Consciousness and Cognition 122 (2024) 103698

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/yccog

Full Length Article

Cognitive flexibility moderates the relationship between openness-to-experience and perceptual reversals of Necker cube

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ARTICLE INFO

Keywords:
Big Five
Bistable perception
Cognitive flexibility
Openness

ABSTRACT

It is not clear whether personality is related to basic perceptual processes at the level of automatic bottom-up processes or controlled top-down processes. Two experiments examined how personality influences perceptual dynamics, focusing on how cognitive flexibility moderates the relationship between personality and perceptual reversals of the Necker cube. The participants viewed stimuli either passively or with the intent to either hold or switch the orientation of the Necker cube. The influence of openness was predominantly evident in conditions necessitating intentional control over perceptual reversals. The link between openness and intentional perceptual reversals was always moderated by cognitive flexibility, which was measured in three different ways. No relationship was detected between personality traits and reversals in the passive viewing condition, suggesting that relatively spontaneous adaptation-inhibition processes may not be personality-dependent. Overall, our research sheds light on the nuanced influence of personality traits on perceptual experiences, mediated by cognitive flexibility.

1. Introduction

Our perceptual world is noisy, dynamic and often ambiguous yet our conscious experience of that world seems comparatively stable. The relative stability of our conscious experience of the perceptual world results from our sensory and cognitive processes which work hard to interpret and resolve this ambiguity into a stable and coherent representation. These processes have been studied by making use of bistable stimuli which have multiple interpretations. It is also well known that individuals differ in how they perceive and interpret the world. For example, persons high in the Big Five trait of neuroticism may be biased to see danger in locations where no obvious threat is present (Jonason & Sherman, 2020). However, it is less clear how personality is reflected in basic perceptual processes. In the present study, we make use of bistable perception to study personality differences in basic visual processes. Because the bistable stimuli stay unchanged and the perceptual interpretation depends on the observer, bistable perception is a useful tool to study individual differences in perceptual processes.

Bistable visual stimuli support at least two different, mutually exclusive interpretations, while the stimulus itself remains unchanged. The Necker cube (Necker, 1832) is a classical ambiguous line-drawn stimulus that can be perceived as in two different orientations in three-dimensional space. For example, the front side of the cube is typically interpreted either in a bottom-right or top-left orientation. In the binocular rivalry paradigm, two different stimuli are presented simultaneously to each eye; the observer, however, does not typically view them simultaneously as the images compete for perceptual dominance (Blake, 2001). During a period

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https://doi.org/10.1016/j.concog.2024.103698
Received 3 March 2024; Received in revised form 2 May 2024; Accepted 6 May 2024
Available online 22 May 2024

of continuous viewing of a Necker cube or binocular rivalry stimuli, observers' perception starts to alternate between the different interpretations. In the present study, we use Necker cubes to study how personality is related to perceptual dynamics.

Both low-level bottom-up and higher-level top-down mechanisms have been suggested, to explain perceptual alterations during bistable perception (Long et al., 1983; Long & Toppino, 2004; Tong et al., 2006; Wilson, 2003). According to low-level explanations, perceptual alterations result from cycles of passive adaptation, recovery, and mutual inhibition of competing neural units in early visual areas (Kornmeier & Bach, 2012). Different groups of neurons code the different perceptual interpretations, which engage in excitatory-inhibitory interactions with each other (Blake, 2001). The alteration of perceptual dominance occurs when the dominant percept is weakened by adaptation, allowing the previously inhibited percept to become dominant.

By contrast, according to top-down explanations, perceptual reversals are mediated by higher-level processes like attention and decision making (Kornmeier & Bach, 2012, Long & Toppino, 2004). For example, the role of top-down processes can be shown by altering instructions: the reversal rates differ depending on whether the observers are asked to look at the stimuli *passively*, to volitionally *hold* their perception unaltered, or to volitionally *switch* their perception (Díaz-Santos et al., 2015). The low-level and high-level mechanisms are not necessarily contradictory. Hybrid models (Sterzer & Kleinschmidt, 2007) assume that higher-level processes in the fronto-parietal areas engage in interaction with the lower-level visual processes, by initiating a re-organization and stabilization of representations through feedback signals from higher-level to the lower-level visual areas.

Individual differences in the perception of ambiguous stimuli have been most clearly observed in psychopathological conditions. Participants with autism spectrum disorder have been observed to experience fewer perceptual reversals than controls, during the viewing of ambiguous stimuli (Kornmeier et al., 2017; Sobel et al., 2005). A study on binocular rivalry (Ye et al., 2019) found that persons with bipolar disorder, schizophrenia, major depressive disorder, and obsessive–compulsive disorder exhibited slower perceptual reversal rates compared to healthy controls. McBain et al. (2011) examined the influence of schizophrenia on the perception of Necker cube stimuli. They found that schizophrenia negatively impacts voluntary control over the interpretation of bistable images (McBain et al., 2011). Relative to passive viewing, compared to normal controls, patients with Parkinson's disease exhibit a significantly lowered capacity in reducing dominance durations in the condition requiring switching of the Necker cube's orientation (Díaz-Santos et al., 2015). This finding indicates perceptual rigidity or a lack of cognitive flexibility in Parkinson's disease.

Few studies have investigated the possible relationship between personality traits and individual differences in perceptual switching in non-clinical populations. An early study using Necker cube stimuli suggested that authoritarianism correlated negatively with reversals when participants were instructed to try and fluctuate the cube as frequently as possible (Jones & Hunt, 1955). The Big Five personality trait model is the prominent model of personality. According to this model, personality consists of five general personality traits: openness, conscientiousness, extroversion, neuroticism, and agreeableness (Goldberg, 1993; McCrae & Costa, 1987; Lang et al., 2011). A study (Antinori et al., 2017b) found that those who score high in industriousness (which is linked to high levels of self-restraint, efficiency, and work ethic) exhibit lower rates of perceptual reversals during binocular rivalry. Industriousness is a facet of the personality trait of conscientiousness. In contrast to this finding, Blake & Palmisano (2021) found no significant relationship between industriousness and perceptual reversals during passive viewings of Necker cube stimuli. They did, however, find in an exploratory analysis that there was a positive relationship between openness and perceptual reversals. Research on binocular rivalry has found evidence that heightened levels of openness is associated with increased rates of mixed percepts and shorter average percept periods (Antinori et al., 2017a; Koivisto et al., 2023). A similar effect has been reported in the perception of structure-from-motion test-cylinders (Poom & Matin, 2022). Mixed percepts occur when components of two stimuli are perceived as a mixture of both with neither stimulus overpowering the perception of the other. In a study conducted by Koivisto et al. (2023) the correlation of openness with rates of mixed percepts was mediated by cognitive empathy. However, it is not clear whether the unique pattern of bistable perception in open personalities results from low-level mechanisms in visual areas, such as more flexible inhibition systems (Antinori et al., 2017a), or from cognitive flexibility in higher-level top-down processes (Koivisto et al., 2023). The top-down hypothesis proposed by Koivisto et al. was grounded in the finding that cognitive empathy mediated the relationship between personality and perception. Cognitive empathy is strongly related to perspective shifting and cognitive flexibility (for *meta*-analysis, see Yan et al., 2020), suggesting that cognitive flexibility may be a key factor underlying the effects of personality on bistable perception.

Cognitive flexibility refers to a person's awareness that in any given situation there are alternatives and options available. It is characterised by a willingness to be flexible and adapt to a situation as well as self-efficacy in being flexible (Martin & Rubin, 1995). The Cognitive Flexibility Scale (CFS) developed by Martin and Rubin is a self-rating scale which consists of statements like "I can communicate an idea in many different ways", "I avoid new and unusual situations", or "I have many possible ways of behaving in any given situation.". Thus, cognitive flexibility defined in this way, refers to an individual's socio-cognitive style rather than to more specific cognitive abilities, and it correlates with prosocial attitudes and behavior like tolerance among religious groups (Lubis & Sianibar, 2022) and racial tolerance (Shen et al., 2013). Another way to define cognitive flexibility is to consider it as part of executive functions (EFs). The model proposed by Miyake et al. (2000) suggests that EFs consist of three processes: cognitive flexibility, inhibition, and updating/monitoring the contents of working memory. In this context, cognitive flexibility refers to the ability to shift one's attention between multiple tasks or mental sets. Cognitive flexibility correlates with the trait of openness when defined either as a broad socio-cognitive style (Lubis & Sianibar, 2022) or as part of EFs (Murdock et al., 2013). Preliminary evidence for a correlation between cognitive flexibility, measured with a task-switching paradigm, and perceptual flexibility during the passive viewing of Necker cube stimuli was provided by Sekutowicz et al. (2016) in a brain imaging study. They found a weak correlation between perceptual flexibility (switching of the Necker stimulus) and cognitive flexibility on a behavioral level. The mean phase duration, however, was strongly associated with neural activation related to task switching, suggesting that perceptual and cognitive switching may share a common mechanism.

It remains unclear at which processing level the previous findings of personality differences in the perception of bistable stimuli have arisen (Antinori et al., 2017a, b; Blake & Palmisano, 2021; Koivisto et al., 2023). Here we studied the relationship between personality traits, cognitive flexibility, and perceptual flexibility in bistable perception using a paradigm that allowed us to separate controlled top-down processes from more spontaneous bottom-up processes. The participants were presented with Necker cubes, displayed after unambiguous cubes. These cubes were presented in a *passive* viewing condition or in a condition where participants were instructed to attempt to view the Necker cube in either the same orientation (*hold* condition) as or the opposite orientation (*switch* condition) to the unambiguous cube which preceded it. In experiment 1, we studied whether self-reported cognitive flexibility would moderate the relationship between personality traits and reversals. We used a variation of intermittent Necker cube presentation (Orbach et al., 1966), in which the stimuli are presented many times with short inter-stimulus intervals (ISIs) provoking instantaneous reversal of the ambiguous figure at the onset of its appearance. Experiment 1 studied the relationship between bistable perception and all the Big Five personality traits and the results motivated us to focus specifically on the trait of openness in Experiment 2.

2. Experiment 1

In experiment 1, we tested whether the Big Five personality traits were related to perceptual reversals of the Necker cube stimuli at low-level bottom-up processes or controlled top-down processes. We also examined whether these possible relationships depended on cognitive flexibility. We hypothesized that if personality traits affect perceptual reversals at low-level processes, then personality traits should be related to reversal rates in the passive task condition where the participants are not explicitly asked to alter their perception (i.e., they simply passively view the stimuli). Alternatively, or in addition, if personality traits are related to individual differences in perceptual reversals at the level of controlled top-down processes, one should observe the effects of personality traits when the task is either to perceive the Necker cube in the same orientation (hold condition) or in the opposite orientation (switch condition) of the unambiguous cube. On the other hand, we hypothesized that if perceptual and cognitive flexibility share resources (Sekutowicz et al., 2016), individuals especially high in cognitive flexibility would be able to voluntarily control their perceptual reversals more frequently than the average person. According to this hypothesis, cognitive flexibility would predict higher perceptual reversal rates (when compared to the passive condition) in conditions where the participants were asked to hold or switch the orientation of the ambiguous Necker cube in relation to the unambiguous cube. In addition, if the relationship between personality traits and controlled reversals depends on cognitive flexibility, an interaction between the task condition, personality trait, and cognitive flexibility should be observed.

2.1. Method

2.1.1. Participants

This study was conducted online using PsyToolkit (Stoet, 2010, 2017) with a total of 160 participants. Seven of the participants failed the attention check trials, scoring 2 standard deviations (SD) below the group mean on the easy control trials which included only unambiguous cubes embedded in the experiment (see Section 2.1.3). The average age of the remaining 153 participants (89 females, 60 males, 3 other, and 1 preferred not to identify their gender identity) was 27.0 years, ranging from 18 to 59 years old. The sample size was based on related past studies (Antinori et al., 2017a; Blake & Palmisano, 2021; Koivisto et al., 2023).

There was a Finnish version and an English version of this study. Of the 153 participants, 86 completed the Finnish version and the remaining 74 participants completed the English version. The Finnish participants were required to be fluent in Finnish and the English version participants were fluent in English. All the participants of the Finnish version were students attending the University of Turku. These students had the possibility of receiving course credits in introductory psychology courses for their participation. The participants for the English version were gathered from around the world. A majority of them resided in the United Kingdom (46 participants) or in the European Union (17 participants). The remaining 11 participants for the English version resided in Australia, the United Arab Emirates, Malaysia, India, and the United States of America. The participants for the English version were collected via social media (r/SampleSize reddit forum, Facebook groups) or via Prolific (https://www.prolific.co) where they were paid 3.78£ for their participation. Informed consent was obtained from each participant. The study was carried out in accordance with the Declaration of Helsinki and it was accepted by the Ethics Committee for Human Sciences at the University of Turku.

2.1.2. Design and questionnaires

All participants in this study were exposed to the experimental phase of the study and three personality questionnaires. The experimental phase consisted of three tasks using ambiguous and unambiguous cube stimuli. This phase had the Task (3: passive, hold, switch) as a within-subjects variable. The experimental tasks were performed before filling-in the questionnaires. The questionnaires measured the Big Five personality traits, cognitive flexibility, and cognitive empathy. The scores from these measures were used as continuous variables in the analyses of the experimental data.

The Short 15-item Big Five Inventory (BFI-S) (Lang et al., 2011) measured the five personality traits (neuroticism, extroversion, openness, agreeableness, and conscientiousness) with 15 statements (3 items/trait) and asked participants to respond with their level of agreement or disagreement on a seven-point Likert scale (from *strongly disagree* to *strongly agree*). Example statements: I see myself as someone who… “worries a lot” (neuroticism)”, “is talkative” (extroversion), “is original, comes up with new ideas” (openness), “is sometimes rude to others” (agreeableness, reversed), “does a thorough job” (conscientiousness).

Cognitive flexibility was measured by the Cognitive Flexibility Scale (CFS) (Martin & Rubin, 1995). The CFS collected data relating to the degree a participant agreed or disagreed with statements dealing with their personal beliefs and feelings about their behavior using a six-point Likert scale. The statements included in this questionnaire were about problem solving behavior (both individual and group) as well as statements about their behavior in new situations and statements about their communication behavior (e.g., "I can communicate an idea in many different ways").

For exploratory purposes, motivated by Koivisto et al.'s (2023) study, the empathy questionnaire Basic Empathy Scale in Adults (BES-A) (Carré et al., 2013) was included, but its results are reported only in the Supplementary File. This questionnaire measured cognitive and emotional empathy with statements related to a participant's perception of emotions in others and how witnessing these emotions made them feel. The participants responded on a five-point Likert scale with how much they agreed or disagreed with these statements.

2.1.3. Experiment: Stimuli and procedure

An ambiguous Necker cube and unambiguous cubes were the two types of stimuli used in the cognitive tasks of this study. The experimental part manipulated the cognitive task (passive, hold, switch) in order to collect information about each participant's perception of the Necker cube's orientation. These stimuli were white, appearing on a black background (Fig. 1). The unambiguous cubes, which had an objective orientation (bottom-right or top-left orientation), served as a reference onto which the participants' perception of the ambiguous Necker cube's orientation was compared. The size of the cubes' front and back faces was 300 × 300 pixels.

Before starting the cognitive tasks, participants were presented a Necker cube and asked to perceive it in both a bottom-right and top-left orientation. In addition, the participants were familiarized with the response buttons. Participants were instructed to use these response buttons to indicate whether two unambiguous stimuli (presented in a similar sequence as the experimental trials described below) had the same or different orientation. Once participants had successfully perceived the Necker cube in both orientations and performed the familiarization task successfully in six successive trials, the three cognitive tasks (passive, hold, switch) were presented.

Each trial (Fig. 1) began with a warning signal lasting 500 ms. Dependent on the task block, this warning signal was either the word "Ready", "Hold", or "Switch". The warning signal was followed by a fixation cross (+) lasting 1000 ms. After this, an unambiguous cube was presented for a duration of 800 ms, randomized to appear in either a bottom-right or top-left orientation. The unambiguous cube was followed by a blank screen for 400 ms before the second stimulus was presented for 400 ms – this second stimulus was either a Necker cube or, in the case of control trials, an unambiguous cube. The positions of the stimuli were jittered by 15 pixels to the up-left, up-right, down-left, or down-right to prevent afterimages. At the end of each trial, the participants indicated whether they perceived the second stimulus in the same (left-arrow button) or in a different (right-arrow button) orientation compared to that of the first (unambiguous) stimulus. If they did not perceive the second stimulus in any 3D-orientation, they were asked to press the down-arrow button.

The three tasks were a passive task, a hold task, and a switch task. In the passive task the participants were asked to passively perceive the stimuli. The hold task required participants to attempt to hold their initial perception of the first cube's orientation – with the intent that this action would increase the likelihood of them perceiving the second cube in the same orientation. In the switch task participants were asked to attempt to reverse their perception of the orientation of the first cube so that the second stimulus would be perceived in this reversed orientation. In all the tasks, the participants were asked to respond according to the first orientation in which the second stimulus was perceived and to ignore any possible reversals occurring after the firstly perceived orientation.

The three tasks were presented in separate blocks. The passive task was always the first to be presented; the order of the hold and switch tasks were counterbalanced across the participants. The passive task was always first, to prevent any carry over from the instructions provided in the hold and switch tasks. Each task involved 20 trials, in 16 of them the second stimulus was a Necker cube and in four of them (control trials) an unambiguous cube was presented second. In both the Necker cube trials and control trials, the first unambiguous cube was presented an equal number of times in a bottom-right and top-left orientation. For half of these control trials the second unambiguous stimulus was presented in reversed orientation relative to the orientation of the first unambiguous stimulus. In each task, the Necker cube and control trials were presented in a random order. Each of the three tasks were preceded by 6 practice trials of the task at hand.

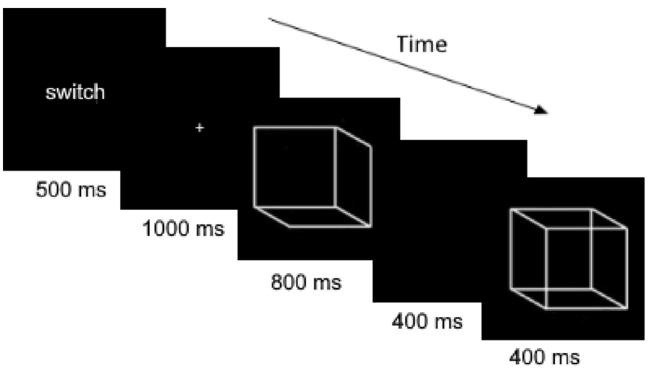

Fig. 1. An example trial in the switch task with the Necker cube as the second stimulus. The unambiguous cube was presented for 800 ms, followed by a 400 ms blank screen after which the Necker cube was presented for 400 ms.

2.1.4. Statistical analyses

The analysis scripts and data are available at OSF.io (https://osf.io/428cv/). The experimental results were analyzed using the lme4 (Bates et al., 2015) package in the R statistical software 3.5.0 (R Core Team, 2021). The results were illustrated using the ggplot2 (Wickham, 2016) and sjPlot 2.4.1 (Lüdecke, 2019) packages. Cronbach's alpha and correlations were calculated with the IBM SPSS Statistics 28.

The control trials in the cognitive tasks consisted of unambiguous cubes, therefore they involved *real* reversals or non-reversals of the stimuli. These trials should be easy for participants who attend to the stimuli. Before the data analyses, we removed the data from the participants ($n = 7$) whose accuracy in the control trials was more than 2 SD below the group mean. Thus, data from 153 participants remained for the analyses of the cognitive tasks.

We began the analyses of the cognitive data with a generalized linear mixed-effect model on reversals with Task (passive, hold, switch) as the fixed effects and random intercept as the random effects. The continuous variables were scaled with the R's scale() function, that is, they were centered and normalized ($M = 0$, $SD = 1$). All single trials were entered into the analyses. The passive task served as the reference category. In the next phase, the scaled five personality trait scores (continuous variable) and their interactions with Task were entered as fixed effects. After this, we studied whether cognitive flexibility alone was related to perceptual reversals in the three cognitive tasks by entering the scaled CFS, Task, and their interaction as fixed effects into a generalized linear mixed-effect model. This was followed by a model in which the personality traits which showed interaction with Task were included in a model which also had Task and CFS interactions as fixed effects.

2.2. Results

2.2.1. Scales

Internal consistencies of the personality scales and their inter-correlations were studied before moving to the analyses of the experimental tasks. Cronbach's alpha was good for Cognitive empathy (0.850), Neuroticism (0.818), and Extroversion (0.841); acceptable for the CFS (0.755), Openness (0.764), and Conscientiousness (0.620); and poor for Agreeableness (0.464). Cronbach's alpha is sensitive to the number of items. The assessment of the Big Five traits was based only on 3 items per trait, so relatively low alpha values for some of the Big Five traits were quite expected. We performed a confirmatory factor analysis to verify the five-trait structure of the BFI-S. The fit of this model to our data was acceptable, RMSEA = 0.077, CFI = 0.901, TLI = 0.870, SRMR = 0.080, confirming the hypothesized five-factor structure.

Table 1 presents descriptive statistics and the intercorrelations (Pearson) between the Big Five personality traits and cognitive flexibility. Openness had a moderate correlation ($r > 0.30$) with the CFS. In addition, the CFS correlated moderately with Conscientiousness, Extroversion, and Cognitive Empathy, while the CFS correlated negatively with Neuroticism. Cognitive empathy showed additional moderate correlations with Extroversion and Agreeableness.

2.2.2. Cognitive tasks

The observed perceptual reversal proportions as a function of Task were 0.514 (SD = 0.164) for the passive task, 0.409 (SD = 0.216) for the hold task, and 0.563 (SD = 0.207) for the switch task (Fig. 2). A generalized linear mixed-effect model (family = binomial) on reversals in the critical trials with Task as the fixed effect showed that reversals were less frequent in the hold task than in the passive task ($B = -0.442$, $SE = 0.059$, 95% CI [−0.558, −0.327], $z = -7.478$, $p < 0.001$) and more frequent in the switch task than in the passive task ($B = 0.211$, $SE = 0.059$, 95% CI [0.096, 0.326], $z = 3.583$, $p < 0.001$).

2.2.3. Big Five traits as predictors of perceptual reversals

The Task and each Big Five personality trait with Task × Trait interactions were entered into the linear mixed-effect analysis as fixed effects. The results showed that Openness was related to a heightened probability of reversals in the switch task condition (Table 2). In addition, there was a smaller negative relation between Agreeableness and reversals in the switch task. Thus, the higher the Openness, the more frequent the occurrence of reversals in the switch task. Whereas Agreeableness was observed to result in less frequent reversals in the switch task. None of the five personality traits were related to reversal rates in the passive or hold tasks.

Table 1
Intercorrelations and Descriptive Statistics for Big Five Personality Traits, and Cognitive Flexibility (CFS).

	1	2	3	4	5	6
1. Openness						
2. Conscientiousness	0.098					
3. Extroversion	0.252**	0.214**				
4. Agreeableness	0.181*	0.209**	0.210**			
5. Neuroticism	−0.118	−0.209**	−0.216**	−0.107		
6. CFS	0.401**	0.445**	0.467**	0.256**	−0.475**	
Mean	5.26	4.92	3.78	5.07	4.30	52.11
SD	1.17	1.07	1.48	1.05	1.50	6.81
Min	1	2	1	2	1	35
Max	7	7	7	7	7	72

Note. *$p < 0.05$, **$p < 0.01$.

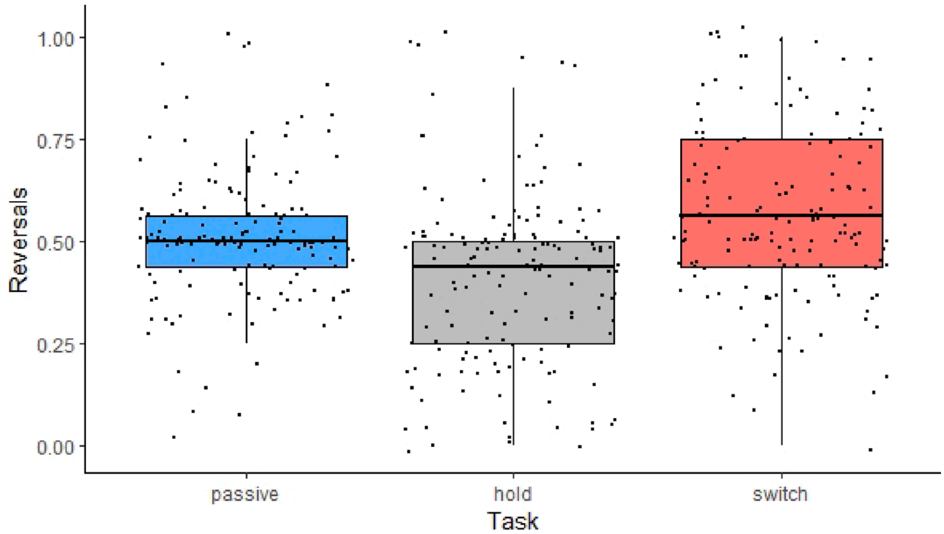

Fig. 2. Reversal proportions in the passive, hold, and switch tasks. The dots represent each individual's data.

Table 2
Big Five Personality Traits as Predictors of Reversal Rates in Passive (Reference), Hold, and Switch Conditions.

Predictors	B	SE	95% CI	z	p
(Intercept)	0.064	0.059	−0.050 – 0.171	1.140	0.252
Task [hold]	−0.444	0.058	−0.560 –-0.328	−7.490	0<.001***
Task [switch]	0.213	0.059	0.097 – 0.329	3.610	0<.001**
Openness	−0.064	0.059	−0.180 – 0.050	−1.100	0.271
Extroversion	−0.016	0.061	−0.135 – 0.103	−0.270	0.791
Conscientiousness	0.035	0.059	−0.081– 0.151	0.590	0.558
Agreeableness	−0.002	0.059	−0.118 – 0.113	−0.380	0.969
Neuroticism	−0.01	0.058	−0.124 – 0.105	−0.170	0.866
Task [hold]:Openness	−0.004	0.062	−0.125 – -0.117	−0.060	0.838
Task [switch]:Openness	0.18	0.061	0.060 – 0.300	2.940	0.003**
Task [hold]:Extroversion	0.110	0.064	−0.114 – 0.136	0.170	0.864
Task [switch]:Extroversion	−0.010	0.063	−0.104 – 0.144	0.320	0.752
Task [hold]:Conscientiousness	0.053	0.062	−0.069 – 0.176	0.850	0.396
Task [switch]:Conscientiousness	−0.107	0.062	−0.229 – 0.015	−1.720	0.086
Task [hold]:Agreeableness	0.025	0.062	−0.096 – 0.146	0.400	0.690
Task [switch]:Agreeableness	−0.132	0.062	−0.253 – −0.010	−2.130	0.033*
Task [hold]:Neuroticism	−0.053	0.061	−0.173 – 0.067	−0.860	0.387
Task [switch]:Neuroticism	−0.001	0.062	−0.121 – 0.121	−0.002	0.999

Note. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Before testing whether self-reported cognitive flexibility as measured with the CFS, moderated the relationship of personality traits with perceptual reversals, we studied whether cognitive flexibility alone was related to perceptual reversals in the three cognitive tasks by entering the centered CFS, Task, and their interaction as fixed effects into a linear mixed-effect model. Reversal rates did not depend on cognitive flexibility in the passive task (B = −0.051, SE = 0.056, 95% CI [−0.161, 0.060], z = −0.903, p = 0.367). The effect of cognitive flexibility in the hold task (B = −0.014, SE = 0.059, 95% CI [−0.101, 0.129], z = 0.238, p = 0.812) or in the switch task (B = 0.073, SE = 0.059, 95% CI [−0.042, 0.188], z = 1.240, p = 0.215) did not differ from that in the passive task.

The results from the model testing whether the relationship between perceptual reversals and Openness and Agreeableness is moderated by cognitive flexibility is shown in Table 3. The moderation effects of Openness and Agreeableness on reversals in the switch task remained statistically significant after accounting for cognitive flexibility, but only the effect of Openness was moderated by cognitive flexibility. The higher the CFS score, the larger the effect of Openness on the difference between reversals in the switch task and passive task (Fig. 3).

2.3. Discussion

It has remained unclear at which processing level the personality differences in perception of bistable stimuli arise (Antinori et al., 2017a, b; Blake & Palmisano, 2021; Koivisto et al., 2023). Experiment 1 found that personality moderated perceptual reversals of Necker cube stimuli only at the level of controlled processes in the task condition where intentional switching of perception was

Table 3
Openness, Agreeableness, and Cognitive Flexibility (CFS) as predictors of reversal rates in Passive (Reference), Hold, and Switch Conditions.

	B	SE	95% CI	z	p
(Intercept)	0.079	0.06	−0.039 – 0.197	1.310	0.189
Task[hold]	−0.428	0.063	−0.552 – −0.304	−6.770	0<.001***
Task[switch]	0.165	0.063	0.042 – 0.289	2.630	0.009**
Openness	−0.064	0.065	−0.191 – 0.062	−1.000	0.320
CFS	−0.032	0.063	−0.156 – 0.092	−0.510	0.612
Agreeableness	0.014	0.059	−0.102 – 0.129	0.230	0.817
Task[hold]:Openness	−0.005	0.068	−0.138 – 0.128	−0.070	0.941
Task[switch]:Openness	0.223	0.068	0.090 – 0.356	3.290	0.001**
Task[hold]:CFS	0.002	0.066	−0.128 – 0.132	0.280	0.978
Task[switch]:CFS	0.034	0.066	−0.096 – 0.163	0.510	0.609
Openness:CFS	−0.027	0.056	−0.136 – 0.082	−0.480	0.628
Task[hold]:Agreeableness	0.042	0.062	−0.079 – 0.164	0.690	0.493
Task[switch]:Agreeableness	−0.152	0.062	−0.274 – −0.032	−2.470	0.014*
CFS:Agreeableness	−0.03	0.057	−0.141 – 0.081	−0.530	0.594
Task[hold]:Openness:CFS	−0.033	0.058	−0.148 – 0.082	−0.560	0.573
Task[switch]:Openness:CFS	0.149	0.059	0.034 – 0.264	2.540	0.011*
Task[hold]:CFS:Agreeableness	−0.007	0.059	−0.123 – 0.110	−0.110	0.910
Task[switch]:CFS:Agreeableness	−0.043	0.06	−0.160 – 0.074	−0.720	0.474

Note. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
CFS = Cognitive Flexibility Scale.

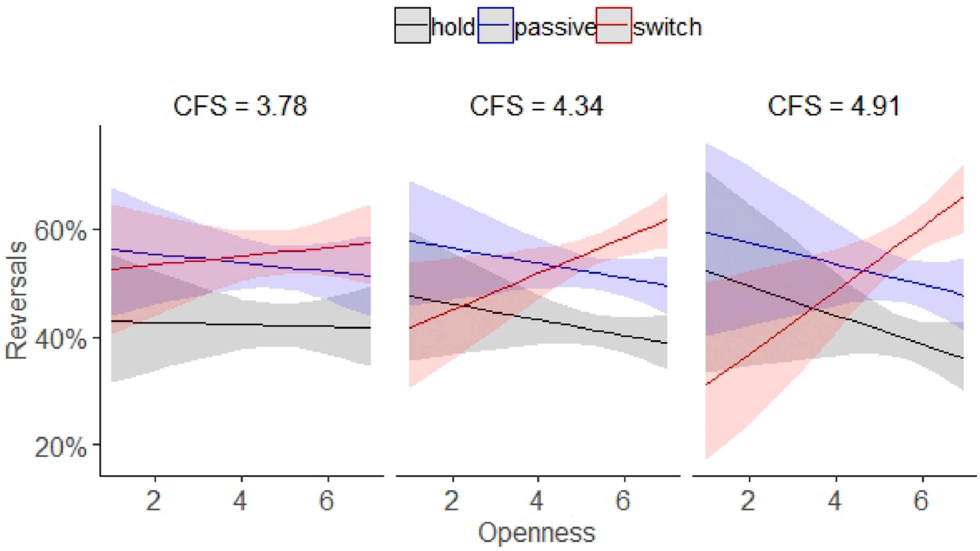

Fig. 3. The modeled 3-way interaction between Task, Openness, and Cognitive flexibility (CFS). The three panels represent the interaction between Openness and Task at three points: 1 SD below the mean of the CFS, at the mean of the CFS, and 1 SD above the mean. The values have been back-transformed to the original scale. The shaded areas represent 95% CIs.

required. In the passive viewing condition, which can be assumed to reflect more spontaneous reversals when compared with the other conditions, no personality effects were detected. Even so there is ample time for participants to control their perception even in this condition. Thus, the results suggest that the personality differences emerge at the level of top-down processes, especially in conditions requiring flexible manipulation of mental images (switch task), but not necessarily in conditions requiring primarily inhibition. In addition, it was the trait of openness which was most clearly related to reversals in the switch condition. Cognitive flexibility alone did not predict perceptual reversals in any of the conditions. In line with the top-down interpretation of personality differences, the relationship between openness and perceptual reversals was moderated by cognitive flexibility. The more cognitively flexible the persons high in openness was, the more intentional reversals occurred in the switch condition, when compared with those in the passive condition.

One should note that cognitive flexibility on its own, measured with the CFS, did not moderate perceptual reversals in any of the task conditions, neither did it interact with any other personality trait than openness. Thus, persons high in openness are perceptually flexible if they are also cognitively flexible but cognitive flexibility, on its own, does not guarantee perceptual flexibility.

There were some weaknesses in Experiment 1. The CFS measured cognitive flexibility with self-reports, which are often susceptible to response biases. In addition, the experimental task directly asked for a report of whether the observers experienced a reversal, a procedure which may also be influenced by participants' bias to respond positively (or negatively). In Experiment 2, we tried to replicate the relationship between openness, cognitive flexibility, and perceptual flexibility with some improvements in these aspects of the tasks.

3. Experiment 2

In the previous experiment cognitive flexibility was measured with self-reporting methods. Experiment 2 assessed cognitive flexibility based on more objective task performances. Openness correlates with creativity (Feist, 1998; Silvia et al., 2009) and creativity is often measured with divergent thinking tasks. Such open-ended tasks do not have pre-defined correct answers, rather the participants are required to produce diverse responses to prompts. The ability to generate diverse ideas by shifting between concepts reflects the ability to think flexibly. Here we used two divergent thinking tasks, the Figural Interpretation Quest (FIQ) (Erwin et al., 2022; Koutstaal et al., 2022) and the Alternate Uses Task (AUT) (Guilford, 1967). In FIQ, a nonsense figure is presented and the task is to generate different interpretations for this non-sense figure. In AUT, participants are asked to generate unusual creative uses for a common object (e.g., brick). Flexibility in divergent thinking tasks has traditionally been scored in different ways; for example, by counting the number of different categories from which a participant produces the responses or as the number of shifts of categories between successive responses. In the present study, we used the objective text-mining approach (Grajzel et al., 2023) to quantify the flexibility of divergent thinking. The idea of this approach is to measure the semantic distance between successive responses. The semantic distance can be objectively quantified on the basis of large semantic spaces derived from numerous texts (e.g., Beaty & Johnson, 2021). The more distant the responses are from each other, the more flexible the thinking.

The present perceptual tasks included the passive, hold, and switch tasks. There were two changes to these tasks. First, instead of indicating whether the Necker cube was perceived in the reversed orientation or not, relative to the unambiguous cube, the task was to indicate the orientation of the Necker cube. This change was assumed to reduce the possible bias to respond positively (or negatively) to the question about whether reversals occurred or not because only the orientation of the second cube stimulus had to be judged. Second, the fixation cross was present until the offset of the second stimulus, which was assumed to help participants to keep eyes fixed throughout the stimulus presentation.

On the bases of the results of Experiment 1, we had pre-registered the following hypotheses: (1) Openness predicts the ability to intentionally reverse the orientation of the Necker cube. (2) Divergent thinking (FIQ, AUT) and cognitive flexibility (CFS) predicts an ability to reverse or hold the orientation of a Necker cube. (3) The effect of openness on perceptual reversals in the switch task is moderated by cognitive flexibility (CFS) and divergent thinking (especially by flexibility in FIQ which asks for dissimilar interpretations for ambiguous figures).

3.1. Method

The experiment was pre-registered at OSF.io (https://osf.io/428cv/).

3.1.1. Participants

The invitation to participate was sent via Prolific (https://www.prolific.co) to 210 participants who had about 2 months earlier taken part in another study examining the relationship between creativity/divergent thinking, openness to experience, and functional blindness. Therefore, we already had their scores for the divergent thinking tasks and openness. All of them were successful in the attention check trials which involved recognition of an animal presented simultaneous with 3 non-animals for 1000 ms and they scored at least 50% correct in an easy change detection task without interruption between the original and changed images. The required sample size was estimated on the basis of Experiment 1. Of the invited participants, 151 participants completed the present experiment with PsyToolkit (Stoet, 2010, 2017). Ten participants failed the pre-registered attention check criteria (i.e., scored 2 SD below the group mean when responding to the orientations of the unambiguous cubes in the control trials; unambiguous cubes were embedded in the experiment identical to what was done in Experiment 1, Section 2.1.3.) and their data was eliminated. Thus, the data analyses were based on 141 participants' results (67 females, 71 males, 2 other, and 1 preferred not to reveal their gender identity). The average age of participants was 31.4 years, ranging from 21 to 40 years. For this study there was only an English version and all the participants were native English speakers. The participants were paid 2£ for the roughly 13 min of participation. They resided in the United Kingdom (97 participants), Ireland (3), USA (35), or Canada (6). Informed consent was obtained from the participants. The study was carried out in accordance with the Declaration of Helsinki and it was accepted by the Ethics Committee for Human Sciences at the University of Turku.

3.1.2. Design and questionnaires

All participants in this study filled in the CFS scale (Martin & Rubin, 1995). Cronbach's α for the CFS was 0.86 in the present sample. After filling-in the CFS, the participants completed the experimental phase of the study. The experimental phase consisted of three tasks (passive, hold, switch) using ambiguous and unambiguous cube stimuli, with a slightly different procedure to that of Experiment 1. In addition, about two months earlier the participants had filled in 12 items measuring Openness from The Big Five Inventory–2 (BFI-2) (Soto & John, 2017) and performed two divergent thinking tasks (FIQ and AUT, each with four items).

Openness measured with the Big Five Inventory–2 (BFI-2) (Soto & John, 2017). Only the 12 items measuring the Big Five trait Openness and its three facets (Intellectual Curiosity, Aesthetic Sensitivity, Creative Imagination) were filled in using a 5-point Likert scale ranging from *disagree strongly* to *agree strongly.* Cronbach's α for the trait Openness score was 0.87.

Figural Interpretation Quest (FIQ). The FIQ tasks included four non-sense object figures (Erwin et al., 2022; subset from stimuli of Koutstaal et al., 2003), with the instructions modified for the purpose of the present study. Each figure was shown for 30 s. The participants were asked to think creatively and generate two interpretations for what the image could represent. They were asked to imagine the two most *semantically different* interpretations they could. The interpretations were entered into two text boxes which were located below the figure.

Alternate Uses Task (AUT). These tasks included four object names (rope, box, pencil, candle), each presented for 30 s. The instructions followed that of Beaty and Johnson (2021): "For the next task, you'll be asked to come up with original and creative uses for an object. The goal is to come up with creative ideas, which are ideas that strike people as clever, unusual, interesting, uncommon, humorous, innovative, or different. Your ideas don't have to be practical or realistic; they can be silly or strange, even, so long as they are creative uses rather than ordinary uses. You can type in as many ideas as you can, but creative quality is more important than quantity. It's better to have a few really good ideas than a lot of uncreative ones. You have 30 s to respond to each object". During the presentation, participants entered their responses into text boxes which were located below the object name.

Flexibility was operationalized as semantic distance between the responses provided in the FIQ and AUT. The semantic distance was determined with SemDis platform (semdis.wlu.psu.edu; Beaty & Johnson, 2021). The responses were spell-checked before entering them into the SemDis where they were pre-processed using the "remove filler and clean" setting which removes "stop words" (e.g., the, an, a, to) and punctuation marks that can confound semantic distance computations. The semantic distance was computed with five semantic models using the multiplicative compositional model (for a detailed description, see Beaty & Johnson (2021)), and the average score across the five models served as the measure of sematic distance in the analyses. For FIQ, the semantic distance was computed between each pair of responses to each stimulus. For AUT, semantic distance was computed between each successive response to each stimulus.

3.1.3. Experimental stimuli and procedure

The experiment used the same stimuli and procedure as Experiment 1 with two modifications. In the present experiment the fixation cross onset followed the warning signal and was present until the offset of the second stimulus. For Experiment 1, the fixation cross was presented only after the warning signal (i.e., 'Ready', 'Hold', 'Switch') and lasted until the onset of the first (unambiguous) stimulus. The second difference was that the participants were asked to respond with the orientation of the second stimulus (top-left or right-bottom), whereas in Experiment 1 they responded according to whether they perceived the two stimuli in the same or in a different orientation.

3.1.4. Statistical analyses

Statistical analyses followed the pre-registered plan. The analysis scripts and data are available at OSF.io (https://osf.io/428cv/). The experimental results were analyzed with the lme4 (Bates et al., 2015) package in the R statistical software 3.5.0 (R Core Team, 2021); the results were illustrated with the ggplot2 (Wickham, 2016) and sjPlot 2.4.1 (Lüdecke, 2019) packages.

Generalized mixed-effect models (family = binomial, link = logit) were used to test the hypotheses. All the responses to the single trials in the experimental tasks were entered as the outcome variables (1 = reversal, 0 = no reversal). Random intercepts for participants were the random effect. First, we tested whether the task manipulation was effective by using the Task (passive, hold, switch) as the fixed effects. After that, we conducted separate analyses for each predictor variable (Openness, FIQ, AUT, CFS) by adding them to the model as the second fixed effect (Task × Openness, FIQ/AUT/CFS). Finally, we tested whether the effect of openness was moderated by each of the other predictor variables (Task × Openness × FIQ/AUT/CFS). The predictor variables were scaled (centered and normalized) before entering them into these models.

3.2. Results

The observed reversal proportions as a function of Task were 0.486 (SD = 0.196) for the passive task, 0.337 (SD = 0.240) for the hold task, and 0.577 (SD = 0.242) for the switch task (Fig. 4). A generalized linear mixed-effect model showed that reversals were less frequent in the hold task than in the passive task (B = −0.657, SE = 0.063, 95% CI [−0.781, −0.533], z = −10.401, $p < 0.001$) and more frequent in the switch task than in the passive task (B = 0.388, SE = 0.062, 95% CI [0.267, 0.509], z = 6.290, $p < 0.001$). These effects show that the task manipulation worked as expected.

The mean score for openness was 44.6 (SD = 8.3) and the corresponding scores were 0.90 (SD = 0.06) for the flexibility in FIQ (i.e., semantic distance between responses), 0.95 (SD = 0.05) for the flexibility in AUT, and 53.9 (SD = 7.2) for the cognitive flexibility in the CFS. Next, we entered each of these predictors and their interactions with Task into separate 2-way models. The full models are reported in the Supplementary Files (Tables S1–S4). Openness, FIQ, and the CFS did not show any fixed effects. Flexibility in AUT interacted with the switch task (B = 0.226, SE = 0.062, z = 3.657, 95% CI [0.105, 0.348], $p < 0.001$), showing that the higher the AUT score, the more perceptual reversals occurred in the switch task, compared with those in the passive task.

Next, we studied the 3-way interactions (Task × Flexibility[FIQ/AUT/CFS] × Openness) to reveal how the different flexibility scores moderate the possible effect of openness on reversal rates. Here we report only the statistically significant effects; the full models are reported in the Supplementary File (Tables S5–S7). In the first model, FIQ, switch task, and openness interacted (B = 0.213, SE = 0.067, 95% CI [0.081, 0.345], z = 3.17, p = 0.002) indicating that the higher the FIQ score and openness, the more reversals occurred in the switch task when compared to reversals in the passive task (Fig. 5A).

Flexibility in AUT moderated the effects of the switch task on reversal rates (B = 0.234, SE = 0.063, 95% CI [0.111, 0.357], z = 3.73, $p < 0.001$) indicating that higher levels of cognitive flexibility led to more frequent reversals in the switch task compared to the

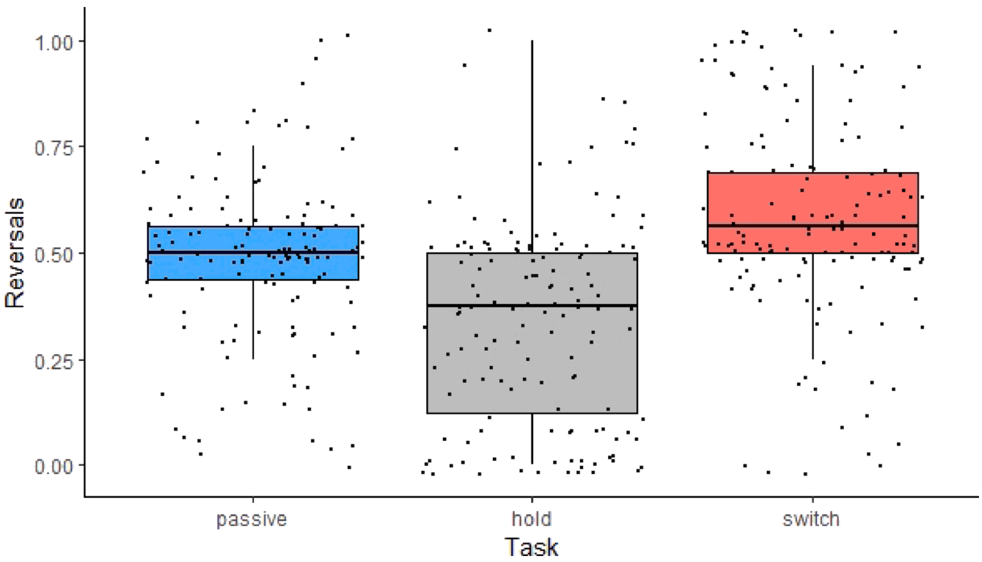

Fig. 4. Observed reversal proportions in the passive, hold, and switch task conditions. The dots represent each individual's data.

passive task. In addition, the hold task, AUT, and Openness interacted (B = −0.147, SE = 0.062, 95% CI [−0.268, −0.026], z = −2.38, p = 0.017) meaning that the higher the flexibility and openness, the better the participants were able to prevent reversals in the hold task. Furthermore, the interaction between the switch task, AUT, and openness was statistically significant (B = 0.198, SE = 0.061, 95% CI [0.077, 0.318], z = 3.22, p = 0.001) suggesting that participants who scored higher than average in AUT and openness could reverse the orientation of the stimuli in the switch task (compared to passive task) more often than the average participant.

Cognitive flexibility as measured with the CFS also moderated the effect of openness on reversals in two conditions. The CFS, openness, and the hold task interacted (B = 0.148, SE = 0.053, 95% CI [0.044, 0.251], z = 2.80, p = 0.005). This interaction suggests that individuals high in openness and self-reported cognitive flexibility were less able to intentionally inhibit perceptual reversals than the average individual. In addition, the CFS, openness, and the switch task interacted (B = 0.164, B = 0.055, 95% CI [0.057, 0.271], z = 3.00, p = 0.003) replicating Experiment 1′s finding that the relationship between openness and intentional perceptual reversals depended on the level of self-reported cognitive flexibility.

3.3. Discussion

Our first hypothesis, assuming that openness predicts the ability to intentionally reverse the orientation of the Necker cube, was not confirmed when openness, on its own, was a predictor. The second hypothesis that FIQ, AUT, and the CFS predict an individual's ability to reverse or hold the orientation of a Necker cube was partly supported by the finding that higher flexibility levels in AUT results in increasingly more frequent reversals in the switch task when compared to the passive task. However, the major finding was that the rate of reversals in the switch condition depended on the interaction between openness and cognitive flexibility, supporting our third hypothesis. All three measures of cognitive flexibility (the self-report scale CFS, the visual divergent thinking task (FIQ), and the verbal divergent thinking task (AUT)) interacted with openness and the switch task. Flexibility in AUT also moderated the relationship between openness and reversals in the hold task. High openness and flexibility in AUT resulted in decreased reversals when the reversals were intentionally inhibited.

In contrast to the results of Experiment 1, openness in Experiment 2 was not directly related to reversals in the switch condition (i.e., the 2-way interaction Task × Openness failed to be statistically significant). This discrepancy can be explained by the fact that in Experiment 2 the contribution of the other Big Five personality traits had not been controlled for. In Experiment 1, Openness correlated with Agreeableness, and Agreeableness was associated with decreased reversals in the switch task. Thus, the uncontrolled influence of agreeableness in Experiment 2 may have made the Task × Openness interaction impossible to detect. In addition, in Experiment 2 the individuals high in openness and self-reported cognitive flexibility (CFS) were less able to intentionally inhibit perceptual reversals than the average individual, whereas in Experiment 1 no such effect was observed. Thus, these findings must be considered with caution. However, the predicted moderation effect showing that openness and the CFS interacted to increase intentional reversals was observed in both experiments.

4. General discussion

In this study, we examined the interplay between personality traits, specifically openness-to-experience, and perceptual processes using bistable perception. Utilizing the Necker cube as a stimulus, our study aimed to unravel how individual differences in personality might translate to variations in perceptual dynamics. The findings of our research underscored a significant moderation role played by

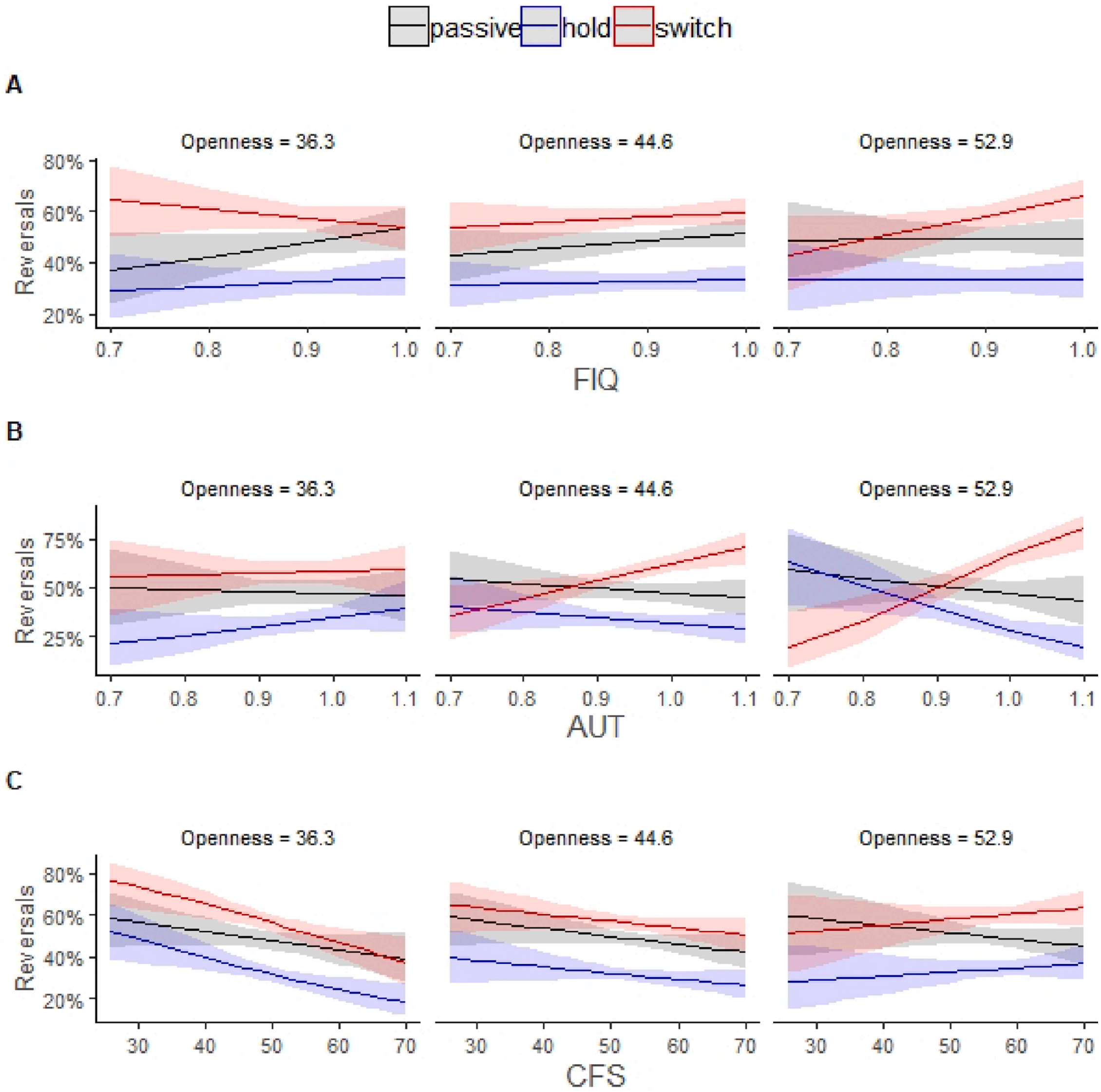

Fig. 5. Reversals in the task condition as a function of openness and cognitive flexibility, measured with (A) Figural Interpretation Quest, (B) Alternate Uses Task, and (C) Cognitive Flexibility Scale. The results are shown at three points of openness: 1 SD below the mean, at the mean, and 1 SD above the mean of openness. The values have been back-transformed to the original scale. The shaded areas represent 95% CIs.

cognitive flexibility in the relationship between openness-to-experience and intentional perceptual reversals of ambiguous Necker stimuli, shedding light on the nuanced ways in which personality traits can influence basic perceptual processes.

Our work contributes to a growing body of literature exploring the connection between personality traits and perceptual experiences. Previous studies (Antinori et al., 2017a, b; Blake & Palmisano, 2021; Koivisto et al., 2023) have suggested potential links, yet the specific mechanisms and the extent of these relationships have remained unclear. In Experiment 1, we tested whether the Big Five personality traits are related to perceptual reversals of the Necker cube at low-level bottom-up processes or at controlled top-down processes and whether the possible relationships depend on cognitive flexibility. The results showed that personality traits were associated with bistable perception only in conditions where intentional control of reversals was required and openness was the only trait that was associated with a heightened ability to alter perception. None of the Big Five personality traits were related to reversal rates during the passive viewing task condition in which no instruction to alter perception was given which is thus more closely related to the spontaneous adaptation-inhibition processes than the other condition. Therefore, the lack of personality effects in the passive condition suggests that the perceptual dynamics in spontaneous adaptation-inhibition processes may not differ between personality traits.

The effects of individual factors on intentional control of perceptual reversals were observed most clearly when high openness was coupled with high cognitive flexibility. This moderation effect was observed in both experiments with self-rated cognitive flexibility

(CFS). In addition, Experiment 2 measured cognitive flexibility also with two divergent thinking tasks, the verbal AUT and the visuospatial FIQ. Flexibility in both these tasks moderated the relationship between openness and perceptual reversals. However, it is not clear whether high openness, on its own, is sufficient for superior performance in the intentional control of reversals. In Experiment 1 openness was positively related to reversals in the intentional switch condition (without the moderation by cognitive flexibility), whereas the pre-registered Experiment 2 failed to replicate this finding. Open personalities are intellectually curious and novelty-seeking (McCrae & Costa, 1987). One can speculate that these motivational factors may explain why specifically openness was related to an enhanced intentional control of reversals. However, these motivational tendencies alone do not guarantee a high level of intentional control. They must be combined with high cognitive flexibility. A flexible cognitive style may enhance the ability of open individuals to intentionally translate their trait-driven propensity for novelty and variety into actual perceptual experiences. This interpretation is in line with previous research indicating the role of top-down processes, such as attention and decision-making, in mediating perceptual reversals (Kornmeier & Bach, 2012; Long & Toppino, 2004).

The view that individual differences contribute to perceptual flexibility via top-down processes is consistent with most current theories of consciousness. Although, the theories disagree on whether the influence is necessary for conscious perception or only modulatory, they converge on the view that conscious visual perception is contributed to by feedback connections from the fronto-parietal areas to the visual cortex (Northoff & Lamme, 2020). Similarly, neural processes underlying perceptual switching are thought to involve the visual cortex (Blake & Logothetis, 2002) as well as the frontal and parietal regions (Brascamp et al., 2018; Leopold & Logothetis, 1999). The top-down signals and their interaction with lower levels may play a role in both the destabilization and stabilization of sensory representations during bistable perception (Brascamp et al., 2018). The interaction between the fronto-parietal and stimulus processing regions is of particular importance in flexible cognition (Sterzer & Kleinschmidt, 2007; Qiao et al., 2020). Individual differences in cognitive flexibility may also contribute to differences in perceptual flexibility via efficient top-down influences (Sekutowicz et al., 2016).

However, cognitive flexibility alone seems not to be sufficient for high perceptual flexibility in bistable perception. High self-reported cognitive flexibility (CFS) or visuospatial flexibility (FIQ) alone was not sufficient for better than average intentional control – they had to be combined with the trait of openness. The exception was the flexibility in AUT, which alone predicted intentional perceptual reversals. It is known, on the basis of previous studies, that enhanced reversal rates in perception of bistable stimuli, including Necker cube, are associated with heightened original (i.e., unusual) responses[1] in AUT (Klintman, 1984) as well as high self-perceived creativity and originality (Bergum & Bergum, 1979a,b), and with creative interpretations of visual patterns (Doherty & Mair, 2012). In addition, simply observing a Necker cube, compared to an unambiguous cube, can improve subsequent creative problem-solving (Laukkonen & Tangen, 2017), suggesting that viewing bistable stimuli may have a causal effect on creative thinking. The present finding that flexibility of divergent thinking, as measured with AUT, interacted with openness both in the hold task and in the switch task of Experiment 2, is an interesting one. This means that open personalities who are flexible in divergent thinking were intentionally able to both inhibit spontaneous perceptual reversals and enhance the occurrence of perceptual reversals. Similar flexibility is thought to be essential for high-quality creative performance in AUT. To produce creative alternate uses for common objects, one needs to *inhibit* the most common uses which are strongly associated with the probe object and come most easily to mind (Beaty et al., 2014). In addition to the inhibition of typical uses, one must be able to *switch* attention to more remotely associated contents and combine them with the object. Thus, generation of original uses for common objects requires both inhibition and controlled switching of attention, as suggested by the hybrid theories of creativity (Beaty et al., 2014). The finding that flexibility in AUT was related to intentional inhibition and switching in the perception of Necker cube stimuli suggests that the cognitive processes required in the conceptual creative task and those in the perceptual tasks share common resources. On the other hand, the visuospatial FIQ task (Erwin et al., 2022; Koutstaal et al., 2022) is relatively new and it requires participants to produce interpretations for non-sense visual objects that they probably have not ever seen. Flexibility in FIQ did moderate the effect of openness on intentional perceptual reversals, but not on intentional inhibition. This is understandable because FIQ clearly requires switching of perspectives to produce different interpretations for the non-sense objects, but there are no previous interpretations which one would need to inhibit (Koutstaal et al., 2024). One should note, however, that in the present study the participants were explicitly asked to produce two as semantically different interpretations as possible for each non-sense figure, which is not included in the common instructions of FIQ (Erwin et al., 2022).

The study was conducted online, which has both benefits and limitations. The online procedure allowed us to collect participant samples with a wide range of ages (18 to 59 years in Experiment 1; 21 to 40 years in Experiment 2) from different countries, rather than limiting the sample to undergraduates in a single University. One of the limitations of online experiments is that the experimenter has little control over the equipment used by participants. Although the PsyToolkit software allowed only desktop or laptop use, it was not possible to control for the luminance and size of the stimuli or the viewing distance. However, due to varying devices and viewing conditions, the generalizability of the results is larger than that of strictly controlled laboratory conditions. Participants' lack of motivation or attentiveness may be a serious problem in online studies. We used easy control conditions to eliminate the data of potentially inattentive or unengaged participants. To keep participants attentive and motivated, the online studies needed to be relatively short, which forced us to use short personality scales, which likely limited the validity and reliability of the results. Despite

[1] In exploratory analyzes we managed to show a similar relationship between flexibility in AUT and intentional control of reversals. We subtracted the reversal in the hold task from the reversals in switch task to obtain a score for intentional reversals; then we divided the participants into high and low intentional control groups. The high group showed higher flexibility than the low group in AUT, $B = -0.018$, $SE = 0.008$, $t = -2.128$, $p = 0.035$, but not in FIQ, $B = -0.015$, $SE = 0.010$, $t = -1.487$, $p = 0.139$.

that, the internal consistency of the personality dimensions was good or acceptable, except in Experiment 1 for the trait of agreeableness, which was measured using the BFI-S (Lang et al., 2011). A limitation in the stimuli is that the unambiguous cube is not genuinely an unambiguous one. Actually, it can be perceived in two ways, convex or concave (as if the cube was open), which may have decreased the effect sizes. Even if some of the participants might have perceived the unambiguous cube as "concave", it likely did not produce too high error variance, because the overall pattern of results shows clearly the expected pattern where the reversals of the Necker cube occur most often in the switch task and least often in the hold task.

In summary, our findings have profound implications on our understanding of the relationship between personality and perception. They suggest that individual differences in personality and cognitive flexibility are indeed related to basic perceptual processes, through top-down mechanisms, potentially influencing how we experience and interact with our visual environment. More generally, the results support shared mechanisms between perception and cognition. However, the study focused only on one type of bistable stimulus and further studies are needed to test whether the results will generalize to other bistable conditions (e.g., binocular rivalry, vase-face illusion, spinning dancer, etc.).

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT-4 in order to improve writing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Mika Koivisto: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Cypriana Pallaris:** Writing – review & editing, Investigation, Formal analysis.

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.

Data availability

Data and R scripts are shared in OSF.io: https://osf.io/428cv/

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2024.103698.

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