



Schizotypal traits and anomalous perceptual experiences are associated with greater visual temporal acuity

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ABSTRACT

One of the main tasks of the human visual system is to organize the temporal flow of visual events into meaningful patterns. It has been suggested that segregation/integration of continuous visual stimuli relies on temporal windows that are phase-locked to brain oscillations in the alpha frequency range (~10 Hz). From a behavioral point of view, the balance between integration and segregation is reflected in visual temporal acuity: the ability to perceive a small temporal gap between two identical stimuli. Disruption of this balance may lead to impairment of perceptual organization processes. Notably, schizophrenia, a condition characterized by unusual perceptual experiences, has been associated with abnormal temporal processing of sensory stimuli and aberrant oscillations.

We asked a large cohort of healthy participants to complete an online version of the two-flash fusion task and two questionnaires for schizotypal personality traits to investigate individual differences in the temporal resolution of perception, particularly its relationship with anomalous perceptual experiences.

We found that two-flash discrimination acuity declines with age and that schizotypal traits are associated with better performances. Although this association was strong for perceptual and cognitive subscales, we found that this result could not be attributed to response biases (e.g., hallucination of two flashes).

While these results appear to contrast with findings of slower alpha rhythms and sensory processing in schizotypy, we propose that a faster visual rate could be the consequence of an oculoopathy or a disconnection between different sensory modalities and their physiological pacemaker.

1. Introduction

One of the primary functions of the human visual system is to organize the temporal flow of visual events into meaningful patterns. This task of temporal organization relies heavily on the system's capacity to detect changes in the timing, order, or duration of visual stimuli, particularly when they are presented in quick succession. Specifically, visual temporal acuity (VTA), often referred to as temporal resolution of perception, is a measure of the ability of the visual system to distinguish between rapidly occurring visual stimuli and events. In essence, VTA assesses how finely the visual system can resolve and discriminate temporal details in the visual environment and reflects a balance between temporal integration and segregation.

Over more than a century of research, a diverse array of tasks and

measures has evolved to quantify VTA (Dunlap, 1915; Eisen-Enosh et al., 2017; Kuhbandner et al., 2009; Ronconi et al., 2020). Two notable measures are the Critical Flicker Fusion Frequency, the highest rate at which a flickering light source can flash before it is perceived as a continuous, steady light (Eisen-Enosh et al., 2017), and the Two-Flash Fusion Threshold, the time interval between two flashes at which they are still perceived as separate events (Dunlap, 1915). These measures have gained popularity for their simplicity, ease of interpretation, and diversity observed within and between individuals and across species (Deodato and Melcher, 2023b; Lafitte et al., 2022; Rose, 1966). Importantly, this variability provided insight into various aspects of cognition. For example, differences in the two-flash fusion threshold can be attributed to factors such as age and arousal (Pearson and Tong, 1968; Venables and Warwick-Evans, 1967) but also physiological factors such

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as the speed of neural oscillations (Deodato and Melcher, 2023b; Samaha and Postle, 2015).

This measure has the potential to serve as a marker for populations with abnormal perceptual organization (i.e., hallucinations and anomalous perceptual experiences), such as schizophrenia. Indeed, previous studies have found that changes in two-flash threshold caused by induced arousal can discriminate between healthy observers and those with schizophrenia (Hieatt and Tong, 1969; Venables, 1963a).

Schizophrenic individuals commonly exhibit deficits in visual processing (Butler et al., 2008; Silverstein et al., 2015; Silverstein and Keane, 2011; Yoon et al., 2013) and temporal processing of sensory stimuli (Capa et al., 2014; Giersch et al., 2009; Grimsen et al., 2013; Herzog and Brand, 2015; Lalanne et al., 2012; Parsons et al., 2013; Stevenson et al., 2017). However, studies focusing on unisensory visual temporal integration have often employed tasks with an unclear relationship with VTA, due to their complexity and possible influence of other factors (e.g., attention). Moreover, investigations of the two-flash fusion task in schizophrenia have been relatively scarce, and the findings lack convergence (Gruzeliier and Venables, 1974, 1975; Hieatt and Tong, 1969; King, 1962; Venables, 1962, 1963a, 1963b, 1966). Furthermore, medications prescribed to individuals with schizophrenia may introduce spurious effects on VTA (Gilleen et al., 2020), which can be challenging to disentangle from the clinical deficits associated with the condition.

To avoid the potentially confounding influences of illness duration, hospitalization, and medications, as well as to generally attain a broader understanding of the disorder, researchers have extended their investigations to encompass the entire schizophrenia spectrum (Gilleen et al., 2020). An effective approach involves measuring schizotypal personality traits within the general population. Indeed, individuals displaying high schizotypal traits have been linked, albeit to a milder degree, with certain neural and behavioral markers of schizophrenia (Trajkovic et al., 2021), including abnormal temporal integration (Cappe et al., 2012; Marsicano et al., 2022).

Driven by the necessity to expand the exploration of VTA and its association with schizophrenia to the general population, in this study, we leveraged recent advancements in web-based experiments and psychophysics to record data from a large sample of participants. A similar web approach has been effective to gain insights into deficits associated with schizophrenia (Kozma-Wiebe et al., 2006) and schizotypy (Marsicano et al., 2022). For example, using a web-based simultaneity judgment task, Marsicano and colleagues found that schizotypal traits predicted lower multisensory temporal acuity (Marsicano et al., 2022).

Our objective was twofold: first, to assess the feasibility of a web-based adaptation of the two-flash fusion task, and second, to investigate the sources of variability in individual differences related to temporal resolution of perception. Specifically, we were interested in the relationship between a purely visual index of temporal integration and schizotypal traits, particularly those associated with perceptual disorganization. This association could shed light on the mechanisms underlying hallucinations and anomalous perceptual experiences in patients with schizophrenia.

2. Methods

2.1. Participants

A total of 100 participants was recruited through Prolific, a dedicated platform for online experiments recruitment. Inclusion criteria were normal or corrected to normal vision, English fluency and age between 21 and 60 years. We aimed at recruiting 20 participants for each decade spanning this range to balance our sample with respect to age. Six participants were preemptively excluded due to differences in the frame rate of their monitor (i.e., refresh rate faster or slower than 60 Hz), another 14 participants were excluded due to poor goodness of fit (see Data Analysis) leaving 80 datasets (42 females) for analyses. Participants received monetary compensation in accordance with Prolific

Guidelines. Data were collected in accordance with the Declaration of Helsinki and the study protocol was approved by the local ethics committee (New York University Abu Dhabi IRB).

2.2. Online experiment

Prior to the beginning of the experiments, participants gave their informed consent and read a separate set of instructions for the optimal execution of online psychophysics tasks. We put emphasis on completing the task in a quiet room with constant luminance and on sitting at arm's length from the computer monitor to minimize variability in viewing distance. Participants were warned that the web page would automatically redirect to an empty URL at any attempt to exit the fullscreen mode, resulting in the rejection of their submission. Additionally, the experiment could not be started from mobile devices (e.g., small tablet and smartphones) or from a different browser other than google chrome. Finally, in order to avoid potential confounds relative to differences in monitor brightness or individual contrast thresholds, for each participant we determined the contrast threshold online with four consecutive staircases. Each staircase consisted of 40 trials and the contrast threshold was obtained by averaging the values of the last 15 trials. The final threshold was obtained by averaging the contrast thresholds of each staircase. To ensure suprathreshold detection performance, the contrast of the flashes in the two-flash fusion task was determined by applying a fixed contrast multiplier (2×) to the contrast threshold (Ronconi et al., 2017).

2.3. Two-flash fusion task

Each trial of the two-flash fusion task started with a white circular fixation at the center of the screen. After a variable interval ranging from 500 ms to 1500 ms, two consecutive white circles (i.e., the flashes) appeared on the left or right side of the fixation. Each flash lasted for 17 ms (1 refresh of the monitor) and the inter-stimulus interval (ISI) was chosen from 5 equally spaced values between 17 and 85 ms. Finally, after 1 s the fixation turned black and a string of text appeared below it, prompting the subject to respond (see Fig. 1). Participants were instructed to fixate on the central circle and report with a key press whether they perceived one or two flashes. The task consisted of 80 repetitions per ISI plus 80 catch trials (i.e., one flash trials, 34 ms), for a total of 480 randomized trials distributed in 8 blocks. At the end of each block the participant was prompted to take a 2–3 min break, the experiment duration was ~40 min.

The experiment was implemented using jsPsych (de Leeuw, 2015) and the psychophysics plugin (Kuroki, 2021), a set of JavaScript tools for web-based psychophysics experiments. Although timing reliability of these instruments has already been tested with research-grade results (Bridges et al., 2020; Marsicano et al., 2023), we confirmed duration and timing of the stimuli in the online experiment with a Photo Sensor.

2.4. Questionnaires

Upon completion of the task, participants were asked to complete two self-report questionnaires: the Schizotypal Personality Questionnaire (SPQ) (Raine, 1991) and the Cardiff anomalous perception scale (CAPS) (Bell et al., 2006).

The SPQ is a 74-items questionnaire aimed at estimating the presence of the nine features of DSM-III-R schizotypal personality disorder (Raine, 1991). Participants answer with “Yes” or “No” statements to questions concerning various aspects of their personality, beliefs and daily life experiences. The SPQ features/subscales can be grouped in order to highlight the three main components of schizotypal personality: Cognitive-Perceptual (subscales: ideas of reference, unusual perceptual experiences, magical thinking, suspiciousness), Disorganization (subscales: odd speech, odd or eccentric behavior) and Interpersonal (subscales: excessive social anxiety, no close friends, constricted affect,

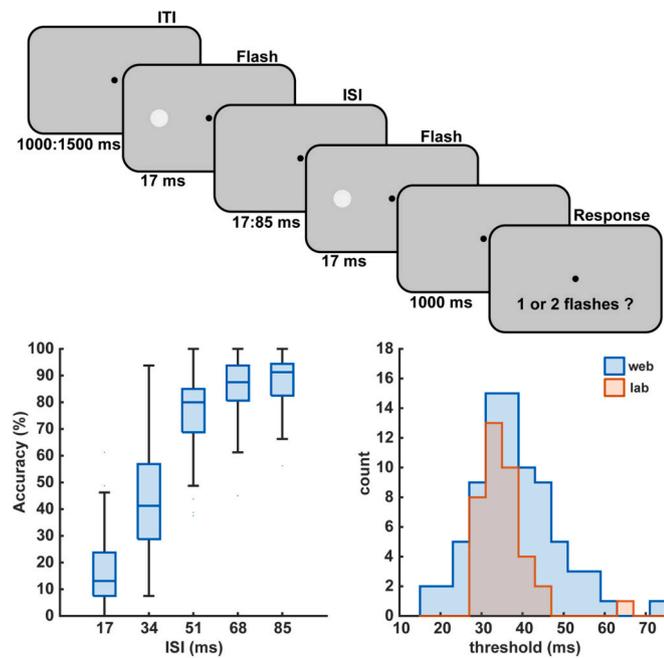


Fig. 1. Design and results of the two-flash fusion task. (Top) Schematics of the two-flash fusion task. (bottom-left) Distribution of accuracy (i.e., two-flash responses) as a function of the Inter-Stimulus Interval (ISI) between the two flashes. Horizontal lines indicate each distribution quartiles. (bottom-right) Distribution of the two-flash fusion threshold in the web-based sample (blue, $n = 80$) and in the in-person sample of Deodato and Melcher (2023) (red, $n = 38$).

suspiciousness) (Fossati et al., 2003).

The CAPS is a 32-items questionnaire that provides a measure of perceptual anomalies (Bell et al., 2006). Participants answer with “Yes” or “No” statements to questions about sensations and perceptions they may have experienced. Notably, the strong association between perceptual anomalies and hallucinations has promoted its usage in schizophrenia spectrum disorders research (Teufel et al., 2015).

2.5. Data analysis

For each participant, we computed the percentage of correct (two-flashes) responses per ISI and a psychometric logistic function was fitted to these data. Participants with a poor goodness of fit ($n = 14$, $R^2 < 0.80$) were excluded from further analyses. The inflection point, or 50 % threshold of the psychometric function, is commonly interpreted as a reliable estimate of the temporal resolution of perception (Deodato and Melcher, 2023b; Samaha and Postle, 2015) and was therefore considered as our primary measure of visual temporal acuity.

To ensure normality of the data, the questionnaires scores and the threshold distribution across participants were tested with the Kolmogorov-Smirnov test. Additionally, this web-based two-flash threshold distribution was compared with an *in-person* distribution ($n = 38$) (Deodato and Melcher, 2023b) with an unpaired *t*-test. Next, following common practices in aging research on psychological traits (Rokach, 2007) and timing-related psychophysics (Hancock, 2010), participants were arranged in four groups according to their age (21–30, 31–40, 41–50, 51–60) (Wilson, 1963) and a one-way ANOVA computed the statistical differences between groups. Additionally, age-related differences in visual temporal acuity were tested with a Pearson correlation between age and threshold to highlight the effect of individual age differences. VTA differences between male and female participants were tested with an unpaired *t*-test.

The relationship between performance in the two-flash fusion task and schizotypal traits was assessed with Pearson correlation coefficient

between the two-flash fusion threshold and each questionnaire score. To ensure that results were not driven by a response bias, the same analysis was repeated using the percentage of wrong responses (i.e., two flashes) in the catch trials (Gruzelier and Venables, 1975). Additionally, to control that results were not driven by an artifact of the curve fitting analysis, we tested the correlations using the raw accuracy from the intermediate ISI (34 ms) in place of the two-flash fusion thresholds (Samaha and Postle, 2015). This ISI was chosen because it is the closest to the average two-flash fusion threshold and the one that shows most variability across participants (see Fig. 1). Finally, for each participant we used the catch trials and the two-flash trials with this intermediate ISI to compute sensitivity, the ability to correctly discriminate between one and two flashes, and bias, representing any systematic tendency to report one or two flashes. To further address the possibility that our findings are the results of a bias, for each questionnaire score, we used a linear mixed effect model with sensitivity and bias as fixed effects. Finally, we used a linear mixed model with the questionnaires' scores and age as fixed effects (i.e., $FF \sim SPQ + AGE$), to detect the presence of spurious relationships with visual temporal acuity in the data. Data analysis was performed using custom MATLAB scripts.

3. Results

The online two-flash fusion task provided results comparable to in-person experiments reported in the literature. Performance increased as a function of ISI in a sigmoid fashion. Although we rejected $\sim 15\%$ of the participants due to poor fitting, in our experience this percentage is close to the rejection rate of in-person experiment (Deodato and Melcher, 2023b). Overall, the goodness of fit of the psychometric function to the data was strong ($M = 0.97$, $SD = 0.04$), meaning that ISI had a clear effect on performance (see Fig. 1), and the average inflection point corroborated previous reports of this measure ($M = 38.09$, $SD = 10.14$) (Deodato and Melcher, 2023b; Drewes et al., 2022; Ronconi et al., 2017; Samaha and Postle, 2015) and was not significantly different when compared with in-person data from Deodato and Melcher (2023) ($p > .05$) (see Fig. 1). The Kolmogorov-Smirnov test confirmed that the threshold was normally distributed in our sample ($p > .05$).

3.1. Visual temporal acuity declines with age

A one-way between subjects' ANOVA was conducted to compare the effect of age group on visual temporal threshold. There was a significant effect of age for the four groups ($F(3,76) = 3.70$, $p = .015$, $\eta^2 = 0.13$) (see Fig. 3). Post hoc comparisons using the Bonferroni correction indicated that the mean threshold of the first group ($M = 32.9$, $SD = 8.8$) was significantly shorter than the third ($M = 40.98$, $SD = 9.01$, $p = .007$) and fourth group ($M = 41.88$, $SD = 10.48$, $p = .005$). The other comparisons

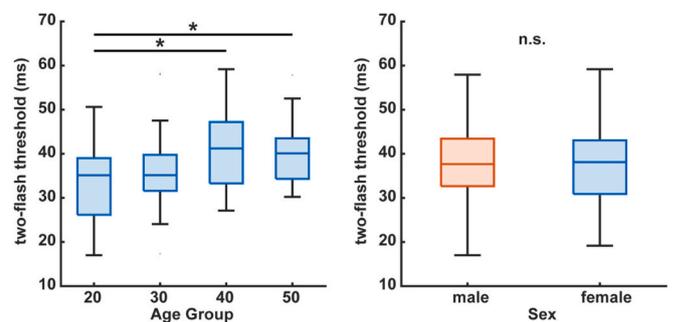


Fig. 2. Effects of age and gender on the two-flash fusion threshold. (Left) Distribution of two flash fusion threshold across four age groups. We found significant ($p < .05$) differences between the first group (21 to 30 years) and the third (41 to 50) and fourth (51 to 60). (Right) No significant differences between the threshold distributions of male ($n = 38$) and female ($n = 42$) participants.

did not reveal significant differences (see Fig. 2). Taken together, these results suggest visual temporal acuity declines with age, although this regression may be most evident considering younger adults. Accordingly, the Pearson correlation revealed a significant positive association between age and visual temporal thresholds ($r(78) = 0.37, p < .001$). This further corroborated the effect of individual age differences on visual temporal acuity, indicating that younger individuals were better at discriminating the flashes. Unsurprisingly, we found no effect ($p > .05$) of self-reported biological sex on two-flash thresholds (Pearson and Tong, 1968).

3.2. Schizotypal traits are associated with better visual temporal acuity

The questionnaires' analysis revealed a negative association between the two-flash fusion threshold and both SPQ ($r(78) = -0.34, p = .002$) and CAPS ($r(78) = -0.24, p = .026$) total scores, meaning that schizotypal traits and anomalous perceptual experiences are associated with shorter threshold and therefore better temporal resolution of perception (see Fig. 3). However, when controlling for non-normality of the data with the Kolmogorov-Smirnov test, only the SPQ scores were normally distributed ($p > .05$), while CAPS scores were not ($p = .002$). To address non-normality and the influence of outliers, we applied Kendall's tau coefficient, and the association with CAPS became marginally significant ($\text{tau} = -0.15, p = .056$). Furthermore, the correlation between SPQ scores and VTA was robust to the influence of outliers as confirmed by robust regression ($R^2 = 0.15, p < .001$). Further examination of the SPQ components revealed an association with both the Cognitive-Perceptual ($r(78) = -0.37, p = .001$) and Disorganization ($r(78) = -0.25, p = .023$) components but no relationship with the Interpersonal schizotypal traits ($p > .05$), which is perhaps unsurprising since the task has no social component. The following SPQ subscales had a significant negative correlation with VTA: ideas of reference ($r(78) = -0.41, p < .001$), unusual perceptual experiences ($r(78) = -0.38, p < .001$), odd speech ($r(78) = -0.29, p = .009$) and excessive social anxiety ($r(78) = -0.25, p = .021$). Notably, the two-flash fusion accuracy at the intermediate ISI (34 ms) also correlated with the SPQ ($r(78) = 0.38, p < .001$) and CAPS ($r(78) = 0.35, p = .001$), proving that this relationship was not a consequence of a fitting artifact (Samaha and Postle, 2015). We found no significant correlation between the questionnaires' scores and the percentage of two-flash responses in catch trials (all $p > .05$), indicating that our results are unlikely to be driven by a response bias. In support of this, sensitivity exhibited a positive correlation with SPQ (Estimate = 6.04, SE = 2.95, $t = 2.05, p = .043$) and CAPS (Estimate = 3.89, SE = 1.11, $t = 3.48, p < .001$). Interestingly, SPQ scores were also negatively correlated with the bias (Estimate = -10.11 , SE = 4.57, $t = -2.208, p = .03$). Finally, a linear mixed model untangled the significant independent effect of age (Estimate = 0.27, SE = 0.087, $t = 3.1, p = .002$) and SPQ scores (Estimate = -0.181 , SE = 0.066, $t = -2.732, p = .007$) on

two-flash thresholds. The same analysis applied to age and CAPS scores yielded significant results for age (Estimate = 0.298, SE = 0.087, $t = 3.406, p = .001$) and a trend for the effect of CAPS (Estimate = -0.342 , SE = 0.174, $t = -1.964, p = .057$). In other words, this analysis showed that the relationship between schizotypal traits and anomalous perceptual experiences and visual temporal acuity cannot be explained in light of the visual decline that accompanies aging or a response bias but is related to cognitive and perceptual aspects of the schizotypal personality.

4. Discussion

4.1. Web-based VTA

Over the course of more than a century, numerous tasks have revealed significant individual differences in VTA both between and within individuals (Kaur et al., 2020; Kuhbandner et al., 2009; Pearson and Tong, 1968; Rose, 1966; Wilson, 1963). Measures of VTA, and speed of processing more generally, remain a valuable metric in both clinical and research settings (Curran and Wattis, 2000; Daley, 1979; Deodato and Melcher, 2023b; Rose, 1966; Venables, 1963a). Here, we were able to measure VTA in a large and heterogeneous sample using a web-based version of the two-flash fusion task. Our data was similar to classic in-person experiment under many aspects. First, to our knowledge this is the first study to take advantage of recent advances in online psychophysics to measure the two-flash fusion threshold in a large sample and is reassuring to observe consistency of central tendency with previous literature (Deodato and Melcher, 2023b; Drewes et al., 2022; Ronconi et al., 2017; Samaha and Postle, 2015). Second, we found that VTA declines with age, which could be indicative of slower speed of processing and cognitive decline in the elderly population (Salthouse, 2000). This finding replicates previous studies and extends to similar measures (e.g., flicker fusion frequency) (Pearson and Tong, 1968; Wilson, 1963).

From a neurophysiological standpoint, visual temporal acuity has been linked to brain oscillations in the alpha frequency range (~ 10 Hz). More precisely, it has been proposed that each cycle of these oscillations corresponds to a perceptual snapshot (VanRullen, 2016). Indeed, studies have reported that discrimination of two consecutive stimuli (e.g., two flashes) depends on their position within an alpha cycle and on the duration of that cycle (Deodato and Melcher, 2023b; Ronconi et al., 2017). Furthermore, it is noteworthy that alpha oscillations have been observed to slow with age, and are similarly regarded as a broader marker of cognitive processing speed (Sargent et al., 2021; Van der Meer et al., 2013). In this context, our web-task offers an inexpensive means to indirectly probe this physiological marker within a large population.

4.2. Do schizotypal traits make you see faster?

Our main result concerns the association between schizotypal traits and, more generally, anomalous perceptual experience and better visual temporal acuity. This association was robust to outliers and was confirmed with both the raw two-flash accuracy and the sensitivity. Schizotypal traits refer to a set of enduring personality characteristics and behaviors that resemble, to some extent, the features of schizophrenia in the general population (Raine, 1991; Zouraraki et al., 2023). These traits are considered to be part of a continuum that spans from normality to psychopathology (i.e., schizophrenia). Indeed, individuals with high schizotypal traits often shares cognitive deficits and neural markers with the schizophrenic population (Zouraraki et al., 2023). In the visual domain, for example, masking effects in which detection of a target is impaired by presentation of a subsequent mask are greater both in the schizophrenic and schizotypal populations (Herzog and Brand, 2015).

We found that individuals with high schizotypal traits performed better in a temporal discrimination task, independent of their age. This

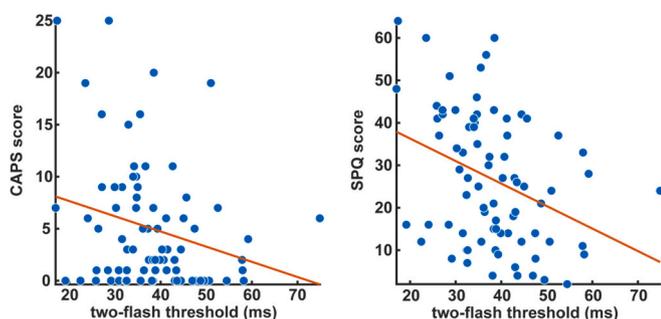


Fig. 3. Correlation between two-flash threshold and SPQ and CAPS scores. Negative correlation between two-flash fusion thresholds and CAPS scores ($r(78) = -0.24, p = .026$) (left) and SPQ scores ($r(78) = -0.34, p = .002$) (right) across participants. Blue circles represent participants. The red line indicates the linear regression of the temporal threshold with the questionnaires scores.

finding stands in open contrast with reports of visual masking deficits (Cappe et al., 2012), larger audio-visual temporal integration thresholds (Marsicano et al., 2022), and generally slower processing speed in schizophrenia and schizotypy (Gilleen et al., 2020). However, this discrepancy could be explained by the fact that our task differs from those previously employed in schizophrenia research in at least one of four main aspects. First, we used overlapping consecutive stimuli to measure visual temporal thresholds. Non-overlapping stimuli (Giersch et al., 2009; Lalanne et al., 2012) introduce the need to switch to different locations and the influence of spatial, rather than temporal, factors such as the well-known attentional deficits in schizophrenia (Carter et al., 2010; Kristofferson, 1967). Second, the two-flash fusion task can be considered a simple detection task that doesn't involve judgements of synchrony or temporal order of the stimuli. Temporal order and synchrony are more complex processes that might be related to other features of the schizophrenia continuum. Although all of these tasks relate to temporal processing, they have been linked to different mechanisms and level of processing that could be independently affected in schizophrenia and schizotypy (Grimsen et al., 2013). Capa and colleagues, for instance, found strongest temporal deficits for temporal order judgements than synchrony judgements in schizophrenics (Capa et al., 2014).

Third, the flashes are extremely simple sensory stimuli on a uniform background. Compared to more complex stimuli and richer displays, this ensures more reliable measurement of low-level temporal integration. Fourth, our stimuli were located in proximity of the periphery, which may involve separate temporal processing mechanisms than the fovea: Schwartz and Winstead found that schizophrenic participants had faster peripheral temporal integration rates, although only with high spatial frequency stimuli (Schwartz and Winstead, 1988). Finally, it's worth mentioning that much research on temporal integration dynamics in schizophrenia has focused on multisensory (i.e., audiovisual) rather than unisensory tasks, which may involve a different set of neural processes and circuits, limiting generalization from one domain to the other (Zhou et al., 2018). Additionally, schizotypy and schizophrenia, though related between each other, could relate differently to VTA. For example, schizotypy lacks the severity of perceptual and cognitive deficits (i.e. hallucinations and delusions) that characterizes schizophrenia. Furthermore, the effect of VTA on schizotypy is based on a correlation and other unaccounted variables could at least partially explain this effect. For example, our results could be driven by viewing distance since schizophrenia has been associated with lower spatial acuity (Hayes et al., 2019) which might prompt participants to sit closer to the monitor. Moreover, given the correlation with the SPQ subscale relating to excessive social anxiety (see Results), increased visual temporal acuity could be related to anxiety-related hyper-vigilance (but see (Melcher et al., 2023) for an opposite effect). Previous investigations of two-flash thresholds in the schizophrenic population are rare and have yielded heterogeneous results (Hieatt and Tong, 1969; King, 1962; Lykken and Maley, 1968; Venables, 1963b, 1966). Overall, no difference was found between schizophrenic and healthy populations (King, 1962; Venables, 1966). However, longer thresholds in schizophrenic patients have been attributed to medication, since both typical and atypical antipsychotics might influence neural processes related to visual processing speed, and it has been speculated that they could have shorter threshold than healthy controls due to greater unregulated cortical arousal (Gruzelier and Venables, 1974).

Given the general cognitive impairment associated with schizophrenia, it's expected that tasks at which high schizotypal observers excel are uncommon. Nevertheless, these tasks may provide valuable insights into the underlying (neural) mechanisms of the clinical condition. Above-average visual performance could still be indicative of a deficit. For example, schizophrenic and high schizotypal individuals have significantly low susceptibility to some visual illusions, which may be suggestive of more accurate vision but has been shown to rather be indicative of impaired visual context processing and aberrant priors

(Dakin et al., 2005; Notredame et al., 2014). Similarly, Teufel and colleagues found that recognition of two-tone images was better in high-schizotypal individuals because of over-reliance on prior knowledge, a mechanism that could be responsible for anomalous perceptual experiences and hallucinations during natural viewing conditions (Davies et al., 2018; Teufel et al., 2015). It is worth noting that schizophrenic patients have shown reduced sensibility to apparent motion displays (Crawford et al., 2010; Sanders et al., 2013). While this finding has been interpreted as indicating reduced susceptibility to motion illusions, an alternative perspective suggests that the same result may signify enhanced stimulus segregation attributed to a faster sensory sampling process (Ronconi et al., 2017).

In our sample, better performance seems to be associated particularly with positive symptoms, we found strong correlations with the CAPS and with the SPQ-subscale relating to anomalous perceptual experiences. Interestingly, the administration of methamphetamine, a powerful stimulant that can lead to transient psychotic symptoms (i.e., hallucinations) and exacerbation of preexisting schizophrenia, has been found to induce a shortening of two-flash fusion thresholds (Kopell et al., 1965). It could be tempting to argue that high-schizotypy participants simply tend to hallucinate two-flashes or, more generally, that their performance stems from a response bias, however, our analysis indicated no evidences for such response biases and even a negative association between perceptual biases and schizotypal traits (see Results). We speculate that faster processing of visual features in schizotypy could be mechanistically linked to proneness to errors/alterations in the perceptual experience. In other words, seeing faster would come at the expense of quality of sensory input, due to, weaker integration, shorter sensory evidence accumulation periods and overreliance on priors (Tarasi et al., 2023).

4.3. VTA, Schizotypy and brain dynamics

In recent years, the neural mechanisms underlying sensory integration/segregation of two flashes have been extensively studied (Deodato and Melcher, 2023b; Ronconi et al., 2017; Samaha and Postle, 2015; Valera et al., 1981). Specifically, it has been found that the speed of alpha oscillations predicts within and between individual differences in two-flash fusion thresholds (Deodato and Melcher, 2023b; Ronconi et al., 2017; Samaha and Postle, 2015; Wutz et al., 2018). It follows that short thresholds and greater VTA, such those observed in high schizotypy individuals, should be associated with faster oscillations. However, this prediction doesn't hold in the case of schizotypy: multiple evidence suggests that both schizophrenia and schizotypy are characterized by slower alpha rhythms (Murphy and Öngür, 2019; Ramsay et al., 2021; Trajkovic et al., 2021). Notably, other temporal tasks and illusions that covary with the speed of alpha oscillations are also different in a way that is suggestive of slower rhythms and longer temporal integration in this population (see triple-flash illusion (Norton et al., 2008), double-flash illusion (Haß et al., 2017) and multisensory binding (Marsicano et al., 2023; Zvyagintsev et al., 2017)). More generally, schizophrenic spectrum disorders have been labeled as oscillopathies (Başar et al., 2016; Tarasi et al., 2022), meaning that they are characterized by alterations in the normal functions and physiology of neural oscillations. Ramsay and colleagues, for example, argued that slower alpha rhythms accounted for global cognitive deficits in schizophrenia (Ramsay et al., 2021).

One possibility is that these disorders are characterized by a disconnection or aberrant connection between one or more sensory parsing processes and their physiological pacemaker (i.e., the alpha rhythm). Previous studies have found that the organizing role of oscillations (Mathewson et al., 2011) might be compromised by neural noise and imbalance in excitation/inhibition (Deodato and Melcher, 2023a; Karvat and Landau, 2024; Ten Oever et al., 2020). Accordingly, E/I imbalance might underly schizotypal perceptual experiences (Ferri et al., 2017). Yoon et al. found a reduced concentration of GABA

(gamma-aminobutyric acid), a neurotransmitter that plays a key role in inhibitory signaling in the brain, in the visual cortex of schizophrenic patients compared with healthy controls (Yoon et al., 2010). Although recent meta-analyses suggest that in vivo GABA differences between schizophrenic and controls should be taken with caution (Egerton et al., 2017; Taylor and Tso, 2015). Moreover, it has been suggested that ineffective regulation of cortical excitation may underly two-flash discrimination performance of schizophrenics (Hieatt and Tong, 1969; Venables, 1963a). This disconnection mechanism could explain faster performance in the two-flash fusion task, but also atypical integration between different sensory modalities, cascading into the organization of the perceptual experience. In this light, our findings add to an existing literature indicating that positive symptoms such as hallucinations and delusions are linked to mistiming and aberrant integration of information from different sensory modalities and internal thoughts (Bear et al., 2017; Stevenson et al., 2017).

In conclusion, the current results challenge the notion that schizotypy is associated with the general slower processing attributed to schizophrenia by showing that participants with higher schizotypal traits had a faster temporal resolution in a simple two-flash visual discrimination task. Given the complex nature of anomalous perceptual experiences, a dissociation between high visual temporal acuity and slower multisensory acuity, for example, could lead to a more disorganized perceptual gestalt experience.

CRedit authorship contribution statement

Michele Deodato: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Luca Ronconi:** Writing – review & editing, Supervision. **David Melcher:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors have no competing interests to declare.

Data availability statement

Raw data and code to replicate the results are available on GitHub (<https://github.com/DeoMiche/-2023-Schizotypy>).

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