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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.

INTRODUCTION

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

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

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

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

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

A further point which we face here is to investigate whether the perceived duration of a time lapse can be influenced by the number of ambiguous figures presented and by their number of reversals. Subjective evaluation of time duration is a fundamental point in psychology research and it has never been studied in association to bistable perception, a situation in which subjective aspects of cognition are of particular relevance. Thus we think that the investigation of the mechanisms underlying the interactions between the two perception domains rests on solid epistemological foundations. In the investigation of temporal processing, there are two main paradigms which may involve different cognitive processes. In the attention-related prospective timing task, participants are informed in advance that they will have to judge the duration of a period of time, for which attention plays a primary role in performance. In contrast, in the memory-related retrospective timing task, participants do not know until the end of the task that they will have to judge its duration, so memory processes seem to be critical (see Vatakis et al., 2018). In general, evidence supports at least two different systems for temporal processing: one based on senses for short durations (≤ 1s, approximately) and one based on high-level cognitive processing for longer durations (Hellström & Rammsayer, 2004; Lewis & Miall, 2003). The perception of short durations (≤ 1s, approximately) is more influenced by the input sensory information (e.g., brightness, spatial frequencies, number of elements comprising the stimulus, and neural adaptation; Xuan et al., 2007; Aaen-Stockdale et al., 2011; Eagleman & Pariyadath, 2009). Instead, the judgments of duration on scales equal to or greater than 3 seconds are influenced by cognitive load (Block et al., 2010). The present work uses an attention-related prospective timing task and only considers durations of 3 minutes. Given that the duration to be judged is long, we expect that the variation of the input sensory information (number of figures presented simultaneously) will have limited effects on the judgment. On the contrary, we predict that the number of perceived alternations may influence the temporal task. To our knowledge, this is the first study linking this type of stimuli to temporal perception. However, it is known that if during prospective temporal judgement tasks the subject performs another activity, and attention is mainly focused on the non-temporal task, the estimate of elapsed time will be lower than when attention is focused on the passage of time (Zakay & Block, 1996, 1997). In contrast, the number of perceived reversals, when attention is paid to the bistable perception task, tends to 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 (Intaitė et al., 2013; Ouhnana & 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.

MATERIALS AND METHODS

Experiment 1

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

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

Experiment 2

Participants

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

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 ($F=0.88$, $p=0.768$, $\eta2=0.003$), Eyedness ($F=0.69$, $p=0.412$, $\eta2=0.022$), Condition ($F=0.78$, $p=0.507$, $\eta2=0.025$) and their interactions: Condition x Handedness ($F=0.50$, $p=0.687$, $\eta2=0.016$), Condition x Eyedness ($F=1.20$, $p=0.315$, $\eta2=0.037$). 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 ($F=0.31$, $p=0.862$, $\eta2<0.001$), Eyedness ($F=0.87$, $p=0.359$, $\eta2=0.027$), Condition ($F=0.05$, $p=0.951$, $\eta2=0.002$) and their interactions: Condition x Handedness ($F=0.80$, $p=0.453$, $\eta2=0.025$), Condition x Eyedness ($F=1.75$, $p=0.183$, $\eta2=0.053$). This results indicates that the fixation point does not statistically influence the lack of reversals increment.

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 ($F=4.756$, $p=0.03$, $\eta2=0.11$) 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 ($F=8.896$, $p=0.005$, $\eta2=0.186$) and no other statistically significant effects (Side: $F=0.516$, $p=0.477$, $\eta2=0.013$; Height: $F=2.136$, $p=0.152$,

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

Experiment 2

Analyses on bistability scores

Analyses were carried out after having excluded 1 participant since she did not perform the task correctly and 6 subjects since they made too large eye movements. The sample of the following analyses is thus n = 25, all subjects who gazed for at least 75% of the time in each condition to the fixation cross (mean = 94.95% of the total test time, standard error = 1.14). Across subjects (mean and standard deviation) bistability scores in the 4 conditions (1F, 2F, 4F, 8F) were 51.8 ± 34.8 for the 1F condition, 44.5 ± 33.6 for the 2F condition, 39.7 ± 22.3 for the 4F condition, and 46.3 ± 22.3 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 factor (Condition, with 4 levels 1F, 2F, 4F, 8F) was carried out. Results showed no significant effects for all factors: Handedness (F=2.04, p=0.167, η^2=0.084), Eyedness (F=0.82, p=0.376, η^2=0.036), Condition (F=0.01, p=0.998, η^2=0.001) and their interactions: Condition x Handedness (F=0.31, p=0.817, η^2=0.014), Condition x Eyedness (F=0.167, p=0.918, η^2=0.008) confirming the result of Experiment 1.

Finally, 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 again no significant effects for all factors: Handedness (F=1.78, p=0.196, η^2=0.075), Eyedness (F=0.71, p=0.407, η2=0.031), Condition (F=0.02, p=0.981, η2=0.001) and their interactions: Condition x Handedness (F=0.28, p=0.752, η2=0.013), Condition x Eyedness (F=0.19, p=0.825, η2=0.009).

Time estimation

For both experiments, an analysis was carried out on the perceived duration of the 4 sessions (conditions), which lasted actually 3 min. For Experiment 1, mean and standard deviation of the perceived duration was 3.28 ± 1.36 min in the 1F condition, 2.73 ± 1.37 min in the 2F condition, 3.15 ± 1.83 min in the 4F condition, and 3.04 ± 1.45 min in the 8F condition. For Experiment 2, mean and standard deviation of the perceived duration was 2.59 ± 1.35 min in the 1F condition, 2.56 ± 1.72 min in the 2F condition, 2.34 ± 1.21 min in the 4F condition, and 2.25 ± 1.29 min in the 8F condition (Fig. 2). Repeated-measures ANOVA on the perceived duration (1F, 2F, 4F, 8F) showed no significant effects (Experiment 1: F=2.235, p=0.089, η2=0.06; Experiment 2: F=0.846, p=0.473, η2=0.03).

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

Control analyses

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

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

Discussion

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

A further aim of the present study was to investigate whether the number of ambiguous figures simultaneously presented and their perceptual reversals could influence the judgement of the duration of a time lapse. No differences were found between the time duration evaluations of the four sessions, but an interesting and seemingly robust result emerged from the analysis of correlations with the bistability score: all correlations (significant and non-significant) were negative, indicating that the more reversals were perceived, the shorter the duration of the session was evaluated. The most evident result was obtained in the 8F condition which showed the highest (and significant) correlation value (-0.44). The overall correlations between the mean of the time evaluations and the mean of the reversals in the 4 conditions showed a similar (-0.30) significant correlation. In our opinion, this finding suggests the presence of a link between the perceptual reversals and the internal clock which can be used to estimate time flow. If between two reversals the time lapse is long (as is the case with a low number of reversals), then the elapsed time evaluation tends to increase.

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

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

In the history of behavioural studies with ambiguous figures, several authors have presented two or more ambiguous images more or less simultaneously (Adams & Haire, 1959; Babich & Standing, 1981; Jensen & Mathewson, 2011; Long & Toppino, 1981; Mathewson, 2018). However, in most of these studies the presentation techniques used were underdeveloped and the instructions given to the subjects did not allow, in our opinion, sufficient control on the afferent information flow occurring during the stimulation. Also the present study has potential confounds related to the lack of eye movements control and the different size of the figures presented in Experiment 1 (5 cm in the 1F and 2F conditions compared to 4 cm in the 4F and 8F conditions). Experiment 2 was however designed to solve these issues by presenting all figures with the same size and by controlling eye movements with an eye tracker instrument. In Experiment 2 we also modified the response buttons: unlike Experiment 1 in which participants were asked to associate each key with a figure, in Experiment 2 they had to press the same button for each perceived reversal. Hence, the results of Experiment 2 allow us to exclude that the reversal rate in Experiment 1 could be influenced by the difficulty due to associate each image to one specific key. Another confound concerns the fixation point, which coincided with the figure only in the 1F condition raising possible different attentional effects compared to the other conditions which could have biased the results. A dedicated control analysis showed that the lack of reversals increase was evident also in the 3 conditions in which the distance of the figures to the fixation point was identical.

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

Concerning the issue of time evaluation, as a limitation of the present study the number of reversals was always associated to the number of the motor responses. In principle, this would not allow to establish a relation between the perceptual reversals and time evaluation, as the same relation holds between the number of motor responses and time evaluation. However, extant literature suggests that the influence of motor activity on time perception is at best limited to the evaluation of short durations in the sub-second domain (Mioni et al., 2016; Hass et al., 2012; Lewis & Miall, 2003). Here the durations were one order bigger (minutes) and their evaluations are more related to cognitive factors such as attention and working memory. Evidence in the literature suggests in fact the existence of at least two different functional and neural mechanisms for temporal perception (Hellström & Rammsayer, 2004; Lewis & Miall, 2003). The processing of smaller time intervals (approximately ≤ 1s) is sensory-based, whereas the processing of longer intervals requires the support of cognitive resources. In this study, varying sensory information (understood as the number of figures) did not produce a significant effect on perceived duration but it was related to the number of perceived alternations. This would seem to confirm that the perception of longer durations is based more on high-level processing than on sensory processing. Thus we expect a negligible influence of the motor response on time evaluation in the present study. Nevertheless, further studies could disentangle this issue for instance using no-report paradigms during bistable perception which do not request a motor response. Although perceived duration is generally assumed to correspond with objective duration, several studies suggest that time perception cannot be placed in a simpleminded framework (Bueti & Walsh, 2009). Previous studies suggested several rules that would govern temporal perception. It has been proposed that the experience of duration is a signature of the amount of energy expended in processing the stimulus (Eagleman & Pariyadath, 2009) and that perceived time is positively related to perceptual vividness and to the ease of extracting information from the stimulus (Matthews & Meck, 2016). Stimulus repetition has been shown to reduce temporal estimation possibly due to a suppression of neural sustained responses (Eagleman & Pariyadath, 2009). This outcome seems to agree with our result of a negative relationship between number of spontaneous reversals and evaluation of the session duration. Consistent with this interpretation, adaptation has often been considered an underlying dynamic of multistable perception (Long & Toppino, 2004; Kogo et al., 2015) and would seem to explain at least 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 duration judgment. As in Block and coworkers (2010), the term cognitive load refers to the required amount of information processed by attention and working memory. Prospective judgments on duration can be thus used as a measure of the amount of mental load required to perform a non-temporal task (Zakay et al., 1999; Block et al., 2010).

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

Data availability

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

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Figures

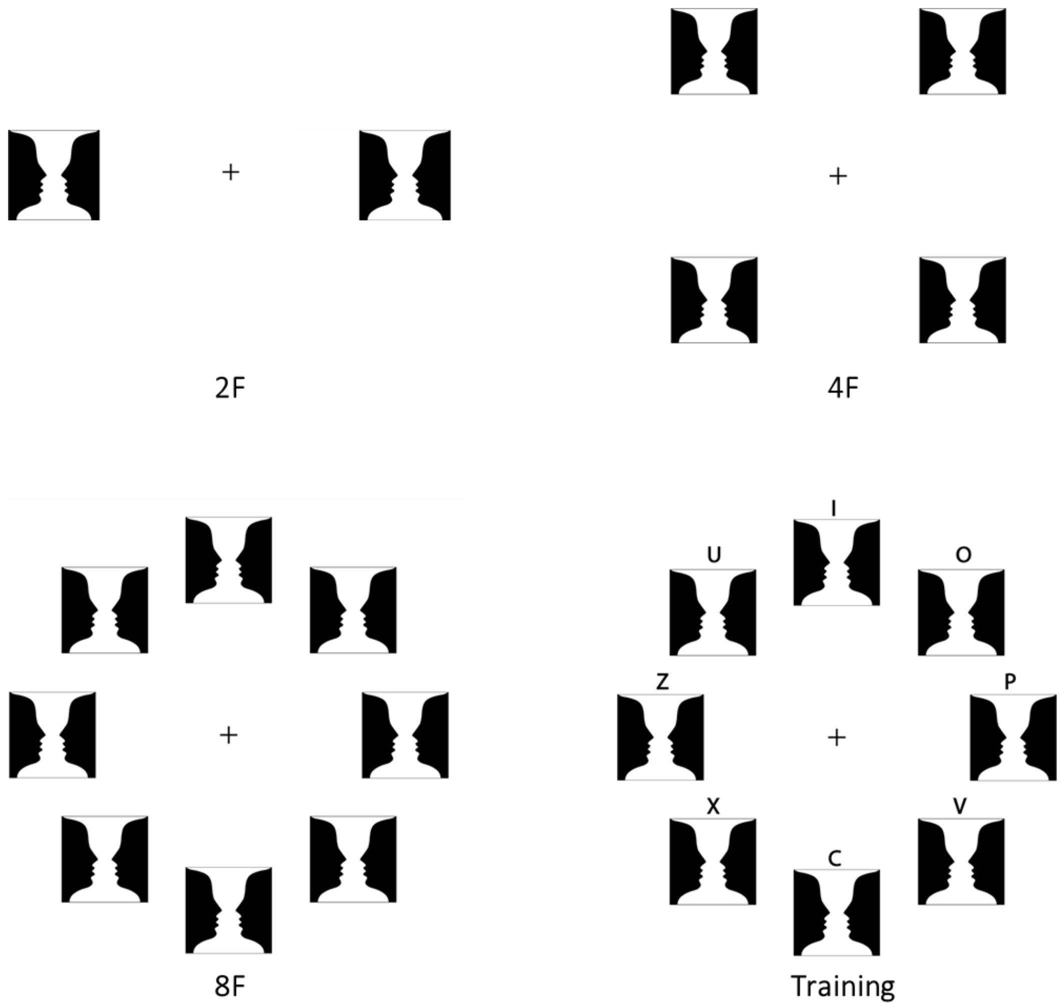

Fig. 1. The stimuli (Rubin's face-vase figures) presented in the two experiments in the 2F condition (*top-left*), 4F condition (*top-right*), and 8F condition (*bottom-left*). The cross indicates the fixation point. In the 1F condition only one Rubin's face-vase figure was presented instead of the cross 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.

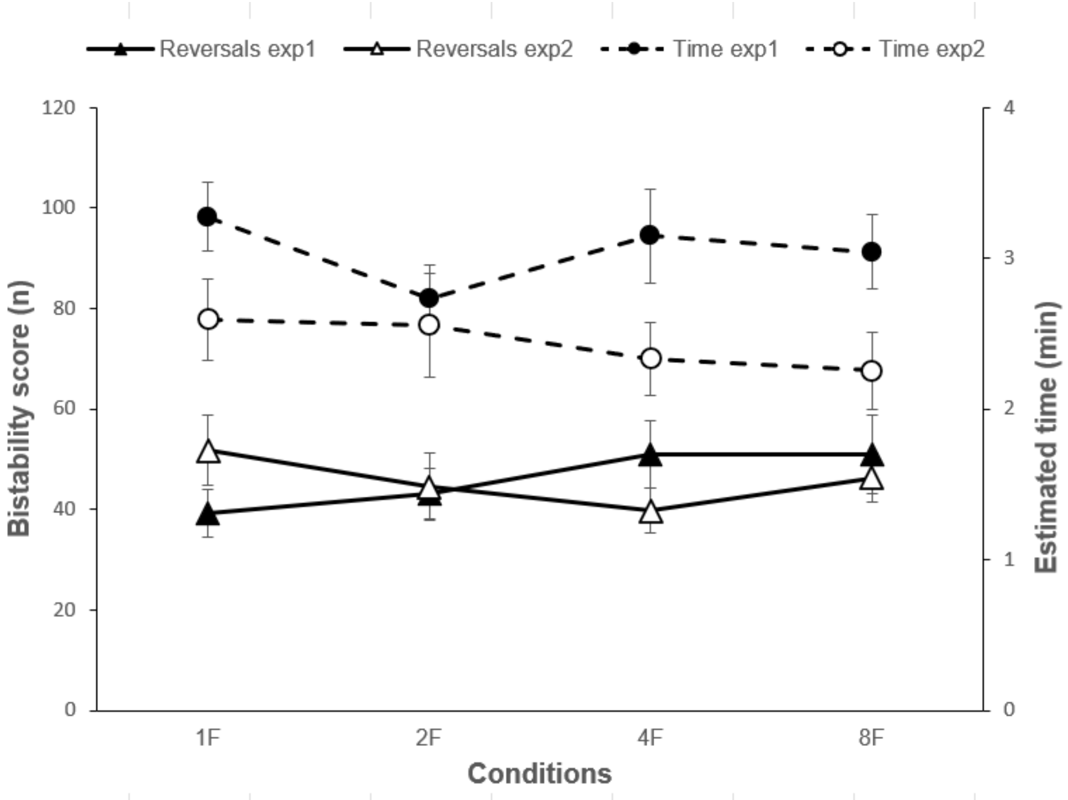

Fig. 2. Means and standard errors for the bistability score (number of reversals) and for the time estimation in the 4 conditions of Experiments 1 and 2.

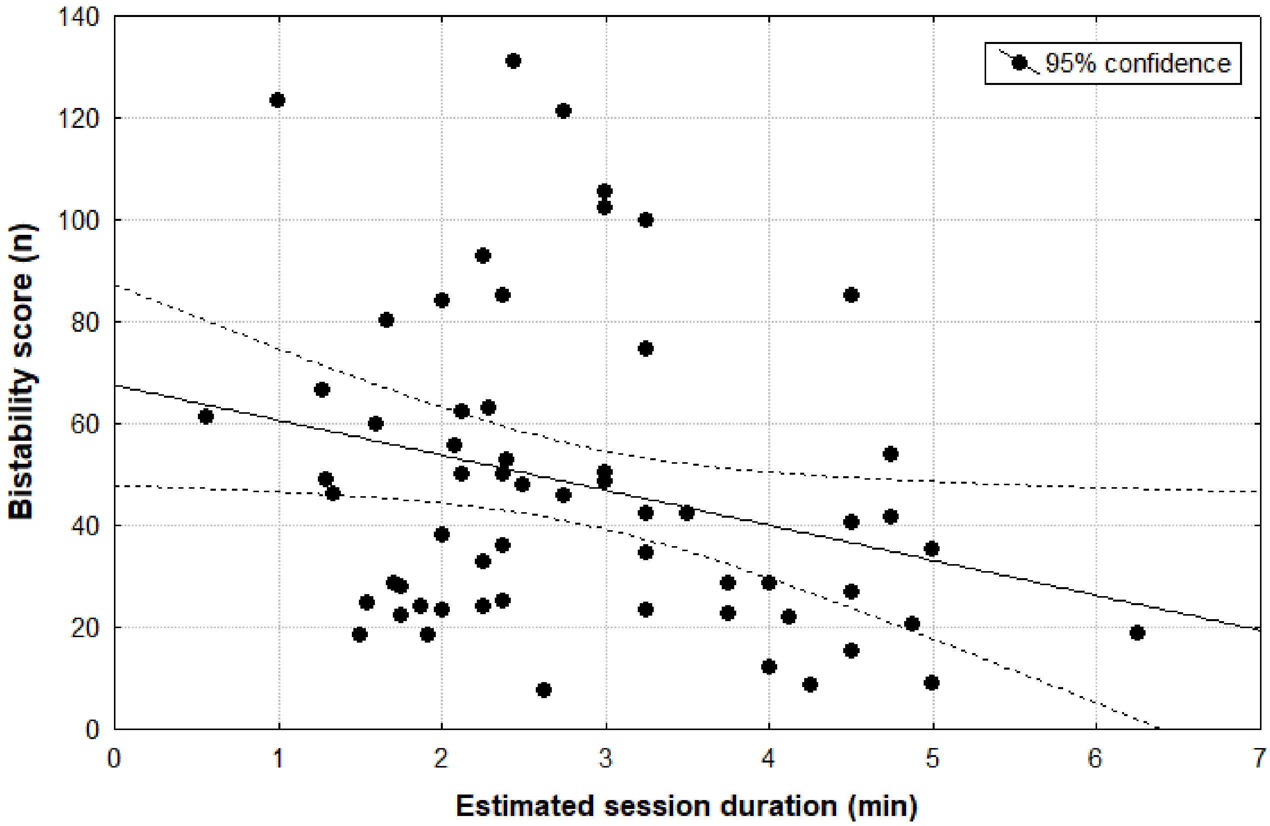

Fig. 3. Scatterplot showing the global correlation (n=60) between the bistability score (n, number of perceived reversals averaged across conditions) and time estimation (min, session duration estimation averaged across conditions) in both experiments together (r = -0.30, p = 0.022).