneity Judgement task. The following Stimulus Onset Asynchronies (SOAs) were used: 25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 375, 400ms

Each participant's simultaneity judgement responses were calculated as the percentage that were simultaneous. For each participant, these percentage scores were fitted with a psychometric Gaussian function (using cftool in Matlab) and the value for the window was taken as the point on the x axis corresponding to 50% simultaneity. Where participant's response curves were at a value greater than 50% simultaneity at 400ms their score was set at 400ms as a proxy. The R2 for each curve was recorded as an indicator of goodness of fit. For the initial analysis a strict inclusion criteria was applied (only those participants with an R^2 of above 0.6 who achieved less than 50% simultaneity by 400ms were included; 55 participants) however as this eliminated 45 of 100 participants, the analysis was repeated including all participants to verify the findings.

2.4 Filled duration illusion

Our implementation of the filled duration illusion was modelled after experiment 2 in Wearden et al. (2007). Two types of timing trial were used: "filled", a single (494hz) tone presented for the duration of the target interval, and "unfilled", two (1046.5Hz) tones of 10ms presented at the beginning and end of the target interval (see figure 2). The use of differing tones for the two conditions allows for clear and immediate differentiation between them. The 10 target intervals were (in ms) 77, 203, 348, 461, 582, 707, 834, 958, 1065 and 1181. Participants completed 5 blocks, each consisting of the 20 stimuli (10 filled and 10 unfilled) in random order for a total of 100 trials. Each trial was commenced by the participant pressing any button. The fixation cross was displayed for between 500 and 1500ms (delay pseudo-randomly generated) followed by the auditory stimulus, during which the fixation cross remained on the screen. Participants were then asked to estimate the duration of the tone, or the gap between tones, in milliseconds using the keyboard number pad. In instructions they were reminded of how milliseconds relate to seconds (0.5 seconds = 500ms, etc.) and at each response they were reminded that responses should be within 50-1500ms. Where responses were beyond this range they were discounted and the participant reminded of this range before the next trial.

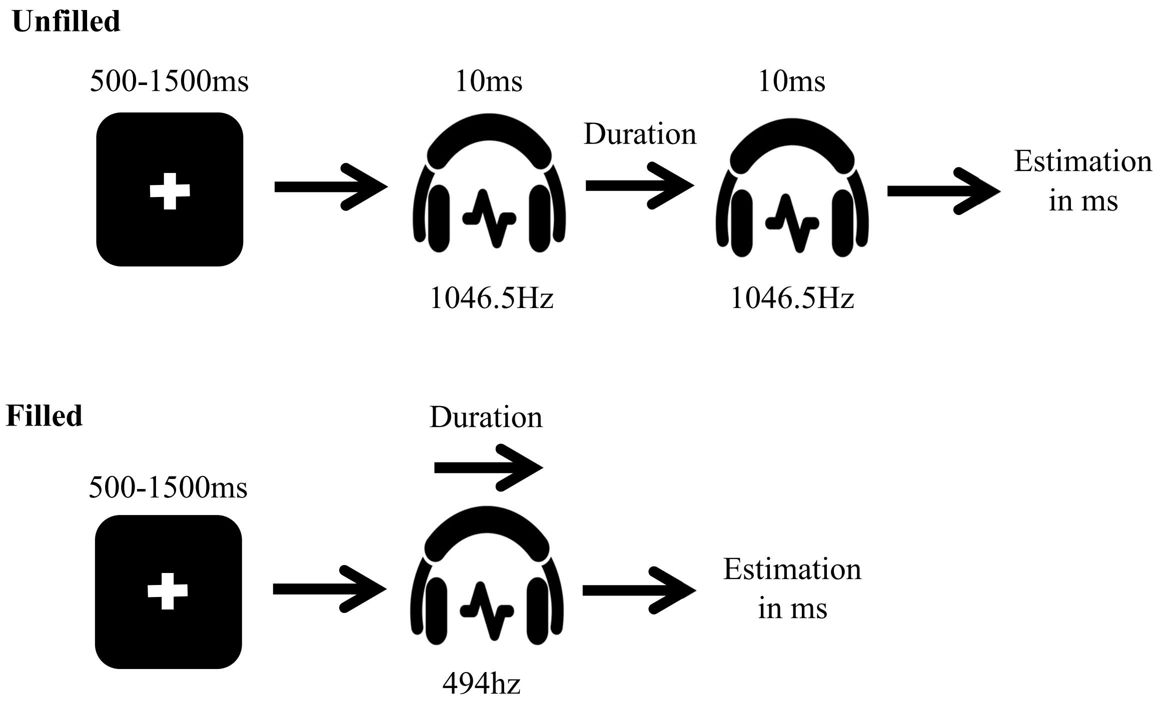

Figure 2: Schematic representation of the Filled Duration task. The following durations were used (in ms): 77, 203, 348, 461, 582, 707, 834, 958, 1065 and 1181

Participants' estimates were regressed against stimulus duration giving a slope and intercept value for filled and unfilled conditions for each participant. Theoretically the intercept relates to delays in the onset of timing, while changes in the slope indicate changes in the "pacemaker" or underlying substrate of timing (Gil & Droit-Volet, 2012) which is primarily of interest for our purposes. The differential of the two slopes is taken as a score representing the size of the filled duration illusion for that individual. Mean scores and the Coefficient of Variation (CoV; standard deviation of estimate / mean estimate), which essentially represents variation adjusted for individual timing performance, were also calculated for each condition and duration.

2.5 Oxford Liverpool Inventory of Feelings and Experiences

All participants completed the short O-LIFE schizotypy scale (Mason et al., 2005) which consists of 43 items. This scale measures schizotypal traits occurring in the general population and comprises of four subscales: Unusual Experiences, Cognitive Disorganization, Introvertive Anhedonia, and Impulsive Nonconformity. The scales have a concurrent validity of between 0.9 and 0.94 and internal reliability (Cronbach α) of 0.62 to 0.8, and a concurrent validity of between 0.9 and 0.94 (Mason et al, 2005). Questions were presented singly on screen and the participant responded with the Y or N key (Yes or No respectively) which automatically initiated the next question. O-LIFE scale scores were calculated in the standard manner for both the overall survey and the four subscales.

3. Results

3.1 Time estimation

An ANOVA was carried out on the time task data (all participants included). This showed a significant main effect of stimulus type, $F_{(1,99)} = 228.04$, $p < .001$, $\eta p^2 = .697$; and stimulus duration, $F_{(9,891)} = 479.21$, $p < .001$, $\eta p^2 = .829$; and a significant type x duration interaction, $F_{(9,891)} = 228.04$, $p < .001$, $\eta p^2 = .343$. The filled-duration illusion was observed as filled durations were longer than empty ones, this difference being greater for longer durations, with a significant differences in means (averaged across target durations), $t_{(99)} = -15.10$, $p < .001$, $d = 1.516$ (see figure 3).

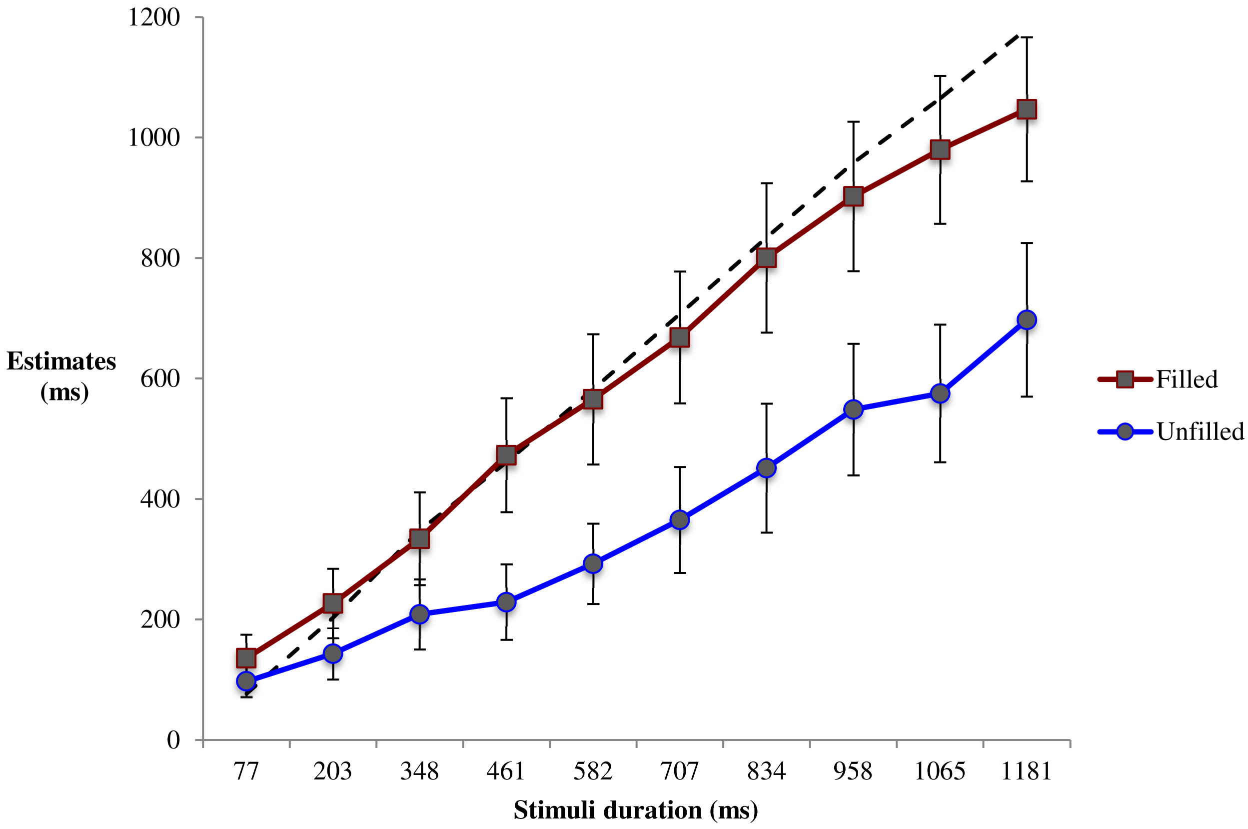

Figure 3; Mean estimates of duration for filled and unfilled intervals plotted against stimulus duration. Error bars show standard error of the mean. Dashed line shows a 1:1 relationship.

Slopes and intercepts were calculated for each participant for filled (M slope=.86, *SD*=.26, M intercept=62.29, *SD*=151.66) and unfilled (M slope=.54, SD=.32, M intercept=17.72, SD=127.88) intervals. Wilcoxon tests show that the filled condition slope is significantly steeper than the unfilled slope (Z=7.83, p<.001, r= *-0.554*) and the filled intercept is also higher (Z=2.60, p=.009, r=-0.183) though a less substantial effect. Simple examination of the slopes shows that the filled condition is closer to 1, 1 being a perfect relationship between increases in duration and increases in estimate, while the unfilled slope shows a general tendency to underestimate compared with real time. The size of the filled duration effect was estimated as the difference between the filled and unfilled slopes for each participant.

The CoV was collapsed across durations and compared between conditions, this showed that performance in the unfilled condition (M=52, SD=.18) was significantly more variable than that in the filled condition (M=.43, SD=.16); $t_{(99)}$=4.95, p < .001 d =0.495, although the effect is small.

3.2 The relationship between TBW and time estimates

In the first instance we applied conservative controls with regard to the SJ data, only including only participants who had a good fit (R^2 > 0.6) and that were not over 50% simultaneity at 400ms. As this resulted in excluding a high number of participants (45), the analysis was repeated without any exclusions to ensure the effect was not derived from creating a sunset of participants (this issue is addressed in the discussion and should be considered for subsequent research using the same task). Figure 4 shows the average judgements of simultaneity for the whole sample (n = 100), fitted with the gaussian function.

For an initial analysis the averaged timing data for each participant was used, including for filled and unfilled conditions. Assessing the relationship between these and the point of 50% simultaneity (POS) via Pearson correlation coefficient we find a significant relationship between the unfilled duration score and POS both where implementing the controls, r=-.49, n=55, p<.001 and including all participants r=-.43, n=100, p<.001. The same relationship was not significant for the filled duration; r=-.26, n=55, p=.058 and r=-.13 n=100, p=.186.

For a more in-depth version of this analysis we utilised the slopes fitted to the timing estimations (as above), which allows the separation of the slope and the intercept, with the latter theoretically relating to the delay in commencing timing. The relationship between the filled duration effect, as measured by slope difference, and the point of 50% simultaneity was also assessed via Pearson correlation coefficient; r=.36, n=55, p=.007 with controls and r=.36, n=100, p<.001 without (see figure 5). As the exclusion of so many participants was a concern the remaining analysis includes all cases but has also been performed implementing the conservative controls to ensure there is no substantial difference; in both cases the results are comparable (a single exception is flagged below). The window of integration appears to relate to the difference in the slopes between conditions as predicted, the positive nature of the relationship suggests that a larger window of integration relates to a greater difference between the slopes.

As a check this analysis was repeated using the difference between the intercepts of the slopes, which represent a difference in orientating to the stimuli; the non-significant result, r=-.16, n=100, p=.123 suggests that the relationship with the TBW is specific to the slopes.

To further analyse this result the individual slopes were correlated against the TBW. The TBW negatively correlated with the slopes for empty intervals, r=-.43, n=100, p<.001, while there is no significant relationship between the TBW and the slopes for full intervals, r=-.13, n=100, p=.201. This is of interest as it implies that the unfilled condition drives the difference between slopes, which may suggest the relationship is with an individual's baseline timing rather than in how stimuli are processed.

CoVs were also correlated against the TBW. Results showed a significant positive relationship both for the filled, r=.27, n=100, p=.007, and unfilled, r=.23, n=100, p=.020, conditions, suggesting that a wider TBW relates to more variable timing in both conditions.

3.3 Schizotypy

In our exploratory analysis the O-LIFE Schizotypy scores demonstrated a relationship to the TBW, r=.24, n=100, p=.015. In particular, the unusual experiences sub-scale was positively correlated with the TBW, r=.32, n=100, p=.001, while Cognitive disorganisation, r=.17, n=100, p=.097, Introvertive Anhedonia, r=.14, n=100, p=.15, and Impulsive Nonconformity, r=.00, n=100, p=.999, showed no substantial relationship. ~~In particular, the unusual experiences sub-scale related positively, *r*=.32, *n*=100, *p*=.001, while other scales did not show any evidence of a relationship (ps>.05).~~ The unusual experiences subscale relates to positive schizotypal traits including hallucinations and perceptual aberrations and so this result supports the relationship between the TBW and the perceptual aspects of schizotypy.

The difference between the timing slopes did not relate to the overall O-LIFE score, *r*=-.001, *n*=100, *p*=.989, but did negatively relate to the impulsive non-conformity sub-scale *r*=-.22, *n*=100, *p*=.030. There were no substantial relationships with other subscales: cognitive disorganisation, *r*=.01, *n*=100, *p*=.922; introvertive anhedonia, *r*=-.03, *n*=100, *p*=.790.; unusual experiences, *r*=.13, *n*=100, *p*=.195. -Further investigating the non-conformity~~The~~ subscale we find it does not correlate substantially with either timing slope but the stronger relationship is found in the case of empty durations, *r*=.18, *n*=100, *p*=.074 rather than filled ones *r*=-.02, *n*=100, *p*=.846. Impulsive non-conformity includes items relating to eccentric, anti-social or impulsive behaviour and implies a lack of self-control, so this result might imply high scoring individuals have a small tendency to overestimate empty durations out of a sense of boredom or impatience making the trials feel longer.

As some studies have found increased variation in timing behaviour related to schizophrenia, the CoV was correlated against O-LIFE scores. There was no relationship with the overall scores in either case (Unfilled; *r*=.04, *n*=100, *p*=.682, filled; *r*=-.02, *n*=100, *p*=.828) but there was something of a relationship between the unusual experiences subscale and the CoV in the filled condition, *r*=.21, *n*=100, *p*=.038, though this was not the case when the stricter selection criteria were applied (this being the only relationship where this was the case) and given the number of comparisons is unlikely be robust. In summary the exploratory analysis of the schizotypy data suggests that future research should continue to explore the relationship between temporal binding and schizotypy but this is unlikely to be a good avenue of exploration with regards to time estimations.

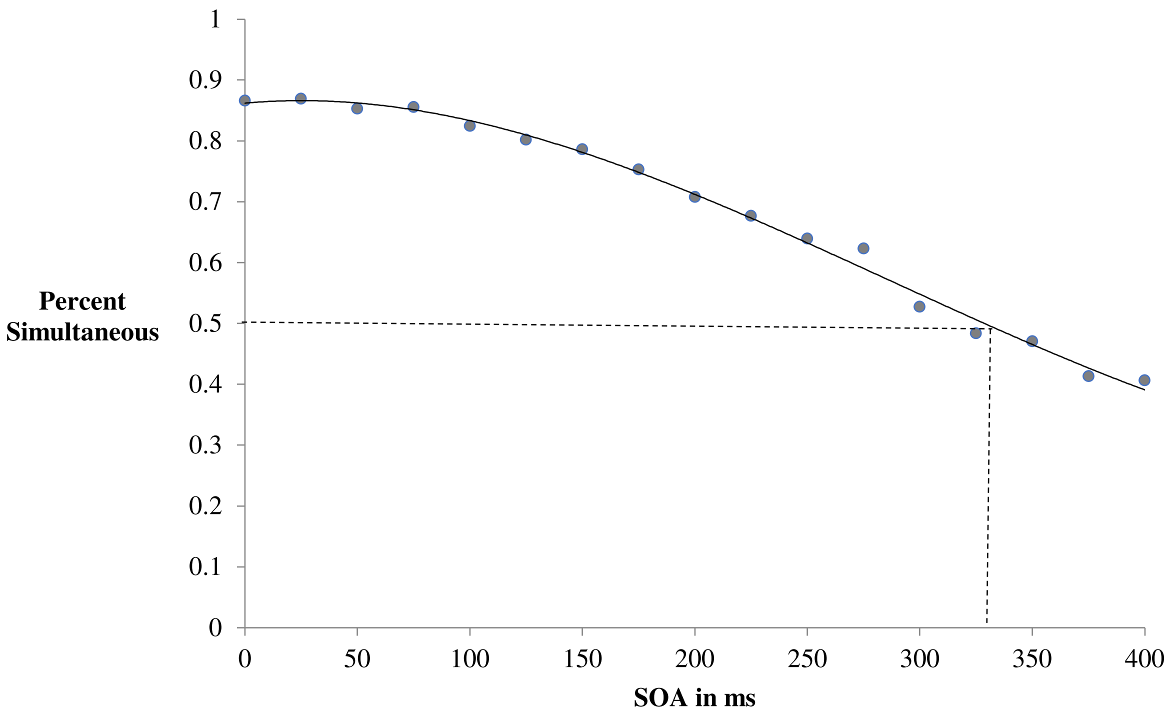

Figure 4: Averaged judgements of simultaneity (n=100) for each stimulus onset asynchrony. This is fitted with a Gaussian function. The dashed line represents 50% judged as simultaneous.

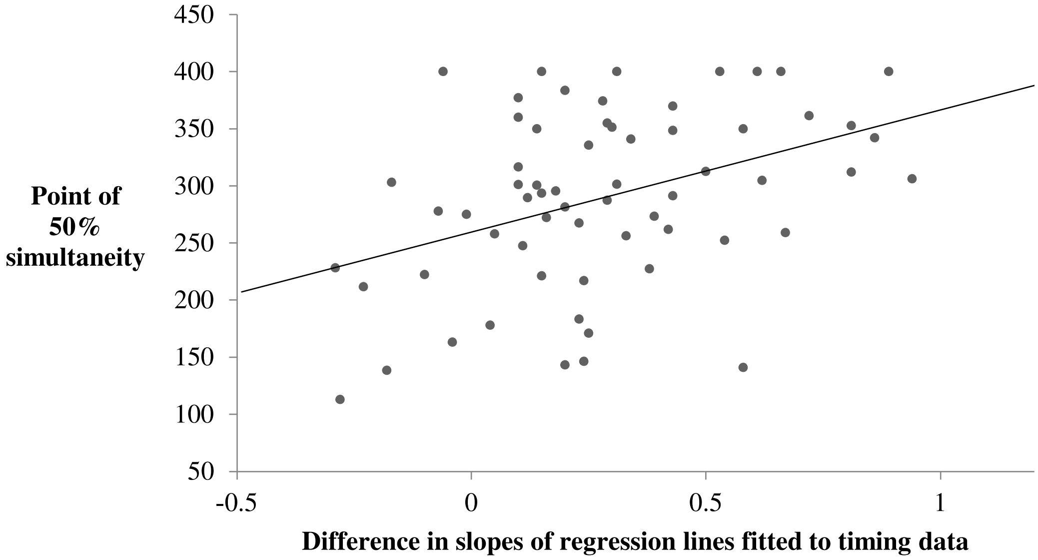

Figure 5: Scatter plot showing the relationship between the window of integration and the difference between slopes in the filled/unfilled timing task

4. Discussion

The intention of this study was to establish whether the individual rate of sensory integration relates to individual differences in the perception of time. In timing we replicate previous research that showed that filled durations are judged longer, and with more variation, than unfilled ones (Wearden et al., 2007). The finding that the point at which a person reports 50% simultaneity in the SJ (their window of integration) is predictive of the difference between the slopes of their reported timings for empty and full intervals supports the hypothesised relationship. In particular, the positive relationship suggests that the larger the window of integration, the greater the difference between filled and unfilled intervals. This finding is coherent with previous evidence that children have a larger filled-unfilled difference (Droit-Volet, 2008) and a wider TBW than adults (Hillock-Dunn & Wallace, 2012; Wang et al., 2005). Notably the TBW also relates significantly and positively, to individual variation in performance in both conditions, suggesting that people with a narrower window of integration may have more consistent timing behaviour.

To understand why the relationship between the filled duration illusion and the TBW is positive, we consider the filled and unfilled slopes individually and observe that the slope of the unfilled interval, and not the filled, correlates significantly, and negatively, with the TBW. This suggests that those making longer estimates in this condition have a smaller TBW. In other words, those with a faster sensory processing cycle estimate the empty duration as longer than those with slower cycles. This could be interpreted as more processing cycles occurring within the duration to be timed, resulting in the interval being perceived as longer, relative to someone with fewer cycles in the same duration. In terms of comparison with real time, the filled condition is relatively close to real time compared to the underestimation in the unfilled condition.

We might ask why the effect might be seen in only the empty condition rather than in both, as previous evidence shows that click trains, putatively acting upon the underlying rate of timing, result in longer estimates of both filled and unfilled stimuli (Wearden et al., 2007), though the effect of click trains is small compared to the filled duration effect. The current research was driven by the question of whether there is a common underlying mechanism that influences both sensory integration and the perception of time. One possible explanation for this finding is that this common mechanism is obscured by the dynamics of the stimulus. In other words, with limited external stimulation our sense of time might relate to the intrinsic speed of our sensory systems, but when relevant stimuli introduce competing temporal dynamics, this relationship becomes decoupled. Existing research does show that performance for the interval varies in accordance with the stimuli that fill it (Buffardi, 1971; Foley et al., 2004; Horr & Di Luca, 2015; Schiffman & Bobko, 1977). Future research should attempt to test this hypothesis in more detail, for instance by changing the dynamics of the stimulation in the filled condition. With regard to click trains we might postulate that it adds the same temporal dynamics to both conditions with the same effect on both.

With regard to variation we find that both conditions show less variation (as measured by the CoV) for individuals who have a narrower window of integration. We interpret this as the narrower TBW representing a more fine-grained sense of time. If we think of temporal binding as representing the frame-rate, or frequency, of sensory processing, then a variation of a few frames between timing judgements would make a comparatively larger difference for someone with longer frames. Alternatively it might be suggested that both a narrower window and more consistent timing may simply relate to better focus on the task, however our findings on variation in filled and empty intervals mirror previous experiments (Wearden et al., 2007) and the effect remains even when we employ conservative controls to which participants we include.

Note that a directly causal relationship is not assumed; both processes (temporal binding and estimation) are clearly part of a wider perceptual system and correspondences between such factors may represent coherence within that system. To address this question, further research should aim to show covariance between the TBW and timing performance. It has been shown that stimulus intensity influences sensory integration (Fister, Stevenson, Nidiffer, Barnett, & Wallace, 2016), and time judgements are influenced by contrast in intensity (Matthews et al., 2011), and so this would be a good candidate mechanism for progressing the research. In particular, it would be a logical progression to move from empty vs full intervals to degrees between no stimuli and high intensity stimuli. If those who experience a greater effect of intensity on sensory integration also experience a greater effect on timing then this would strongly support a relationship between the two. To relate this directly to neural processes, one might also consider varying temporal binding via neuromodulation (Cecere et al., 2015) or entrainment (Ronconi & Melcher, 2017) and applying the same manipulation during the timing task.

We also conducted an exploratory analysis positing that the TBW and timing behaviour may relate in a similar manner to schizotypy. The results find a relationship between the TBW and schizotypy scores, with this being driven by the Unusual Experiences subscale, which relates to positive schizotypal traits such as perceptual differences. This replicates previous findings (Ferri et al., 2017; Ferri et al., 2018) which used scores from the Schizotypal Personality Questionnaire (Raine, 1991) suggesting this finding is robust across measures.

By contrast time judgements did not relate substantially to overall schizotypy scores but showed some relationship with a different sub-scale, impulsive non-conformity. There is one exception in that the CoV for full conditions showed some relation to Unusual Experiences, but this requires further substantiation as it was not significant when more robust criteria were applied. This contrasts with previous studies that did find a relationship between timing and positive characteristics of schizotypy using the O-LIFE (Reed & Randell, 2014) and SPQ (Lee et al., 2006), however the results are not directly comparable as both used a temporal bisection task rather than verbal estimation. Our findings are exploratory and as such require further experimental confirmation. Based on the information available we tentatively suggest that if there is a relationship between positive schizotypy and duration judgements this is likely to be either timing task specific or relatively weak, such that a very large sample or pre-selection for high schizotypal individuals is required. Another consideration is that Lee et al. (2006) only found the relationship at 1000-2000ms, so the durations used here may be below the range in which the effect is robust, though Reed and Randell (2014) found a relationship using sub-second stimuli.

The relationship between subjective timing and impulsive non-conformity, in our experiment, was unexpected. The simplest explanation might be to suggest that higher impulsive nonconformity individuals might engage less well overall with task demands and thus show less manipulation effect. However, as multiple comparisons are made, and we did not preselect for high and low schizotypy individuals or use a clinical sample, conclusions are necessarily tentative.

These results suggest that, though a wider TBW appears to relate both to schizotypy and time judgements, these may be two separate relationships. Future work may look to assess this using different timing tasks, in particular temporal bisection, and by preselecting in relation to schizotypy; assuming that a relationship can be replicated in the right paradigm then it would be possible to test whether these measures account for separate proportions of the variance in the TBW.

While these results are largely consistent with the literature, the average width of the temporal binding window identified in our study may appear larger than usual, as some individuals did not reach 50% simultaneity within a 400ms offset. This is a limitation for the current study as applying rigorous controls resulted in eliminating a substantial proportion of the participants, although the remainder were still in excess of the number suggested to be required by power analysis. It should be considered that the paradigm used here is different to the typical temporal binding task in that the typical task analysis first determines a point of subjective similarity (PSS) then considers the window relative to this, while the current variation of the task purely considers the absolute time difference in time between the two stimuli. This means that for a proportion of participants, the PSS will occur within what is here represented as the (right) TBW resulting in a longer window. As there were further differences, such as using smaller differences between SOAs and providing less training than is typical in this task, further research would be required to investigate the discrepancy and ascertain definitively whether the relationship found in this experiment is driven by the position of the PSS or the width of the window around it. As the result is similarly significant regardless of whether those participants not reaching 50% simultaneity are included, the primary finding appears robust. This is especially the case considering the relatively high numbers of participants and given that training and individual supervision, factors that may promote relative conformity, were minimised.

4.1 Conclusions

In conclusion, this investigation provides strong support for a relationship between individual differences in the timing of sensory integration and timing behaviour. This finding provides a basis for further work to elucidate the exact nature of this relationship and provides evidence that time, one of the most basic elements of perception, may be experienced a little differently by each of us according to how we process primary sensory information.

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CRediT authorship contribution statement

Benjamin Fenner: Funding acquisition, Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing - original draft. Nicholas Cooper: Supervision, Conceptualization, Methodology, Writing - review & editing. Vincenzo Romei: Conceptualization, Methodology, Writing - review & editing. Gethin Hughes: Supervision, Conceptualization, Methodology, Formal analysis, Writing - review & editing. Declaration of

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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