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A tentative I/O curve with consciousness: effects of multiple simultaneous ambiguous figures presentation on perceptual reversals and time estimation

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Abstract

This study was aimed at investigating mechanisms of consciousness using bistable perception. In 4 experimental conditions, 1, 2, 4 or 8 Rubin's face-vase ambiguous figures were presented for 3 minutes. In Experiment 1, 40 subjects looked at the center of the screen and pressed a specific key correspondent to the figure where they perceived a reversal. In Experiment 2, 32 subjects controlled with eye-tracker performed a similar task in which they pressed the spacebar whenever they perceived a reversal in any of the figures. At the end of each condition subjects estimated its duration. Results showed that changing the number of figures does not alter the number of reversals, producing a flat I/O curve between the two parameters. Estimated time lapse showed a negative correlation with the number of reversals. These findings are discussed considering the relationships between bistable perception, attention, and consciousness, as well as the time perception literature.

Keywords: consciousness, attention, bistable perception, time perception.

30 INTRODUCTION

31 In the last two decades, the study of the behavioural and neural bases of consciousness has found a
32 prominent place in the literature of psychology and neuroscience (De Graaf et al., 2012; Koch et al.,
33 2016; Zeman, 2001). Considerable advancements have been made in the field on both the empirical
34 (Overgaard, 2017) and theoretical aspects of research (Dehaene & Naccache, 2001). Some scientists
35 have even begun to measure diverse features of consciousness creating in fact a mathematics of
36 experience (Balduzzi & Tononi, 2009; Seth et al., 2008) and bringing thus consciousness to all effects
37 in the ranks of the empirical sciences.

38 One broadly used paradigm to investigate the behavioural and neural aspects of consciousness is
39 based on ambiguous figures. These figures are physically invariant pictures allowing more than one
40 interpretation. They give often rise to bistable percepts, that is, to perceptual experiences made up
41 by a sequence of different visual images elicited by the objects which are intrinsically part of the
42 figure. Most ambiguous figures allow two object interpretations, whose perception reverses
43 alternately from one to the other. This perceptual bistability has been investigated in its neural bases
44 (Kornmeier & Bach, 2012; Leopold & Logothetis, 1999), in the influence on it of the mechanisms of
45 priming (Goolkasian & Woodberry, 2010), in the effects of spatial context in which the images are
46 presented (Ouhanna et al., 2017), in its occurrence in clinical cases (Allen & Chambers, 2011) and in
47 its significance for the neural and behavioural correlates of consciousness (Brancucci & Tommasi,
48 2011; for a general review see: Brascamp et al., 2018). Examples of ambiguous figures are the Rubin's
49 vase-face figure (Rubin, 1915), the Necker cube (Necker, 1832), the duck-rabbit figure (McManus et
50 al., 2010), and the old/young woman (Boring, 1930). A perhaps even wider literature has grown for
51 a companion paradigm of ambiguous figures, i.e. binocular rivalry, another method to obtain bistable
52 perception whereby two different figures are simultaneously presented one to the left and the other
53 to the right eye (Tong et al., 2006; Brascamp et al., 2015).

54 Bistable perception is particularly worthwhile for the research on consciousness (Brancucci et al.,
55 2011, 2016, 2018; Wang et al., 2013). The reason for this is that while the ambiguous figure is one
56 and does not change during its presentation, the associated conscious experience reverses from one
57 percept to the other. This allows researchers to ascribe measurable events which occur
58 simultaneously with the perceptual reversals to behavioural or neural events strictly related to
59 consciousness (Parkkonen et al., 2008; Sterzer et al., 2009). A more usual way to elicit different
60 percepts would be to present different images (e.g., a face followed by a tree, and so on). In this way,
61 however, behavioural or neural changes associated with the consequent perceptual changes cannot

62 be exclusively ascribed to processes related to consciousness as they could have been elicited simply
63 by the differences due to the physical inputs.

64 In a recent paper (Brancucci et al., 2020) we described the outcomes of a study in which we used the
65 divided visual field paradigm with vertical or horizontal division and the simultaneous presentation
66 of two identical ambiguous figures. Results showed that the temporal interdependence of the
67 reversals in the two hemifields was very low, and that, during in average 1/3 of the stimulation time,
68 subjects experienced simultaneously the two different interpretations of the same figure in the two
69 hemifields. The type of visual field division did not influence either frequency or temporal
70 interdependence of the reversals. Moreover, when one single ambiguous figure was presented, the
71 number of reversals was approximately the sum of the reversals observed with two simultaneously
72 presented figures.

73 Now, we move from these two main outcomes to further investigate the mechanisms of
74 consciousness hidden in bistable perception. Established that the perception of two ambiguous
75 figures presented simultaneously can reverse independently for each figure, presenting more
76 ambiguous figures at the same time the present study aims at drawing an input/output (I/O) relation
77 between the number of ambiguous figures simultaneously presented and the observed number of
78 perceptual reversals. The analysis of the relationship between the number of simultaneously
79 presented ambiguous figures and the number of observed perceptual reversal can shed light on the
80 nature of the mechanisms eliciting reversals and on the behavioural and neural correlates of
81 consciousness. An increase of the number of reversals associated to a higher number of figures
82 presented would suggest a strong dependence of perceptual bistability on field effects and possibly
83 the presence of multiple central mechanisms generating bistable conscious perception. Of note, the
84 notion of multiple central mechanisms is related to the topographical organization of the visual
85 system where the presentation of many (ambiguous) figures generates activity maps at different
86 levels, starting from the retina, in which the representation of each figure is spatially segregated from
87 the others. Conversely, a non-increased number of reversals would point to a strong role of top-down
88 attention in the generation of the reversals and on the presence of a limited number (possibly one)
89 of central mechanisms at the basis of bistable perception and possibly of consciousness. In fact, given
90 the intrinsic ability of ambiguous figures to generate perceptual bistability, it is reasonable that
91 increasing the number of ambiguous figures generates a scene in which reversals are facilitated, thus
92 inducing field effects. Conversely, a lack of increase of the number of reversals would suggest the

93 presence of top-down attentional filter mechanisms which act on the reversals and tend to reduce
94 them.

95 A further point which we face here is to investigate whether the perceived duration of a time lapse
96 can be influenced by the number of ambiguous figures presented and by their number of reversals.
97 Subjective evaluation of time duration is a fundamental point in psychology research and it has never
98 been studied in association to bistable perception, a situation in which subjective aspects of cognition
99 are of particular relevance. Thus we think that the investigation of the mechanisms underlying the
100 interactions between the two perception domains rests on solid epistemological foundations. In the
101 investigation of temporal processing, there are two main paradigms which may involve different
102 cognitive processes. In the attention-related prospective timing task, participants are informed in
103 advance that they will have to judge the duration of a period of time, for which attention plays a
104 primary role in performance. In contrast, in the memory-related retrospective timing task,
105 participants do not know until the end of the task that they will have to judge its duration, so memory
106 processes seem to be critical (see Vatakis et al., 2018). In general, evidence supports at least two
107 different systems for temporal processing: one based on senses for short durations ($\leq 1s$,
108 approximately) and one based on high-level cognitive processing for longer durations (Hellström &
109 Rammsayer, 2004; Lewis & Miall, 2003). The perception of short durations ($\leq 1s$, approximately) is
110 more influenced by the input sensory information (e.g., brightness, spatial frequencies, number of
111 elements comprising the stimulus, and neural adaptation; Xuan et al., 2007; Aaen-Stockdale et al.,
112 2011; Eagleman & Pariyadath, 2009). Instead, the judgments of duration on scales equal to or greater
113 than 3 seconds are influenced by cognitive load (Block et al., 2010). The present work uses an
114 attention-related prospective timing task and only considers durations of 3 minutes. Given that the
115 duration to be judged is long, we expect that the variation of the input sensory information (number
116 of figures presented simultaneously) will have limited effects on the judgment. On the contrary, we
117 predict that the number of perceived alternations may influence the temporal task. To our
118 knowledge, this is the first study linking this type of stimuli to temporal perception. However, it is
119 known that if during prospective temporal judgement tasks the subject performs another activity,
120 and attention is mainly focused on the non-temporal task, the estimate of elapsed time will be lower
121 than when attention is focused on the passage of time (Zakay & Block, 1996, 1997). In contrast, the
122 number of perceived reversals, when attention is paid to the bistable perception task, tends to
123 increase (Paffen et al., 2006). Consequently, we predict that the number of perceived reversals is

negatively correlated with duration judgments and that the direction of this correlation will remain constant as the number of figures changes.

To join these goals, in the present study we presented 1, 2, 4 or 8 copies of the same ambiguous figure (the Rubin's vase; Rubin, 1915) simultaneously, and asked subjects to press a key when they experienced a perceptual reversal from the vase to the face profiles or viceversa. In Experiment 1 subjects had to press a specific key associated to each of the presented figures, whereas in Experiment 2, to exclude an effect of the type of response on the reversal rate, participants had to press a key regardless from the figure in which the reversal was perceived. In addition, to ascertain that the participants looked at the fixation cross during the tasks, eye movements were recorded in Experiment 2. At the end of each condition we asked subjects to estimate the duration of the session, which lasted actually 3 minutes. A firm theoretical point on which this study bases is that perceptual reversals elicited by ambiguous figures are pure changes in consciousness, which do not depend from stimulus changes or from other "external" variables which change in synchrony with the reversals. Although the literature shows that the context can influence the number of reversals (Intaitè et al., 2013; Ouhana & Kingdom, 2016), based on the above results (Brancucci et al., 2020) the main hypothesis of the present piece of work is that, despite the different number of ambiguous figures presented in the 4 experimental conditions, the number of perceptual reversals and the estimation of time tends to remain constant.

142
143

144 MATERIALS AND METHODS

145 Experiment 1

146 *Participants*

Forty participants (22 females) aged between 19 and 30 years (mean age = 22.03, standard error = 0.38) took part in the study. The needed sample size was estimated with the G*power 3.1 software (Faul et al., 2009) by performing an a priori analysis considering all results (average) of the sole previously published work on the same topic (Brancucci et al., 2020). A number of 22 participants was needed to achieve, with a power of .90 ($\alpha = .05$; correlation between measures = 0.68), a medium/small effect size (Cohen's $f = 0.236$). Handedness scores measured by means of the Edinburgh Handedness Inventory (Oldfield, 1971; according to which the handedness score ranges from -100 = totally left handed, to +100 = totally right handed), showed that 37 subjects were right-handed (i.e. score > 0) and 3 left-handed (mean 54.63 ± 7.22). Eyedness, measured with the same

test in which one item is dedicated to eye preference, showed that 15 subjects had left eye preference, 6 subjects had no eye preference, and 19 subjects had right-eye preference (mean 0.17 ± 0.23). Participants were enrolled if they did not complain of particular visual impairments and all of them had normal or corrected-to-normal vision. The study was carried out in accordance to the principles expressed in the Declaration of Helsinki of year 2013 and was approved by the local research ethics committee.

Stimuli

The Rubin's face-vase figure (Rubin, 1915) was presented in 4 different conditions: single figure (1F), 2 figures (2F), 4 figures (4F), 8 figures (8F). In the 1F condition one Rubin's vase was presented at the centre of the screen. In the 2F condition, 2 Rubin's vases were presented simultaneously, one in the LVF and the other in the RVF. In the 4F condition, 4 Rubin's vases were presented simultaneously, two in the RVF (one in the upper and one in the lower RVF) and two in the LVF (one in the upper and one in the lower LVF). In the 8F condition, 8 Rubin's vases were presented simultaneously in a circle, each at the same distance from the centre (Fig. 1).

The computer display was 34 cm wide and 27 cm high. The absolute dimension of the figures in the 1F and 2F conditions was 5 cm, in the 4F and 8F conditions it was 4 cm. In terms of visual angle, this resulted in a difference of 0.8° . In the 2F, 4F, and 8F conditions the centre of each image was 6.5° from the central fixation point. In each condition, stimuli were presented continuously for 3 min.

Procedure

The 4 conditions were presented in 4 blocks in a pseudorandom order counterbalanced across participants, wherein the 8F condition was preceded by a training phase to familiarize the participants with the answer buttons due to its greater difficulty. Subjects were tested in a quiet room and sat comfortably in front of the computer monitor (approximately 70 cm from subject's head), with both hands placed on the keyboard. During the experiment, participants were instructed and trained to look at the centre of the screen and to not shift their gaze and their attention from the fixation cross. In order to prepare participants to the experimental tasks, before starting they were familiarized with a Rubin's face-vase figure. Participants were instructed to press a button when they perceived a reversal in one of the presented images. In the 1F condition they were asked to press the spacebar with their right hand to indicate a reversal perception in the image centrally displayed. In the 2F condition participants had to press the "A" button with the left hand and the "L" button with the right

188 hand to indicate a reversal perception respectively in the LVF or RVF. In the 4F condition participants
189 had to press the “Z” or the “V” button with their left hand to indicate a reversal perception in the
190 lower LVF or lower RVF, respectively, and the “U” or the “P” button with their right hand to indicate
191 a reversal perception in the higher LVF or higher RVF, respectively. In the 8F condition, the “Z”, “X”,
192 “C”, “V” buttons were associated to the left hand, and the “P”, “O”, “I”, “U” buttons to the right hand,
193 and each button corresponded to one image of the Rubin’s vase (see Fig. 1, bottom). Before this
194 condition a specific training was performed in which particular care was devoted to the avoidance of
195 ocular movements. Participants were required to look at the centre of the screen and to press the
196 button corresponding to one of the 8 images which lighted on the monitor. The training sessions
197 were presented with increasing difficulty where in the first step the images lighted in sequence
198 following their circular arrangement, then in a spatially random way. The time limit for providing the
199 response decreased progressively (every 8 stimuli) from 5s to 3s. Participants were required to repeat
200 the training until 80% accuracy was achieved before they could start the experimental session for the
201 8F condition. No eye-tracking control was performed in Experiment 1. Participants were aware that
202 at the end of each condition they had to report the subjective evaluation of time duration and were
203 asked not to count during the conditions (Rattat & Droit-Volet, 2012). Participants wrote down their
204 answer on a sheet of paper on which the following sentence (here translated into English) was written
205 in Italian: "Indicate how much time has passed for each condition". Five out of 40 subjects did not
206 perform this task.

207 The experiment ran automatically using a software written in E-Prime (Psychology Software Tools
208 Inc., Pittsburgh, PA, United States) and participants’ responses and reaction times were registered by
209 the computer. The total duration of the experiment was approximately 20 min.

210

211 **Experiment 2**

212 *Participants*

213 Thirty-two participants (17 females) aged between 19 and 39 years (mean age = 25.33, standard error
214 = 0.87) recruited from the same population of university students as the previous sample (no subject
215 was recruited in both experiments) volunteered to take part in the study. The needed sample size
216 was estimated as in Experiment 1. Handedness and eye dominance were assessed as in Experiment
217 1 and showed that 31 subjects were right-handed (i.e. score > 0) and 1 left-handed (mean = 86.10,
218 st. dev. = 15.03) and that 12 subjects had left eye preference, 13 right eye preference, and 7 no eye
219 preference. Participants were enrolled with the same rules of Experiment 1. Seven of them were then

not included in the analyses due to problems related to the execution of the task (1 female) or to eye movements (5 females, 1 male).

Stimuli and procedure

The Rubin's face-vase figure was presented in 4 different conditions (1F, 2F, 4F, 8F) as in Experiment 1. The absolute dimension of the figures was here 4 cm in all conditions and the centre of each figure in the 2F, 4F, and 8F conditions was 6.5° from the central fixation point. Presentation conditions and duration of stimuli were identical to those of Experiment 1. Subjects task was here to press the spacebar with one hand each time they perceived a reversal in one of the presented figures regardless from which figure it was. At the end of each session, subjects were requested to estimate its duration.

Eye-tracker recordings

Participants were seated in front of a computer monitor (size: 1920 x 1080 pixels) approximately 70 cm away from their head as in Experiment 1. Eye movement data were collected with a Gazepoint GP3 eye-tracker sampling at 60 Hz. OGAMA software (Voßkühler et al., 2008) was used to display the stimuli and to record task responses and eye-tracker data. The eye tracking equipment was calibrated using a grid of 5 points, 1 in the centre and 4 displaced in the 4 corners of the screen. During the calibration, participants were required to gaze for 1 second at each dot. Throughout the experiment, participants were asked to keep their gaze at the centre of the screen and to not shift it from the fixation cross. For each session we obtained the spatial coordinates of each fixation and after the task we analysed the percentage of total dwell time on the fixation region (a box of 4 cm around the fixation cross). Then we removed 6 participants (1 male) whose gaze remained on the fixation region for less than 75% in one of the conditions, and the statistical analyses were performed on subjects who looked in the fixation region for an average time of 94.95% (standard error = 1.14).

Results

Statistical analyses were carried out with the software Statsoft Statistica 8.0. Shapiro-Wilk test for normality distribution showed that the analysed variables met not normality criteria ($p < 0.01$ for all variables). Since the analysis of variance (ANOVA) procedure is robust enough to tolerate violations of the normality assumption (Pituch & Stevens, 2015), we preferred to avoid data transformations

that could bias the results. Preliminary statistical analyses indicated that the order of condition administration (whether participants first received the 1F, 2F, 4F or 8F), did not influence the bistability scores. This variable was therefore not included in the subsequent analyses.

255

Experiment 1

Analyses on bistability scores

We define as 'bistability score' the total number of reversals observed in the 180 s presentation of the ambiguous figures. Across subjects (mean and standard deviation) bistability scores in the 4 conditions (1F, 2F, 4F, 8F) were 39.2 ± 29.8 for the 1F condition, 43.1 ± 31.1 for the 2F condition, 51.0 ± 42.0 for the 4F condition, and 51.1 ± 49.5 for the 8F condition (Fig. 2).

A repeated measures multivariate ANOVA with bistability score as a dependent variable, Handedness and Eyedness as continuous predictors, and one within-subjects factor (Condition, with 4 levels 1F, 2F, 4F, 8F) was carried out. Results showed no significant effects for all factors: Handedness ($F=0.88$, $p=0.768$, $\eta^2=0.003$), Eyedness ($F=0.69$, $p=0.412$, $\eta^2=0.022$), Condition ($F=0.78$, $p=0.507$, $\eta^2=0.025$) and their interactions: Condition x Handedness ($F=0.50$, $p=0.687$, $\eta^2=0.016$), Condition x Eyedness ($F=1.20$, $p=0.315$, $\eta^2=0.037$). This result indicates that the number of reversals when 1, 2, 4, or 8 ambiguous figures are simultaneously presented does not change statistically.

We performed a similar analysis excluding the condition 1F to control for a possible confound of the fixation point which coincides with the figure only in that condition. Results showed no significant effects for all factors: Handedness ($F=0.31$, $p=0.862$, $\eta^2<0.001$), Eyedness ($F=0.87$, $p=0.359$, $\eta^2=0.027$), Condition ($F=0.05$, $p=0.951$, $\eta^2=0.002$) and their interactions: Condition x Handedness ($F=0.80$, $p=0.453$, $\eta^2=0.025$), Condition x Eyedness ($F=1.75$, $p=0.183$, $\eta^2=0.053$). This results indicates that the fixation point does not statistically influence the lack of reversals increment.

275

Effects of figures positions on the screen

Subsequently, analyses were carried out within the conditions with multiple figures presentation (2F, 4F, 8F) to investigate whether the position of the figure in the screen could exert some effect on the reversals. In the 2F condition, one-way repeated measures ANOVA with the factor Side (LVF, RVF) showed a main effect ($F=4.756$, $p=0.03$, $\eta^2=0.11$) with more perceptual reversals occurring in the LVF. In the 4F condition, two-ways repeated measures ANOVA with Side (LVF, RVF) and Height (UVF, WVF) as factors showed a significant interaction Side x Height ($F=8.896$, $p=0.005$, $\eta^2=0.186$) and no other statistically significant effects (Side: $F=0.516$, $p=0.477$, $\eta^2=0.013$; Height: $F=2.136$, $p=0.152$,

284 $\eta^2=0.052$). Tukey post-hoc comparisons showed that concerning the LVF more reversals occurred in
 285 the left WVF compared to the left UVF ($p=0.004$) and that concerning the UVF more reversals
 286 occurred in the upper RVF compared to the upper LVF ($p=0.029$). Number of reversals did not differ
 287 between right WVF compared to the right UVF ($p=0.946$) and between the lower RVF compared to
 288 the lower LVF ($p=0.568$). In the 8F condition, two-ways repeated measures ANOVA with Side (LVF,
 289 RVF) and Height (UVF, WVF) as factors showed no significant effects (Side: $F=2.546$, $p=0.119$,
 290 $\eta^2=0.061$; Height: $F=0.115$, $p=0.736$, $\eta^2=0.003$; Side x Height: $F=3.756$, $p=0.060$, $\eta^2=0.088$). Factor
 291 levels have been here calculated considering the sum of the 3 positions corresponding to each
 292 quadrant in the visual field (e.g. the left-up quadrant was considered as the sum of the reversals in 3
 293 positions corresponding to the letters Z, U, I in Fig. 1). Of note, a very similar result has been observed
 294 in the analogous analysis considering only the 4 positions corresponding to the letters U, O, X, V in
 295 Fig. 1 (specifically, the interaction was here identical, which is obvious from a statistical point of view).
 296

297 Experiment 2

298 *Analyses on bistability scores*

299 Analyses were carried out after having excluded 1 participant since she did not perform the task
 300 correctly and 6 subjects since they made too large eye movements. The sample of the following
 301 analyses is thus $n = 25$, all subjects who gazed for at least 75% of the time in each condition to the
 302 fixation cross (mean = 94.95% of the total test time, standard error = 1.14). Across subjects (mean
 303 and standard deviation) bistability scores in the 4 conditions (1F, 2F, 4F, 8F) were 51.8 ± 34.8 for the
 304 1F condition, 44.5 ± 33.6 for the 2F condition, 39.7 ± 22.3 for the 4F condition, and 46.3 ± 22.3 for
 305 the 8F condition (Fig. 2).

306 A repeated measures multivariate ANOVA with bistability score as a dependent variable, Handedness
 307 and Eyedness as continuous predictors, and one factor (Condition, with 4 levels 1F, 2F, 4F, 8F) was
 308 carried out. Results showed no significant effects for all factors: Handedness ($F=2.04$, $p=0.167$,
 309 $\eta^2=0.084$), Eyedness ($F=0.82$, $p=0.376$, $\eta^2=0.036$), Condition ($F=0.01$, $p=0.998$, $\eta^2=0.001$) and their
 310 interactions: Condition x Handedness ($F=0.31$, $p=0.817$, $\eta^2=0.014$), Condition x Eyedness ($F=0.167$,
 311 $p=0.918$, $\eta^2=0.008$) confirming the result of Experiment 1.

312 Finally, we performed a similar analysis excluding the condition 1F to control for a possible confound
 313 of the fixation point which coincides with the figure only in that condition. Results showed again no
 314 significant effects for all factors: Handedness ($F=1.78$, $p=0.196$, $\eta^2=0.075$), Eyedness ($F=0.71$,

315 $p=0.407$, $\eta^2=0.031$), Condition ($F=0.02$, $p=0.981$, $\eta^2=0.001$) and their interactions: Condition x
316 Handedness ($F=0.28$, $p=0.752$, $\eta^2=0.013$), Condition x Eyedness ($F=0.19$, $p=0.825$, $\eta^2=0.009$).

317

318 Time estimation

319 For both experiments, an analysis was carried out on the perceived duration of the 4 sessions
320 (conditions), which lasted actually 3 min. For Experiment 1, mean and standard deviation of the
321 perceived duration was 3.28 ± 1.36 min in the 1F condition, 2.73 ± 1.37 min in the 2F condition, 3.15
322 ± 1.83 min in the 4F condition, and 3.04 ± 1.45 min in the 8F condition. For Experiment 2, mean and
323 standard deviation of the perceived duration was 2.59 ± 1.35 min in the 1F condition, 2.56 ± 1.72 min
324 in the 2F condition, 2.34 ± 1.21 min in the 4F condition, and 2.25 ± 1.29 min in the 8F condition (Fig.
325 2). Repeated-measures ANOVA on the perceived duration (1F, 2F, 4F, 8F) showed no significant
326 effects (Experiment 1: $F=2.235$, $p=0.089$, $\eta^2=0.06$; Experiment 2: $F=0.846$, $p=0.473$, $\eta^2=0.03$).

327 Correlation analysis on the data of both experiments together ($n=60$; partial correlations controlling
328 for the experiment) between the bistability score and the perceived duration indicated that all
329 correlations were negative and ranged from $r = -0.14$ to $r = -0.44$. Specifically, in the single conditions
330 they were $r = -0.24$, $p = 0.070$ (1F); $r = -0.17$, $p = 0.192$ (2F); $r = -0.14$, $p = 0.278$ (4F); $r = -0.44$, $p <$
331 0.001 (8F) being this last correlation significant after Bonferroni correction for 4 comparisons. The
332 global partial correlation computed between the mean stability scores and the mean perceived
333 duration in the 4 conditions was also significant: $r = -0.30$, $p = 0.022$ (Fig. 3).

334

335 Control analyses

336 A further analysis was performed on all subjects of both experiments ($n=60$) to control whether the
337 number of reversals in the different subjects was consistent across conditions. To this aim, Pearson's
338 r correlation coefficients were pairwise calculated between the 4 conditions (1F, 2F, 4F, 8F). Results
339 showed correlation coefficients ranging from $r = 0.50$ to $r = 0.77$ with p always < 0.001 . This result
340 indicates that subjects who saw more reversals did this in all conditions and vice versa, and is in
341 accordance with previous similar evidence in the literature (Cao et al., 2018).

342 In the subsample of Experiment 2 in which we recorded eye movements ($n=25$), we made a further
343 control analysis across conditions to see whether the tendency of maintain the gaze correctly on the
344 fixation point was related to the number of perceived reversals. In such an analysis we correlated %
345 correct fixation time to the number of reversals and observed no relation ($r = -0.027$, $p = 0.897$).

346

347

348

349 Discussion

350 The present study was primarily aimed at finding a relation between the number of ambiguous
351 figures simultaneously presented and the perceptual reversals experienced by the subjects. Results
352 showed that changing the number of figures does not significantly alter the number of reversals
353 observed. The I/O curve (Fig. 2) shows that despite an increase of the number of simultaneously
354 presented figures, the number of reversals tends to remain constant. Specifically, since with one
355 ambiguous figure (1F condition) we observed about 40 reversals in 3 minutes, with 8 figures one
356 would have expected to observe about 320 reversals in the same time lapse, instead only about 50
357 were observed. As explained in the Introduction, a lack of increase of the number of reversals despite
358 an increase of the number of presented figures suggests a major role of top-down attention. Top-
359 down attention, as a general, non-specific, and content-limited mechanism, does not act specifically
360 on each representation of the figures remaining independent of their number, and its limited capacity
361 is possibly a cause of the decrease of the ratio reversals/number of figures. A further key role in the
362 route to consciousness is possibly played by central mechanisms related to the identification of the
363 stimulus. The lack of increase of the number of reversals when more figures are presented should
364 exclude that the underlying mechanisms operate at the level of object identification or slightly after
365 it ("object-token"; Zimmer and Ecker, 2010) as there each reversal mechanism would operate
366 independently for different objects producing instead an increase of reversals. These observations
367 speak in favor of a limited number (possibly one) of central mechanisms at the basis of bistable
368 perception and of consciousness.

369 A further aim of the present study was to investigate whether the number of ambiguous figures
370 simultaneously presented and their perceptual reversals could influence the judgement of the
371 duration of a time lapse. No differences were found between the time duration evaluations of the
372 four sessions, but an interesting and seemingly robust result emerged from the analysis of
373 correlations with the bistability score: all correlations (significant and non-significant) were negative,
374 indicating that the more reversals were perceived, the shorter the duration of the session was
375 evaluated. The most evident result was obtained in the 8F condition which showed the highest (and
376 significant) correlation value (-0.44). The overall correlations between the mean of the time
377 evaluations and the mean of the reversals in the 4 conditions showed a similar (-0.30) significant
378 correlation. In our opinion, this finding suggests the presence of a link between the perceptual

379 reversals and the internal clock which can be used to estimate time flow. If between two reversals
380 the time lapse is long (as is the case with a low number of reversals), then the elapsed time evaluation
381 tends to increase.

382 Several further results which go beyond the main scope of the present study were observed, which
383 we think are worth to be discussed. We detected more perceptual reversals in the LVF than in the
384 RVF when two ambiguous figures were presented simultaneously in the two lateral visual hemifields,
385 a condition (2F) in which the classical visual hemifield-paradigm stimulation mode was employed.
386 This result points to a major implication of the right hemisphere in the genesis of the perceptual
387 reversals, as the LVF projects mainly to the right visual cortex. A first explanation of this result is
388 possibly related to the right hemispheric parietal specialization for attention. It is known that
389 attention shows a bias towards the left in healthy subjects (pseudoneglect, Nicholls et al., 2017) and
390 the number of reversals during bistable perception has been shown to be directly proportional to
391 attentional resources (Paffen et al., 2006). A further explanation lies in the right hemispheric
392 superiority in the processing of faces (Hasson et al., 2001; Prete et al., 2015; Sergent & Bindra, 1981),
393 one of the two possible interpretations of the Rubin's vase, and on the fact that the ambiguous figure
394 presented is inherently a non-verbal stimulus. For presently unknown reasons, this superiority would
395 produce more reversals between the two interpretation of the Rubin's vase as if competition
396 between preferred stimuli would produce less perceptual stability compared to non-preferred
397 stimuli. Further research is needed to elucidate this interesting issue.

398 In the 4F condition, a more complex result was produced by an interaction between the UVF-WVF
399 and the LVF-RVF, or in other words between the concurrent horizontal and vertical divisions of the
400 visual field. Considering the left part of the visual field, more reversals occurred in the lower
401 compared to the upper quadrant, and considering the upper part of the visual field, more reversals
402 occurred in the right compared to the left quadrant. This complex result is in accordance with a
403 previous finding which shows that only the LVF has different responses between its upper and lower
404 parts (Lee et al., 2009), but it contrasts with other reports which found a right hemisphere
405 specialization for the UVF in addition to that for the LVF (Thomas et al., 2015; D'Anselmo et al., 2018).
406 More specific studies on up-low (UVF-WVF) asymmetries in visual attention suggest that these are
407 elusive or strictly dependent on the specific task requested (Thomas & Elias, 2011).

408 In the history of behavioural studies with ambiguous figures, several authors have presented two or
409 more ambiguous images more or less simultaneously (Adams & Haire, 1959; Babich & Standing, 1981;
410 Jensen & Mathewson, 2011; Long & Toppino, 1981; Mathewson, 2018). However, in most of these

411 studies the presentation techniques used were underdeveloped and the instructions given to the
412 subjects did not allow, in our opinion, sufficient control on the afferent information flow occurring
413 during the stimulation. Also the present study has potential confounds related to the lack of eye
414 movements control and the different size of the figures presented in Experiment 1 (5 cm in the 1F
415 and 2F conditions compared to 4 cm in the 4F and 8F conditions). Experiment 2 was however
416 designed to solve these issues by presenting all figures with the same size and by controlling eye
417 movements with an eye tracker instrument. In Experiment 2 we also modified the response buttons:
418 unlike Experiment 1 in which participants were asked to associate each key with a figure, in
419 Experiment 2 they had to press the same button for each perceived reversal. Hence, the results of
420 Experiment 2 allow us to exclude that the reversal rate in Experiment 1 could be influenced by the
421 difficulty due to associate each image to one specific key. Another confound concerns the fixation
422 point, which coincided with the figure only in the 1F condition raising possible different attentional
423 effects compared to the other conditions which could have biased the results. A dedicated control
424 analysis showed that the lack of reversals increase was evident also in the 3 conditions in which the
425 distance of the figures to the fixation point was identical.

426 The present results are generally in line with the studies cited at the beginning of the previous
427 paragraph and together with them show important consequences for the interpretation of the
428 experimental results obtained so far with ambiguous figures. As anticipated in the Introduction, the
429 main result of the study has some cues in the literature, in particular in the research studying the
430 relations between consciousness and attention, two aspects of cognition which are very closely
431 related, yet different (Koch & Tsuchiya, 2007). Paffen and coworkers (2006) demonstrated that
432 distracting focal attention during bistable perception slows down the number of reversals per time
433 unit. They showed that shifting attention from binocular rivalry stimuli to a simultaneously presented
434 motion-detection task reduces the rate of rivalry alternations. It appears that rivalry dynamics
435 depend on the amount of attentional resources allocated to the rival stimuli. When this amount is
436 reduced by increasing the difficulty of a concurrent task, the rivalry reversal rate slows further. This
437 drop in alternation rate is not attributable to a degraded ability to track rivalry alternations while
438 performing the detection task since under pseudo-rivalry conditions mimicking real rivalry
439 alternations, observers reliably tracked stimulus alternations. In our experiments, actually, presenting
440 more than one ambiguous figure at one time has led to a reduced amount of attention that could be
441 allocated to one single figure. This mechanism could explain why the number of reversals observed
442 does not increase with the number of simultaneous ambiguous figures presented and is in tight

443 agreement with the notion that attention allocation increases the number of reversals during bistable
444 perception.

445 Concerning the issue of time evaluation, as a limitation of the present study the number of reversals
446 was always associated to the number of the motor responses. In principle, this would not allow to
447 establish a relation between the perceptual reversals and time evaluation, as the same relation holds
448 between the number of motor responses and time evaluation. However, extant literature suggests
449 that the influence of motor activity on time perception is at best limited to the evaluation of short
450 durations in the sub-second domain (Mioni et al., 2016; Hass et al., 2012; Lewis & Miall, 2003). Here
451 the durations were one order bigger (minutes) and their evaluations are more related to cognitive
452 factors such as attention and working memory. Evidence in the literature suggests in fact the
453 existence of at least two different functional and neural mechanisms for temporal perception
454 (Hellström & Rammsayer, 2004; Lewis & Miall, 2003). The processing of smaller time intervals
455 (approximately $\leq 1s$) is sensory-based, whereas the processing of longer intervals requires the
456 support of cognitive resources. In this study, varying sensory information (understood as the number
457 of figures) did not produce a significant effect on perceived duration but it was related to the number
458 of perceived alternations. This would seem to confirm that the perception of longer durations is
459 based more on high-level processing than on sensory processing. Thus we expect a negligible
460 influence of the motor response on time evaluation in the present study. Nevertheless, further
461 studies could disentangle this issue for instance using no-report paradigms during bistable perception
462 which do not request a motor response. Although perceived duration is generally assumed to
463 correspond with objective duration, several studies suggest that time perception cannot be placed in
464 a simpleminded framework (Buetti & Walsh, 2009). Previous studies suggested several rules that
465 would govern temporal perception. It has been proposed that the experience of duration is a
466 signature of the amount of energy expended in processing the stimulus (Eagleman & Pariyadath,
467 2009) and that perceived time is positively related to perceptual vividness and to the ease of
468 extracting information from the stimulus (Matthews & Meck, 2016). Stimulus repetition has been
469 shown to reduce temporal estimation possibly due to a suppression of neural sustained responses
470 (Eagleman & Pariyadath, 2009). This outcome seems to agree with our result of a negative
471 relationship between number of spontaneous reversals and evaluation of the session duration.
472 Consistent with this interpretation, adaptation has often been considered an underlying dynamic of
473 multistable perception (Long & Toppino, 2004; Kogo et al., 2015) and would seem to explain at least
474 a small part of the variability in perceptual reversals (Pastukhov & Braun, 2011). In particular, as a

consequence of adaptation, reversals tend to be more frequent when an ambiguous figure is continuously displayed for a few minutes. Theoretically, both low-level neural mechanisms and high-level cognitive processes (as clarified in the next paragraph) can provide valid interpretations for the observed effect on temporal judgment (Intaite et al., 2013; Meng & Tong, 2004; Toppino, 2003), and we do not rule out that either explanation can have some bases. Resolving this issue would require independent modulation of attentional and adaptation mechanisms. Future studies could resolve such theoretical questions in the field of temporal perception. Intuitively, the underestimation of the temporal interval might be related to a common experience, namely that in some situations time seems to pass more quickly (or slowly). In truth, subjective judgments about the speed of time seem to be dissociated from those of interval length estimation (e.g. Droit-Volet & Wearden, 2016; Deinzer et al., 2017; Thönes & Oberfeld, 2015; Wearden, 2015); however, there are data demonstrating a correlation between the two measures (Sucala et al., 2010). The paradigm used here can be easily adapted to investigate these processes and whether they are influenced by the same factors.

Our result of a negative relationship between the number of spontaneous reversals and evaluation of the session duration seems consistent with the Attentional Gate Model (Zakay & Block, 1996, 1997). In prospective temporal judgement tasks (when the subject is aware from the beginning that he/she will have to report the duration of the event) the accuracy of the estimate is influenced by the degree of attention paid to the task. If during the temporal estimation task the subject performs another activity, i.e. bistable perception, and the attention is mainly placed on the non-temporal task, the estimate of elapsed time will tend to have negative values. Furthermore, as already reported above, focusing attention on bistable figures increases the perceived reversals. Thus, by integrating the AGM theory with the effects of attention in bistable perception tasks, it follows that an increase in the number of perceived reversals is negatively correlated with perceived duration. On a practical level, this negative correlation could be used as an index of the subject's ability to direct attention to a main task. The highest correlation was observed in the 8F condition. This probably occurred because the increase in the number of figures increased the difficulty of the task and interfered more with the evaluation of time. We hypothesise that this more negative correlation cannot be explained solely in terms of how much attentional resources were allocated to the two tasks. In fact, a higher/lower demand for attentional resources to the bistable perception task would also translate into an increase/decrease in the number of perceived reversals (Paffen et al., 2006), but this was not observed. This, instead, would seem to be related to the cognitive load required by the bistable perception task. Indeed, increasing cognitive load in prospective paradigms leads to a decrease in

507 duration judgment. As in Block and coworkers (2010), the term cognitive load refers to the required
508 amount of information processed by attention and working memory. Prospective judgments on
509 duration can be thus used as a measure of the amount of mental load required to perform a non-
510 temporal task (Zakay et al., 1999; Block et al., 2010).

511 The relation investigated here and the associated I/O curve should not be confounded with the
512 classical relations studied by psychophysics. Psychophysics quantitatively investigates the
513 relationship between physical stimuli and the sensations they produce, studying the effect of
514 systematically varying the properties of a stimulus along one or more physical dimensions
515 (Gescheider, 1997). That is, psychophysics bases its roots on situations in which the stimulus is always
516 changed experimentally and the effects of the changes are measured from behaviour. In the present
517 study instead, the pivotal point is that the measurements start from situations in which the stimulus
518 is always constant (the ambiguous figure does not change) but it produces changes in perception,
519 which can be thus assumed as changes in consciousness (O'Regan & Noë, 2001) – an assumption that
520 cannot be made in the experiments of psychophysics.

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523 **Data availability**

524 Data are available in the Open Science Framework website at URL: <https://osf.io/98scp/> .

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Figures

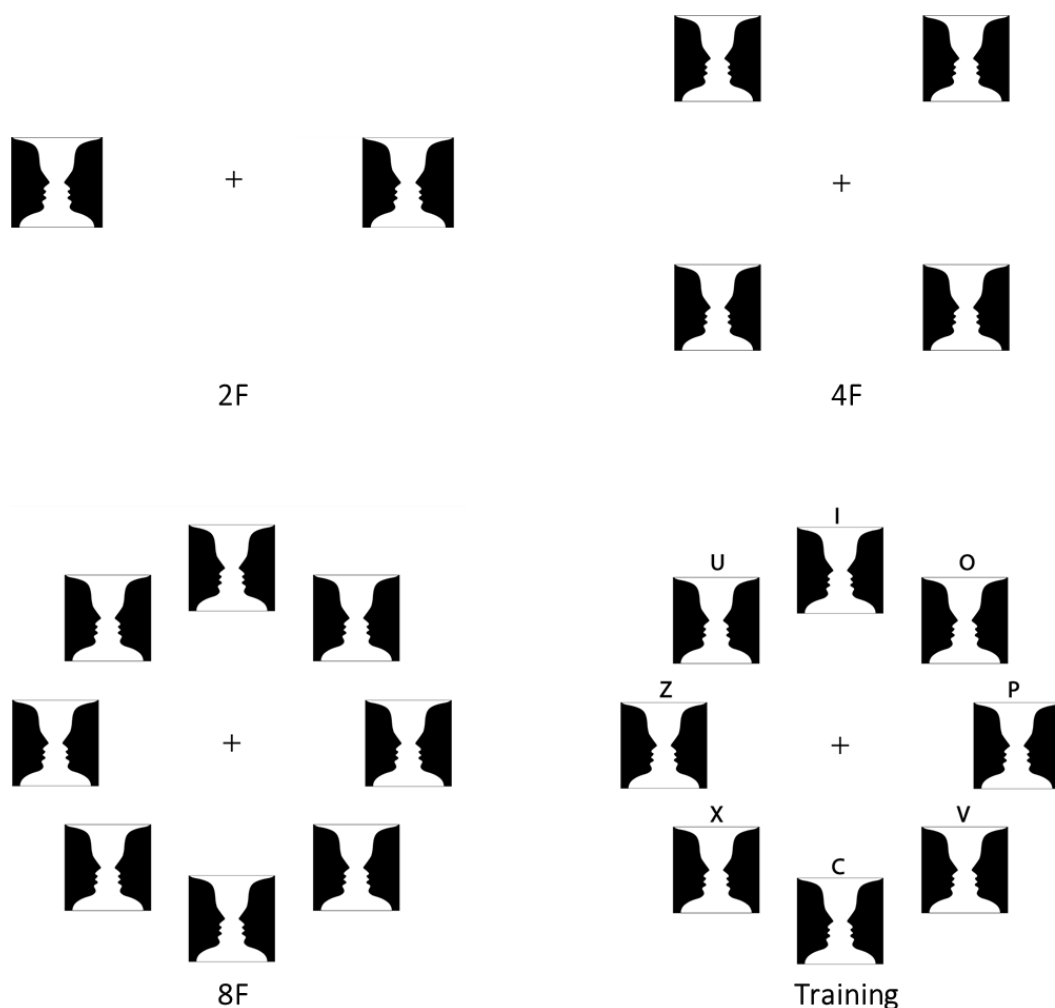
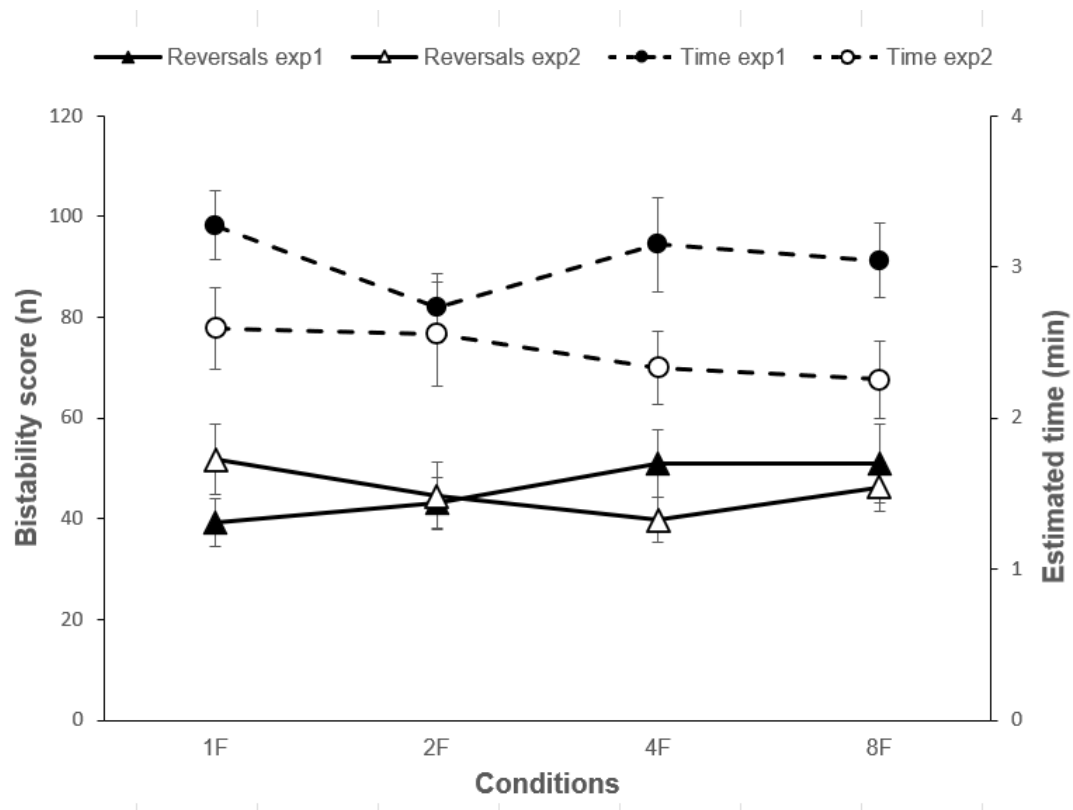


Fig. 1. The stimuli (Rubin's face-vase figures) presented in the two experiments in the 2F condition (*top-left*), 4F condition (*top-right*), and 8F condition (*bottom-left*). The cross indicates the fixation point. In the 1F condition only one Rubin's face-vase figure was presented instead of the cross at the center of the screen. *Bottom-right*: the stimulus presented before in the training session for the 8F condition. Letters above each image indicate the button that was to be pressed to indicate a reversal perception in the corresponding image. See text for the relative size of the figures presented in the two experiments.

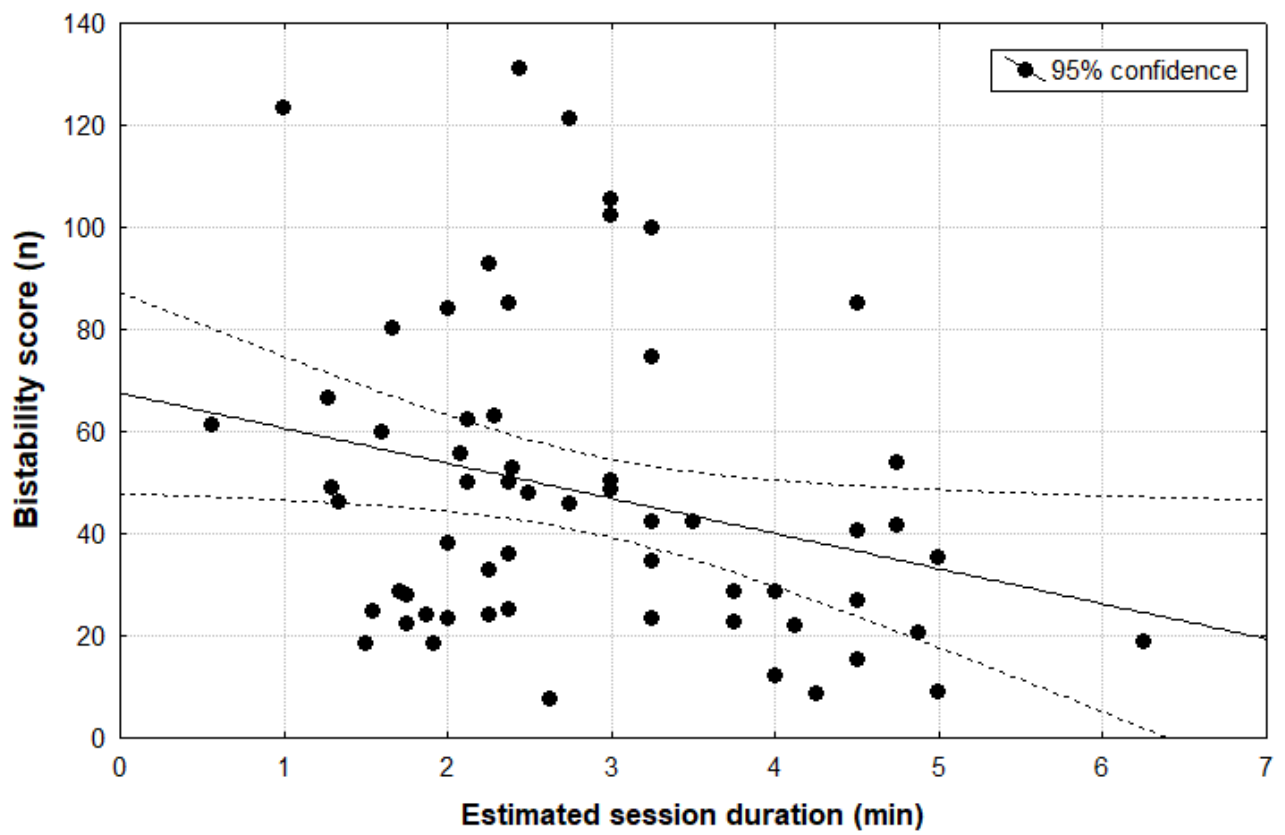
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Fig. 2. Means and standard errors for the bistability score (number of reversals) and for the time estimation in the 4 conditions of Experiments 1 and 2.

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753 **Fig. 3.** Scatterplot showing the global correlation ($n=60$) between the bistability score (n , number of
754 perceived reversals averaged across conditions) and time estimation (min, session duration
755 estimation averaged across conditions) in both experiments together ($r = -0.30$, $p = 0.022$).