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Mental rotation and schizotypal personality traits: A Bayesian approach

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People diagnosed with schizophrenia exhibit mental rotation differences, suggesting that clinical levels of positive symptoms, such as psychotic hallucinations, are related to disruptions in their monitoring and manipulation of mental representations. According to the psychosis continuum, findings in people with a high level of schizotypal personality traits are expected to be qualitatively similar, but research concerning this topic is scarce. A spared mental imagery manipulation in this population only could suggest that this ability might be a possible protective factor, or that the emergence of clinical-level positive symptoms could be paired with disruptions in this capacity. To explore this issue, 205 undergraduate students (122 women) completed a novel mental rotation task identifying the stimulus that was a 90, 180, or 270° rotation of a black circle with colored portions and were assessed with the Schizotypal Personality Questionnaire. Men performed better in most conditions. No relationship was detected between schizotypal personality traits and accuracy in the task. These results do not support that mental imagery manipulation disruptions may be related to schizotypal personality traits in non-clinical populations. Thus, they might instead be associated with the onset of psychosis disorders as mental representation handling is hindered. However, additional research is required including the general population, as well as those with higher levels of psychotic symptoms and psychosis disorders. Future research could also focus on working memory processes related to mental representation manipulations of different sensory modalities such as auditory mental representations and their relationship with schizotypal personality traits and clinical populations.

Key words: Schizotypal personality traits, Psychosis continuum, Mental rotation, Bayesian statistics.

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INTRODUCTION

Schizotypy refers to a latent personality organization that harbors liability for schizophrenia spectrum disorders (Barrantes-Vidal, Grant & Kwapil, 2015; Lenzenweger, 2018), and is often interchangeably referred to as subclinical psychotic symptoms (DeRosse & Karlsgodt, 2015). It has been proposed that psychotic experiences such as the ones present in schizotypal personality disorder or schizophrenia are distributed along a continuum. This continuum ranges from mental health (normal dissociative states) to diagnosable psychiatric disorder when transitory expressions of psychosis become persistent and impairing (van Os, Linscott, Myin-Germeys, Delespaul & Krabbendam, 2009). Findings at the behavioral, brain structural, functional, and molecular levels certainly support a link between levels of schizotypal traits (or schizotypy) and schizophrenia (for a review, see Ettinger, Meyhöfer, Steffens, Wagner & Koutsouleris, 2014). Finally, there is also evidence for a psychosis continuum from studies with both twins and relatives of people with schizophrenia (van Os, Linscott, Myin-Germeys, Delespaul & Krabbendam, 2009), suggesting a genetic predisposition towards psychotic disorders which interacts with environmental factors, generating psychotic symptoms (Barrantes-Vidal, Grant & Kwapil, 2015) that can become expressed at clinical, subclinical, and non-clinical levels (Raine, 2006).

Although there is still not a total consensus on the number and nature of the factors of schizotypy (e.g., some measures of schizotypy include scales regarding impulsive nonconformity or psychoticism; Mason, 2015), strong evidence supports that schizotypal personality traits could conform to three factors (Positive, Negative, and Disorganized; also called Cognitive-Perceptual, Interpersonal, and Disorganized) which parallel those identified in schizophrenia research (Battaglia, Cavallini, Macciardi & Bellodi, 1997; Calkins, Curtis, Grove & Iacono, 2004; Fonseca-Pedrero, Debbané, Ortuño-Sierra *et al.*, 2018; Raine, Reynolds, Lencz, Scerbo, Triphon & Kim, 1994; Reynolds, Raine, Mellingen, Venables & Mednick, 2000; Thomas, Rossell, Tan *et al.*, 2019). These factors, as commonly measured with the Schizotypal Personality Questionnaire (SPQ; Raine, 1991), have been proposed to be the Cognitive-Perceptual factor, which includes ideas of reference, magical thinking, unusual perceptual experiences, and paranoid ideation or suspiciousness; the Interpersonal factor, which involves constricted affect, lack of close friends/social withdrawal, and excessive social anxiety; and the Disorganized factor, which is characterized by odd thinking and speech, and eccentric behavior (Fonseca-Pedrero *et al.*, 2018).

Since schizotypal personality traits can be regarded as schizophrenia proneness or a subclinical manifestation of it (Claridge, 1997), but not all people with a high level of schizotypal personality traits develop full-blown schizophrenia, studies have been carried out with the goal of better-characterizing people with schizotypal personality traits in order to identify potential protective or compensatory mechanisms, as well as environmental risk factors (Ettinger *et al.*, 2014). This could in turn help detect critical levels in these factors and intervene before a disorder is developed. Findings from these studies reveal that people with high levels of schizotypal personality traits have higher perceptual thresholds, deficits in executive function (Steffens, Meyhöfer, Fassbender, Ettinger &

Kambeitz, 2018), sustained attention, inhibition and working memory (capacity and manipulation), higher distractibility (Marsh, Vachon & Sörqvist, 2017), and worse nonverbal memory performance, as well as differences in language production and interpretation (for reviews, see Ettinger, Mohr, Gooding *et al.*, 2015; Siddi, Petretto & Preti, 2017).

In addition, psychosis research has also focused on mental imagery, a process that consists in the generation, maintenance, and manipulation of internal representations (Pearson, Naselaris, Holmes & Kosslyn, 2015). Mental imagery has been related to hallucinations; however, although both involve the generation of internal representations that can even become as vivid as actual objects that are being perceived at the moment, they differ in perceived agency (hallucinations are involuntary) and timings of prefrontal and sensory areas (Linden, Thornton, Kuswanto, Johnston, van de Ven & Jackson, 2011). Mental imagery differences (e.g., exceptional vividness) have been observed in people with schizophrenia (Benson & Park, 2013) or with high schizotypal personality traits (Oertel, Rotarska-Jagiela, van de Ven *et al.*, 2009). Differences have also been reported in processes related to mental imagery. For example, enhanced visuospatial imagery manipulations were observed in people with schizophrenia (Benson & Park, 2013), regardless of the working memory deficits usually described in this population (Park & Gooding, 2014). To explain this dissociation between working memory and visuospatial imagery performance, it has been proposed both that mental imagery is enhanced at the expense of working memory performance or that abnormal connectivity between the frontal and parietal cortices could underlie these results (see Park & Gooding, 2014).

Mental rotation is another process that is directly related to mental imagery. It consists in the transformation of a mental image from the orientation at which it is presented to the one of a particular comparison stimulus (Searle & Hamm, 2017), and is carried out by the dorsal frontoparietal network (Ptak, Schnider & Fellrath, 2017). Mental rotation is usually highly associated with mathematical skills (Laski, Casey, Yu, Dulaney, Heyman & Dearing, 2013), navigation (Ploran, Rovira, Thompson & Parasuraman, 2015), and other visuospatial skills such as mental folding (Castro-Alonso, 2019). Furthermore, as in other visuospatial skills, sex differences are consistently identified in mental rotation (Voyer, Voyer & Saint-Aubin, 2017), with men performing better on average and women featuring higher activations of the dorsomedial prefrontal cortex and other high-order heteromodal association cortices, which suggests the use of bottom-up strategies in men (Butler, Imperato-McGinley, Pan *et al.*, 2006). The importance of mental rotation resides in its putative relation towards mental image monitoring: disturbances in mental rotation could be interpreted as action monitoring deficits, since mental rotation requires the maintenance of a mental image which has to be actively manipulated (Ecker, Brammer, David & Williams, 2006), while monitoring the rotation to avoid under or overshooting, involving brain areas that are related with action monitoring (de Vignemont, Zalla, Posada *et al.*, 2006). Thus, mental rotation deficits could result in or reflect an inability to control mental images and realize that they are generated or manipulated internally (de Vignemont *et al.*, 2006; Mazhari, Tabrizi & Nejad, 2015). This interpretation has implications for the positive dimension of psychosis (e.g., considering something that was imagined as if it was perceived from an external stimulus). A spared mental imagery manipulation (i.e., during mental rotation) in people presenting psychosis disorders would suggest that positive symptoms, such as psychotic hallucinations in schizophrenia may be related to characteristics of the mental images themselves such as their vividness (their detail), and not disruptions in their monitoring and manipulation. Conversely, deficits in the manipulation of mental imagery would instead suggest that positive symptoms might be associated with a worse agency over these stimuli (for a review on mental imagery and aberrant perception, see van de Ven & Linden, 2012). Similarly, a lack of mental representation manipulation disruption only in non-clinical populations might suggest that the emergence of clinical levels of positive symptoms could be paired with disruptions in monitoring and manipulation of mental representations, or that this ability might be a possible protective factor against them. Accordingly, research on the nature of this relationship between mental imagery and positive symptoms might lead to training programs and interventions that target specific impairments such as deficits of executive control on mental images. Mental rotation performance has been shown to be spared or even enhanced in people with schizophrenia (Thakkar & Park, 2012), although some studies have reported the opposite (c.f., Agarwal, Danivas, Amaresha *et al.*, 2015; Chen, Yang, Zhao *et al.*, 2012; for differences in men, but not in women, see Jiménez, Mancini-Marïe, Lakis, Rinaldi & Mendrek, 2010). Similarly, results from the very limited number of studies examining mental rotation in schizotypy have been contradictory. Thakkar and Park (2010) revealed a positive relationship between mental rotation performance and the Interpersonal (or negative) factor of the SPQ (Raine, 1991 – this test measures the three schizotypal factors previously mentioned) in women, and Steinisch, Sulpizio, Iorio *et al.* (2011) reported improved performance in both men and women with high global schizotypy that were also measured with the SPQ in an array and self-mental rotation task. On the contrary, Vastano, Sulpizio, Steinisch, Comani and Committeri (2014) detected a negative relationship between mental rotation performance and Cognitive-perceptual scores in the SPQ, while other studies (e.g., Jha, Read, Hurd & Crespi, 2018) have found spared – but neither enhanced nor impaired – mental rotation in people with high schizotypy. Thus, it can be concluded that more research is needed to better elucidate the relationship between schizotypy and mental rotation performance. Particularly, those including non-clinical samples, since research based on them feature reduced effects of illness variables (e.g., chronicity or comorbidity), medication or hospitalization (Mason, 2015), so they may facilitate the identification of causal, resilience, and compensating factors (Barrantes-Vidal, Grant & Kwapil, 2015).

Therefore, the main aim of this study is to further explore the association between the levels of schizotypal personality traits and mental rotation performance in a non-clinical population by using a mental rotation task with different difficulty levels. When assessing mental rotation, most studies employ tasks that present either the stimulus-to-be-rotated at the same time as one or several comparison stimuli (e.g., Collins & Kimura, 1997), while others display the comparison stimuli afterward (e.g., Griksiene, Monciunskaite, Arnatkeviciute & Ruksenas, 2018), and usually use reaction times to calculate the rate of mental rotation as an index of mental rotation ability in tasks without time limits. Some authors have introduced time pressure into their designs, which increased error rates and revealed accuracy-reaction time trade-off effects (e.g., Liesefeld, Fu & Zimmer, 2015). Since our goal was to detect subtle effects (Ettinger *et al*., 2015) that might not appear if they were beneficial and the task was easy, or if they were impairing and the task was hard (as we could not presume the direction of a possible schizotypy-mental rotation relationship), the use of a task that features two distinct difficulty levels, which most studies do not utilize, is required. Although the direction of this possible schizotypy-mental rotation relationship cannot be presumed due to previous contradictory findings (Jha, Read, Hurd & Crespi, 2018; Steinisch *et al*., 2011; Thakkar & Park, 2010; Vastano, Sulpizio, Steinisch, Comani & Committeri, 2014), it is expected to find sex differences in the mental rotation task, as this is a typical result in mental rotation paradigms (Boone & Hegarty, 2017).

METHOD

Participants

Undergraduate students (N = 205; 122 women) between 18 and 53 years old (M = 21.19, SD = 5.10) were selected by convenience and snowball sampling. They received one course credit for participating and one extra for scheduling appointments for another two students (who had to participate before credits were awarded). Thirteen participants (eight female) with total accuracies below chance level in the mental rotation task or incomplete questionnaire responses were removed from data analyses. All participants had normal or corrected-to-normal vision, were Spanish-speaking and naïve with respect of the purpose of the experiment. The employed dataset and script can be accessed at https://osf.io/w6czt/.

Materials

Schizotypy assessment. Schizotypy was measured with the Spanish version of the SPQ (Raine, 1991, adapted to the Spanish context in Fonseca-Pedrero, Fumero, Paino *et al*., 2014). The SPQ is a self-report scale based on the definition of Schizotypal personality disorder by the revised third edition of the Diagnostic and Statistical Manual of Mental Disorders (*DSM–III–R*; American Psychiatric Association, 1987). This questionnaire is composed of 74 dichotomous items. The scores of this scale have shown acceptable psychometric properties, with high internal consistency (measured with ordinal alpha, ranging from 0.80 to 0.91) and adequate validity evidence in the Spanish context, where the scales conform to a three-factor structure: the Cognitive-Perceptual factor (α = 0.83) ranges from 0 to 33 and integrates the four subscales Odd Beliefs or Magical Thinking, Unusual Perceptual Experiences, Ideas of Reference, and Suspiciousness. The Interpersonal factor (α = 0.88) has a score ranging from 0 to 33 and integrates the four subscales Social Anxiety, Lack of Close Friends, Constricted Affect, and Suspiciousness. Finally, the Disorganized factor (α = 0.79) has a score ranging from 0 to 16 and integrates the two subscales Odd Or Eccentric Behavior and Odd Speech (Fonseca-Pedrero *et al*., 2014). The questionnaire was applied using a paper-and-pencil format. The three factors showed an adequate internal consistency, measured with McDonald's Omega total (Cognitive-Perceptual: ω = 0.86, 95% confidence interval, [CI 0.83, 0.89]; Interpersonal: ω = 0.88, 95% CI [0.85, 0.90]; Disorganized: ω = 0.81, 95% CI [0.77, 0.85]), calculated using JASP (JASP Team, 2022).

Mental rotation assessment. Mental rotation was assessed with a task designed using the E-Prime 2.0 software (Psychology Software Tools, 2007), adapted from Carmona, Marí-Beffa and Estévez (2019). The stimuli were displayed over a black background and consisted in 436-pixel-diameter circles with a white outline that was segmented into 16 equal portions (two of them colored white) by eight radial lines, which were also white (Fig. 1). There were four (two hard and two easy) different sample stimuli, which were selected based on the placement of specific parts of the stimuli regarding the vertical and horizontal axes. All stimuli were thus

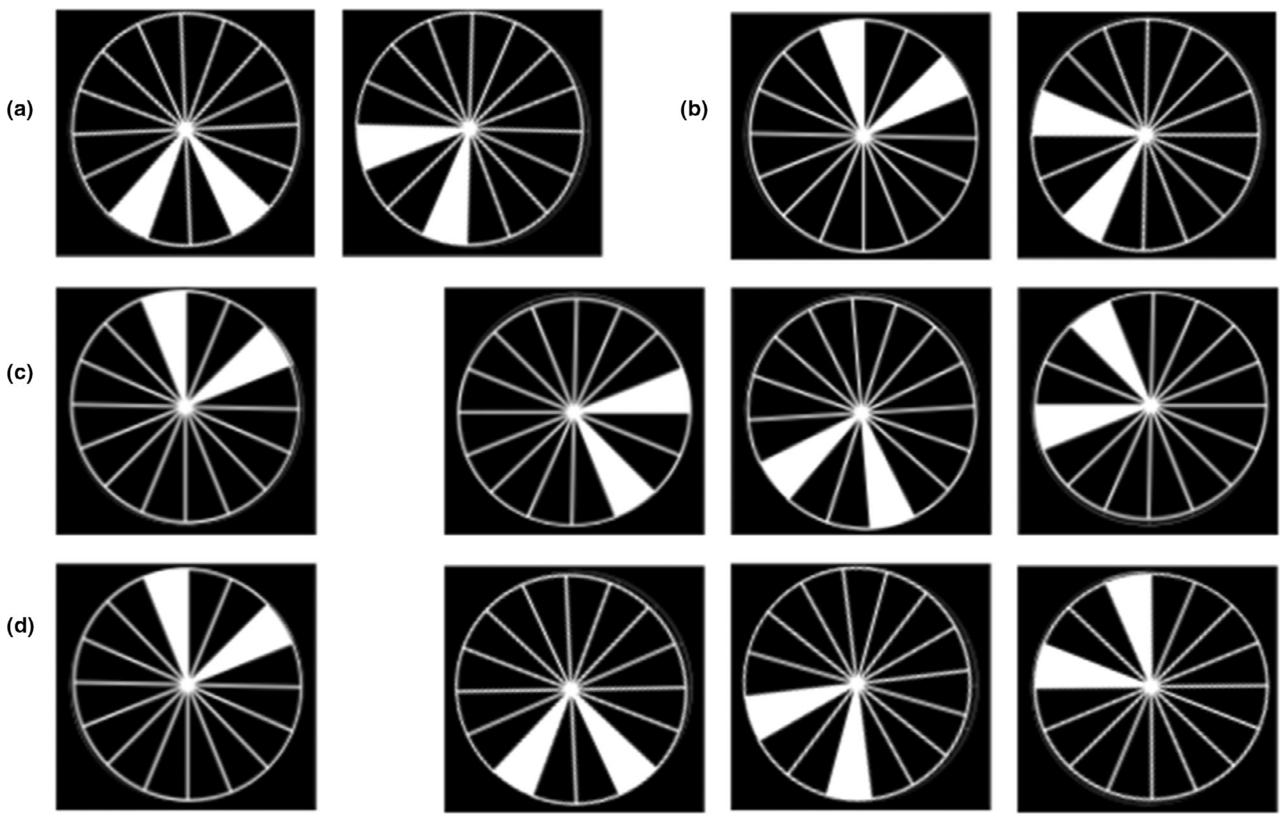

Fig. 1. Easy (a) and hard (b) sample stimuli, and examples of a sample stimulus with (c) all three correct comparison stimuli (90, 180, and 270-° rotations) and (d) three possible distractor stimuli.

identical, except for the angle in which they had been rotated, avoiding effects from other stimuli characteristics such as stimulus type (Tomasino & Gremese, 2016). In order to create two different difficulty levels, we manipulated the distance of the colored parts to the vertical and horizontal axes. When both white portions are placed at equal distance from the vertical or horizontal axes the whole circle could be rotated at once taking the relative placement of the white portions to the axes as reference points (i.e, *easy*), whereas when the portions were not equidistant with a vertical or horizontal axis, the stimulus could need several partial rotations before correct angle identification (which is also known as piecemeal mental rotation; Zhao & Sala, 2018). Thus, the sample stimuli were chosen to create two alternative difficulty levels, an easy condition and a harder one (Fig. 1a,b), expecting that clockwise and counterclockwise rotations would not differ in difficulty (Searle & Hamm, 2017). This was tested in a previous unpublished pilot study ($N = 12$). Results from this pilot study revealed that, as expected, those stimuli that featured white portions that were framed by both axes, or had their colored portions equidistant to an axis, featured a higher average accuracy (difference of means = 15%, 95% Highest Density Interval (HDI) from 9% to 21%, mean of the posterior = 15.3%). Analyses have been performed on accuracy proportion, but means are shown as percentages to improve readability. More information about the statistics employed is detailed below.

Two distractor stimuli, and 12 stimuli that could serve as a comparison or distractor stimuli, depending on the trial, were used. The correct comparison stimulus was rotated 90°, 180° or 270° from the sample stimulus, while another three comparison stimuli (that were presented simultaneously and served as distractors) were rotated between 0° and 337.5°, with increments of 22.5°, except for the 90°, 180°, and 270° rotations (for an example, see Fig. 1c and d). In any given trial, only one correct comparison stimulus was presented.

Procedure

Participants booked an appointment at times specified in a web-based calendar. Upon their arrival, they were briefly informed about the study and subsequently gave their written informed consent. Verbal instructions were provided, highlighting that the computerized task would consist in mentally rotating a stimulus that would appear in the center of their screens. Specifically, they were told that they had to choose the same stimulus that would have appeared on the screen a few seconds earlier rotated 90°, 180° or 270° from its original orientation between four comparison stimuli. Participants were also told that there would be no feedback following their responses and that they had to respond as quickly and accurately as possible. Afterwards, they were accompanied to an experimental room equipped with a computer, where the mental rotation task and the SPQ were individually administered in succession. At the beginning of the mental rotation task, which lasted approximately 15 min, a diagram of an example trial was shown (which was similar to Fig. 2), along with the written instructions, which were as follows: “Welcome to the experiment. A circle will briefly appear in the center of the screen. Pay attention to it, as, after a delay, you will have to recognize the image that you saw, rotated 90°, 270°, or 180° between four options by clicking on it with the mouse. Try to answer as fast and precisely as you can.” Participants were not informed of which of the three correct degrees would appear in any given trial. The viewing distance was about 60 cm.

After reading the instructions, participants completed four practice trials in order to familiarize themselves with the task. Next, the 48 experimental trials randomly presented in two blocks of 24 trials each, began. Two sample stimuli (an easy and a hard one) were assigned to each block, they were counterbalanced across participants. Each trial started with a 1,000 ms fixation cross (+; see Fig. 2). After an interval of 500 ms, the sample stimulus was presented for 1,000 ms. The screen remained blank for 5,000 ms and then four comparison stimuli were shown for either 10,000 ms or until a response was made. The next trial started automatically after a 3,000 ms blank screen. Once the mental rotation task had concluded, participants completed the SPQ.

RESULTS

SPQ data

The descriptive statistics of the scores for each of the three SPQ factors by sex are shown in Table 1.

Since mental rotation tasks with different difficulty levels can be solved by strategies that involve a trade-off between reaction

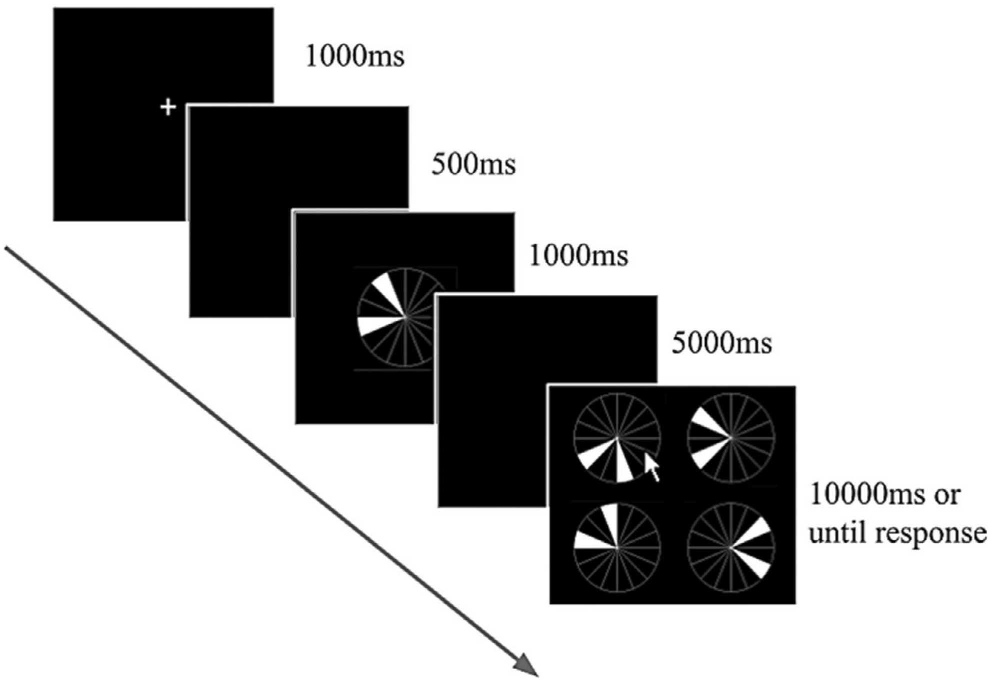

Fig. 2. Schematic representation of the stimulus sequence (from left to right).

Table 1. *Descriptive statistics of the scores of each schizotypy factor measured by the SPQ, as well as total score, as a function of sex*

Men (*n* = 77)										
						Percentiles				
Dimension	*M*	*SD*	Min-Max	Sk	*K*	10	25	50	75	90
Cognitive-perceptual	10.96	6.65	0–26	0.30	−0.65	2	6	11	15.50	21
Interpersonal	12.05	6.61	1–30	0.57	−0.29	3	7	11	17	23
Disorganized	6.34	3.90	0–16	0.50	−0.43	1	3	6	9	12
Total score	26.35	12.54	3–60	0.50	−0.08	10	16.50	26	34	46
Women (*n* = 112)										
Cognitive-Perceptual	8.74	5.70	0–24	0.44	−0.47	2	4	8	14	16
Interpersonal	11.47	6.60	0–29	0.36	−0.43	4	6	11	16	20
Disorganized	4.15	3.34	0–15	0.86	0.54	0	1	4	7	8
Total Score	21.86	11.84	0–55	0.27	−0.26	6	12	22	30	36.80

Note: K = Kurtosis; M = mean; SD = standard deviation; Sk = skewness.

time and accuracy, only accuracy was used to analyze task performance (Liesefeld, Fu & Zimmer, 2015).

Bayesian general linear model

We were interested in evaluating the proportion of correct responses in each condition, as well as the effect schizotypal personality traits levels may exert in performance, and we decided to employ Bayesian data analysis for all our contrasts. Bayesian data analysis does not require making corrections or adjustments when several of these contrasts are made, since there is only one posterior distribution that we can explore from multiple perspectives without affecting the inference process, which may considerably reduce the false alarm rate (Kruschke, 2015).

A Bayesian analysis was conducted which predicted the proportion of correct responses from the variables sex, difficulty, rotation, and the three schizotypy factors in each of these conditions (see the Appendix). This model is a fully-Bayesian counterpart to a frequentist general linear model.

All these analyses were performed using the free software “R” (R Core Team, 2020), with the package “RStan”(Stan Development Team, 2022), employing Markov chain Monte Carlo (MCMC) sampling for full Bayesian statistical inference. For each chain, 12,500 samples were saved after 2,500 warmup samples, with four chains for each analysis, so the total number of samples was 50,000. The Gelman-Rubin test (commonly known as $\hat{R}$) revealed a correct convergence of all the chains, with values below 1.10 for all parameters (Gelman & Rubin, 1992).

Sex and difficulty differences in mental rotation performance

For estimating the differences of means, we generated a posterior distribution from the substraction between the posterior distributions of the means of each condition being compared.

In Bayesian data analysis, the posterior distributions of the parameters of interest (in this case, the difference between means), may be used to make decisions along with their 95% HDI and a Region Of Practical Equivalence (ROPE). The 95% HDI is the span of most credible values and that cover the 95% of this distribution, and the ROPE consists in a range around certain values of interest, such as zero when we are performing mean comparisons. If the HDI completely excludes the ROPE, the values inside the ROPE are said to be not credible. If the HDI falls completely inside the ROPE, we accept these values for practical purposes. If the HDI partially overlaps with the ROPE, the decision is to be withheld (Kruschke, 2011). We will consider as credible all those differences in which the HDI excludes the value zero, therefore, the ROPE for this section will be the interval (0,0). In this section, only those differences that resulted credible in our analyses will be commented on.

Results of men and women performance in the rotation task are depicted in Fig. 3. They revealed that men scored higher in easy 90° trials (difference of means = 19.2%, 95% HDI from 9.2% to 26.5%, mean of the posterior = 17.7%), in easy 180° trials (difference of means = 9.4%, 95% HDI from 2.4% to 16.7%, mean of the posterior = 9.5%), and easy 270° trials (difference of means = 19.4%, 95% HDI from 9.4% to 26.7%, mean of the posterior = 18.0%). No differences were found between men and women in any of the three hard conditions.

Differences were also present, in both groups, between the hard and easy difficulties in all degrees, with the easy difficulty having higher scores from both men (90° difference of means = 33.9%, 95% HDI from 24.1% to 43.2%, mean of the posterior = 33.5%; 180° difference of means = 20.1%, 95% HDI from 11.8% to 27.8%, mean of the posterior = 19.7%; 270° difference of means = 28.0%, 95% HDI from 18.5% to 36.9%, mean of the posterior = 27.4%) and women (90° difference of means = 23.3%, 95% HDI from 15.8% to 29.8%, mean of the posterior = 22.7%; 180° difference of means = 12.8%, 95% HDI from 6.2% to 17.7%, mean of the posterior = 12.0%; 270° difference of means = 13.7%, 95% HDI from 6.5% to 20.5%, mean of the posterior = 13.6%).

Men and women had a similar, but not identical, performance pattern regarding rotation degree. For women, 180° was easier than 90° and 270° in the easy (90° difference of means = 16.5%, 95% HDI from 8.0% to 22.1%, mean of the posterior = 15.0%;

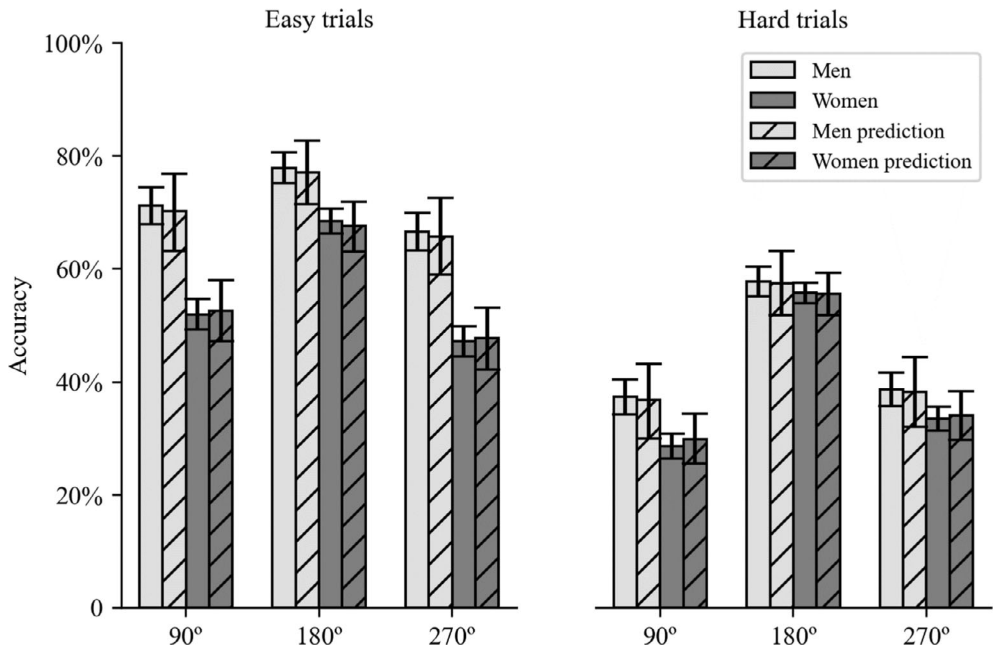

Fig. 3. Mental rotation performance by degree, difficulty, and sex. *Notes*: Means of participants' accuracy percentages as a function of trial difficulty, degree, and sex. Error bars represent the standard error of the mean in the bars labeled "Men" and "Women." Bars with hatches represent the means of the posterior, and their error bars represent the lower and upper limit of the 95% HDI. Predicted data based on the Bayesian linear model also considers the relationship between schizotypal personality traits and performance, in addition to degree, difficulty, and sex. The model showed an adequate fit, as depicted by the similarity between bars with (predicted data) and without (experimental data) hatches.

270° difference of means = 21.2%, 95% HDI from 12.8% to 26.8%, mean of the posterior = 19.8%) and hard conditions (90° difference of means = 27.1%, 95% HDI from 19.8% to 31.4%, mean of the posterior = 25.7%; 270° difference of means = 22.2%, 95% HDI from 15.8% to 27.2%, mean of the posterior = 21.4%). For men, 180° was easier than 270°, but not 90° in the easy condition (270° difference of means = 11.3%, 95% HDI from 2.4%% to 24.2%, mean of the posterior = 11.3%). However, as in women, 180° was easier than 90 and 270° in the hard condition for men (90° difference of means = 20.4%, 95% HDI from 11.9% to 29.3%, mean of the posterior = 20.7%; 270° difference of means = 19.1%, 95% HDI from 10.7% to 27.5%, mean of the posterior = 19.1%).There were no differences between the 90 and the 270° in the easy or hard condition for either group.

Schizotypal personality trait levels and mental rotation performance

From the model previously mentioned and expressed in the Appendix, we also extracted the regression coefficients. Standardized regression coefficients are provided in order to ease the interpretation. A ROPE of (−0.05, 0.05) on the standardized regression coefficients was defined so a change of less than ±0.1 standard deviations on the dependent variable when the predictor variable increases in ±2 standard deviations would be considered negligible (Kruschke, 2018). This variation would correspond to half a small effect size based on Cohen's *d* (Cohen, 1988). No credible effect of schizotypal personality traits was found on the performance of the mental rotation task for any of the sexes (as shown in Table 2) or conditions, nor for the total task accuracy, since none of their 95% HDIs completely excluded the ROPE (−0.05, 0.05).

DISCUSSION

This study was conducted to explore the association between schizotypy and mental rotation in a novel mental rotation task where participants had to discern between different rotations of the same sample stimulus with different difficulty conditions. As expected (Kaufman, 2007; Levine, Foley, Lourenco, Ehrlich & Ratliff, 2016; Parsons, Larson, Kratz *et al.*, 2004; Suzuki, Shikishima & Ando, 2011), men performed better than women, but this only occurred in the easy difficulty condition. Additionally, participants showed a similar response pattern, with higher precision in most 180° trials than 90° and 270° trials (men performed similarly in easy 90° and 180° trials), and a similar accuracy between 90 and 270° trials. It is not surprising that this angle was easier to identify, since mental rotation can be performed with a direct "left is right and right is left" or "up is down and down is up" strategy when axes of the two frames of reference are in direct opposition through a 180° rotation (Shah & Miyake, 2005). The stimuli used in this study, circles with visible axes that could be taken as frames of reference, could facilitate the use of this strategy. The decline in accuracy in the hard trials is also consistent with a possible use of piecemeal (in which participants have to perform separate rotations for each feature to be compared) versus holistic (where participants rotate the stimulus as a whole) mental rotation (Zhao & Sala, 2018). Future studies could assess whether participants did employ one or the

Table 2. *Means of the posteriors of the standardized regression coefficients, and 95% HDI of each SPQ factor as a function of sex for each of the conditions in the task, as well as for participants' total accuracy*

	Sex						
	Men (n = 77)						
		Easy trials			Hard trials		
Dimension	Total accuracy	90°	180°	270°	90°	180°	270°
Cognitive-perceptual	−0.04 (−0.27, 0.18)	0.07 (−0.21, 0.36)	0.01 (−0.26, 0.26)	−0.04 (−0.32, 0.25)	0.06 (−0.22, 0.33)	−0.12 (−0.38, 0.14)	−0.11 (−0.37, 0.16)
Interpersonal	0.14 (−0.16, 0.43)	0.16 (−0.18, 0.50)	0.20 (−0.13, 0.51)	0.16 (−0.19, 0.49)	0.03 (−0.30, 0.36)	0.06 (−0.25, 0.38)	−0.06 (−0.38, 0.27)
Disorganized	0.10 (−0.19, 0.37)	0.04 (−0.28, 0.38)	0.06 (−0.25, 0.36)	0.10 (−0.24, 0.42)	0.05 (−0.28, 0.37)	0.10 (−0.21, 0.40)	0.10 (−0.22, 0.42)
	Women (n = 112)						
		Easy trials			Hard trials		
	Total accuracy	90°	180°	270°	90°	180°	270°
Cognitive-perceptual	−0.09 (−0.30, 0.10)	−0.15 (−0.43, 0.13)	−0.18 (−0.43, 0.07)	−0.05 (−0.33, 0.22)	0.02 (−0.22, 0.28)	−0.14 (−0.37, 0.09)	0.09 (−0.17, 0.33)
Interpersonal	−0.10 (−0.35, 0.15)	−0.09 (−0.42, 0.22)	−0.15 (−0.45, 0.14)	−0.09 (−0.41, 0.23)	0.11 (−0.18, 0.42)	−0.13 (−0.41, 0.15)	−0.03 (−0.32, 0.26)
Disorganized	0.13 (−0.13, 0.38)	0.14 (−0.19, 0.47)	−0.08 (−0.39, 0.22)	0.07 (−0.26, 0.39)	0.21 (−0.10, 0.52)	0.02 (−0.27, 0.30)	0.02 (−0.29, 0.32)

other strategy depending on the task difficulty by using eye-tracking measures or directly asking participants whether they had to perform several different rotations in the hard difficulty.

Regarding schizotypy and mental rotation, no relationship was found between them. Our results are similar to those reported by Jha, Read, Hurd and Crespi (2018) with undergraduate students, as SPQ scores were not associated with performance in a novel mental rotation task. Considering the psychosis continuum (DeRosse & Karlsgodt, 2015), it is expected that clinical populations could show psychotic symptoms at higher severity than non-clinical populations, such as university students, which might not present enough severity of these traits to affect their visuospatial abilities (Martin & Fleming, 2019). Thus, our results might not generalize to populations with a higher intensity of psychotic symptoms. A recent study (Bâ, Curtis & Pellizzer, 2022) found that first-episode psychosis and chronic schizophrenia patients, but not ultra-high-risk individuals showed impaired viewer and object mental rotations. These results, taken together with those from this study, may suggest that schizotypy and psychosis are different constructs. Specifically, populations that show psychosis symptoms at a clinical level have a worse control of their mental imagery than healthy controls, while this worsening has not appeared to be related to schizotypal personality in healthy participants. As mental imagery dysfunctions in psychopathology are related to impaired monitoring – but not vividness – of mental images (van de Ven & Linden, 2012), a pathway towards psychosis disorders could stem from failures in the systems that control and monitor their mental representations, while people with higher positive schizotypy traits (e.g., unusual perceptual experiences) might have a higher degree of agency on them than people that show positive symptoms at the clinical level (Carruthers, 2012). Nevertheless, due to the fact that clinical populations also present several confounding factors, such as illness, medication, or institutionalization (Cohen, Mohr, Ettinger, Chan & Park, 2015), assigning the reason of possible mental rotation effects to psychosis alone in clinical populations should be exerted with caution. Therefore, a different interpretation of these differences could be that medication and other patient-related variables could generate these disparities. Future studies could thus employ samples from different clinical populations that are not related to psychotic disorders (such as people diagnosed with substance use disorders, eating disorders or mood disorders) in order to assess whether mental rotation differences are due to clinical confounds or a core deficit of schizophrenia. Likewise, future studies could feature a sample that encompasses the complete psychosis continuum, including those with higher levels of psychotic symptoms. Furthermore, longitudinal studies of people at clinical high-risk of psychosis could be carried out, assessing whether mental imagery manipulation gets impaired before the onset of psychotic disorders. Future studies could also further explore this issue by, for instance, using tasks with a wider range of difficulties (e.g., tasks that had conditions that ranged from floor to ceiling effects by using, for example, simpler stimuli with a single colored portion) which could better clarify if there is any specific effect of schizotypal personality trait levels when an even easier condition is met. Our results, nevertheless, suggest that difficulty is not related to this lack of association, since we employed two different difficulty levels that ranged from conditions where participants had an accuracy that was bordering chance levels to conditions with accuracies close to 80%. It is worth noting that the importance of the employed analytical approach could be decisive to draw conclusions. When literature is not consistent regarding the existence of a relationship between two variables, such as the case of schizotypy and mental rotation (e.g., Jha, Read, Hurd & Crespi, 2018; Steinisch *et al.*, 2011; Thakkar & Park, 2010; Vastano, Sulpizio, Steinisch, Comani & Committeri, 2014), the effect size should also be taken into account to ensure that the effect is not spurious or due to randomness. As explained above, the use of HDIs and ROPEs using a Bayesian approach may be useful for this purpose (Kruschke, 2011).

A limitation of the present study is that the applied task to assess mental rotation featured a delay between the appearance of the stimulus that had to be rotated and the comparison stimuli, which required that the sample stimulus is maintained in working memory, involving visuospatial storage and processing (Miyake, Friedman, Rettinger, Shah & Hegarty, 2001), while no other working memory processes were assessed. Even though some studies have reported that people with a high level of schizotypal personality traits perform worse in working memory tasks (e.g., Schmidt-Hansen & Honey, 2009; Zouraraki *et al.*, 2016), performance in the present rotation task, which entailed working memory function, did not change as schizotypal personality trait levels increased. Future tasks should present the initial stimulus alongside the rotated targets to reduce the effect of working memory encoding, retention, and retrieval (Griksiene, Arnatkeviciute, Monciunskaite, Koenig & Ruksenas, 2019), as well as to further explore the relationship between different working memory operations (e.g., storage, processing) and systems, and schizotypal personality traits and psychosis disorders in order to investigate possible relationships between disorder onset and different mental imagery impairments. Another limitation of this study is only including healthy undergraduate students. To increase the generalizability of the findings and assess whether there is a differential functioning of schizotypy and mental rotation in clinical and non-clinical samples, it would be desirable to develop studies that included participants from both the general and clinical populations.

CONCLUSION

Our results have shown a sex effect in mental rotation performance as well as no relationship between schizotypy and mental rotation that is consistent with previous literature. These results support that mental imagery manipulation disruptions are not related to non-clinical schizotypal personality traits, but might instead be related to the onset of psychosis disorders. However, additional research is required featuring a sample that encompasses the complete psychosis continuum, including the general population, as well as those with higher levels of psychotic symptoms and psychosis disorders. Future research could also focus on different working memory processes related to mental representation manipulations in other sensory modalities (e.g., one cannot rotate auditory content, so mental rotation performance does not necessarily represent ability to manipulate verbal mental representations, which should be related to auditory hallucinations) and their relationship with schizotypal personality traits and clinical populations. As an example, the ability to inhibit involuntary verbal imagery (e.g., Velasquez, Gazzaley, Toyoda, Ziegler & Morsella, 2021) could be evaluated.

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DATA AVAILABILITY STATEMENT

The employed dataset and script can be accessed at https://osf.io/w6czt/.

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APPENDIX A

Bayesian general linear model

The following model was conducted for predicting the proportion of correct responses from the variables of sex, difficulty, and rotation considering the effect of each schizotypal personality factor:

$$P_{[i]}\tilde{N}\left(p_{[i]},\sigma_{[\mathrm{cond}[i]]}\right), \qquad \text{(A1)}$$

$$p_{[i]} = \beta_{0[\mathrm{cond}[i]]} + \beta_{\mathrm{CP}[\mathrm{cond}[i]]} * \mathrm{CP}_{[i]} + \beta_{\mathrm{IN}[\mathrm{cond}[i]]} * \mathrm{IN}_{[i]} + \beta_{\mathrm{DI}[\mathrm{cond}[i]]} * \mathrm{DI}_{[i]}, \qquad \text{(A2)}$$

$$0 < \beta_{0[\mathrm{cond}[i]]} < 1\tilde{N}\left(0.5,\sigma_{[\mathrm{cond}[i]]}\right), \qquad \text{(A3)}$$

$$0 < \sigma_{[\mathrm{cond}[i]]}E\tilde{x}p(1), \qquad \text{(A4)}$$

$$\beta_{\mathrm{CP}[\mathrm{cond}[i]]}\tilde{N}(0,0.2), \qquad \text{(A5)}$$

$$\beta_{\mathrm{IN}[\mathrm{cond}[i]]}\tilde{N}(0,0.2), \qquad \text{(A6)}$$

$$\beta_{\mathrm{DI}[\mathrm{cond}[i]]}\tilde{N}(0,0.2). \qquad \text{(A7)}$$

The symbol "~" means "distributed as", with $N(x,y)$ indicating a normal distribution with mean $= x$ and standard deviation $= y$, and $\mathrm{Exp}(x)$ indicating an exponential distribution with $\lambda = x$. Equation (A1) represents the likelihood of the model, with P representing the empirical proportion of correct responses for the case *[i]*, which identifies each participant in each condition. Equation (A2) shows the general linear model. Due to the nature of our task, there were 14 possible conditions (indicated by the subscript *cond[i]*), as there were two possible difficulties (Hard and Easy), by three possible rotation degrees (90, 180, and 270), by two possible sexes depending on the participant (Men or Women), as well as one more estimation for the global accuracy in all conditions separately for men and for women. For each estimated proportion of correct responses (p), an intercept (β_0) was employed as an estimate of the mean proportion of correct choices in each condition, and three slope parameters (β_{CP}, β_{IN}, β_{DI}) were employed to calculate the effect schizotypal personality factors may have on each condition. Lastly, the letters CP, IN, and DI, represent the score in the Cognitive-Perceptual factor, the Interpersonal factor, and the Disorganized factor respectively. Data regarding schizotypal personality traits was standardized before running the current model.

Equations (A3–A7) represent the priors of our parameters. Instead of extracting these priors from our sample or using extremely vague priors, we followed recommendations in McElreath (2020) and used plausible priors for all the estimated parameters. With respect to the estimation of the probability of a correct response, we allowed its dispersion to better adjust to the different conditions due to the free values of σ.