Universitat Pompeu Fabra Barcelona

The Dynamics of Perceptual Bistability

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Abstract

During prolonged observation of ambiguous stimuli ("bistability") perception spontaneously switches back and forth between interpretations. At present, it is not fully understood what causes these switches in perception. Recent studies suggest that the intermittent alternations are driven primarily by neuronal noise, not by adaptation (as has been previously thought). In this context, it has been said that 'relaxation' techniques, and in particular meditation training, can reduce certain sources of noise. Indeed, previous research suggests that some types of meditation practice may entail perceptual benefits such as a greater degree of stability in perceptual tasks on attention regulation. Therefore, the present study investigates the dynamics of perceptual bistability using ambiguous motion plaids in a sample of experienced meditation practitioners (N=10, 7 females) and contrasts their performance to that of a control group (N=10, 5 females) untrained in meditative techniques. The perceptual task took place before and after a 30-minute relaxation/meditation period. It is hypothesised that relaxation leads to a reduction of noise and therefore to enhanced stability in the perceptual task as expressed by decreased alternation rates and increased dominance durations. Furthermore, is assumed to be more pronounced in meditators than controls. The findings confirm a decrease in mean alternation rates following meditation/relaxation, but not enhanced effects in the meditation compared to the control groups.

I. Introduction

This research project studies perceptual bistability. Bistability is a phenomenon that occurs when a stimulus has multiple different perceptual interpretations. Famous examples of such perceptual rivalry include reversible figures such as the "Necker cube" (fig. 1; Necker, 1832), figure-ground segregation like the "face-vase illusion" (Rubin, 1921), ambiguous motion displays (fig.3; Hupé & Rubin, 2003), and binocular rivalry (Wheatstone, 1838). As one views a bistable stimulus, perception spontaneously switches back and forth between interpretations, termed perceptual alternations. This is because rivalling percepts compete for dominance in the conscious experience of the observer (Leopold & Logothetis, 1999) during which typically only one percept is visible at a time, something that is referred to as mutual exclusivity.

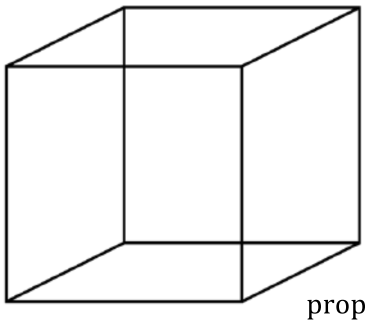


Figure 1 shows an example of a figure with multiple interpretations: the Necker cube

Psychophysics has extensively studied the dynamics of perceptual alternations and the statistical properties of percept durations. Bistable images have several key properties: (1) Firstly, the durations of dominance (of each percept) are distributed according to positively skewed probability distribution (e.g. lognormal or gamma; Brascamp, van Ee, Pestman & van den Berg, 2005) and this has been demonstrated for both binocular rivalry and ambiguous motion displays (Hupé & Rubin, 2003; Rubin & Hupé, 2004). (2) Secondly, ambiguous stimuli can be biased towards one of the percepts by manipulating the stimulus parameters (e.g. contrast, speed) (Hupé & Rubin, 2003; Moreno-Bote, Shpiro, Rinzel & Rubin, 2008; 2010). (3) Thirdly, individuals have some degree of voluntary control over the rate of perceptual reversals as they can focus attention on a particular percept and change reversal frequency (Leopold & Logothetis, 1999; Kornmeier & Bach, 2012). These properties uniquely show that both high-level cognitive areas and low level sensory processing mechanisms are involved in the phenomenon of bistability (for review see Long & Toppino, 2004).

Binocular rivalry (which involves presenting two contrasting images to each of the eyes) is probably the most studied phenomenon among those mentioned here. The term "binocular rivalry" was coined by Levelt's seminal work *On Binocular Rivalry* (Levelt, 1965). He formulated four propositions on the behaviour of dominance durations in relation to stimulus strength, the suggested variable that influences binocular rivalry. The long-lasting impact of Levelt's research is partly due to a high practical value: it concisely captures the disperse evidence then available in only four propositions. However, more recent studies have shown that they hold true (i.e. are congruent with empirical results) only partially when regarded from a contemporary point of view (Brascamp, Klink & Levelt, 2015). Therefore, researchers in the field (including contributions by Levelt himself) have composed a review as part of the 50th anniversary of publication which provides an evaluation of original work with regard to the consequential body of literature followed after. This led to the emergence of four *modified* versions of Levelt's original propositions. This thesis will concentrate on the second and third modified propositions, which posit that increasing the stimulus strength difference across the two eyes leads to a reduction in switching rate (III), and it will mainly affect the mean dominance duration corresponding to the stronger stimulus (II) (see fig.2). In short, the relevant modifications are grounded in the argument that any modulation that leads to an increase in the difference between the two eyes' stimulus strengths will result in a decrease in switching rate (fig 2, left panel).

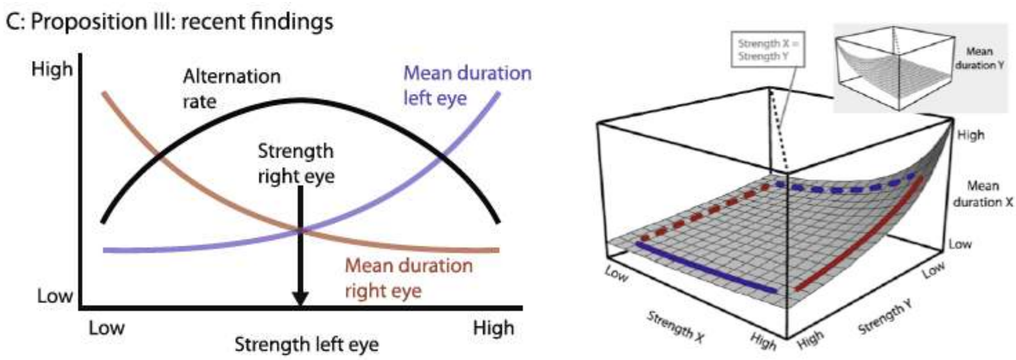


Figure 2 (left panel) illustrates assumptions of the modified version of the third proposition (and directly related implications of II). According to this newly formulated approach, increasing the difference in stimulus strength between the two eyes leads to a reduction in alternation rate along side enhanced mean dominance duration of the relatively stronger stimulus. In the right panel results are plotted in stimulus-strength-space and inserted on a surface that displays dominance durations of one eye labelled X and in the inset those of the other eye labelled Y, respectively. The dashed diagonal indicates equal stimulus strength whereby any divergence from this line mainly results in increased dominance durations of the stronger stimulus (figures adapted from Brascamp et al., 2015).

Another development in the relevant literature concerns generalising the above-described findings on binocular rivalry to other phenomena of perceptual bistability

(Moreno-Bote et al., 2008). For example, Hupé and Rubin (2003; 2004) used so-called motion plaids (see fig.3) to extensively study the dynamics of perceptual bistability in the past, validating its suitability for this kind of experiment.

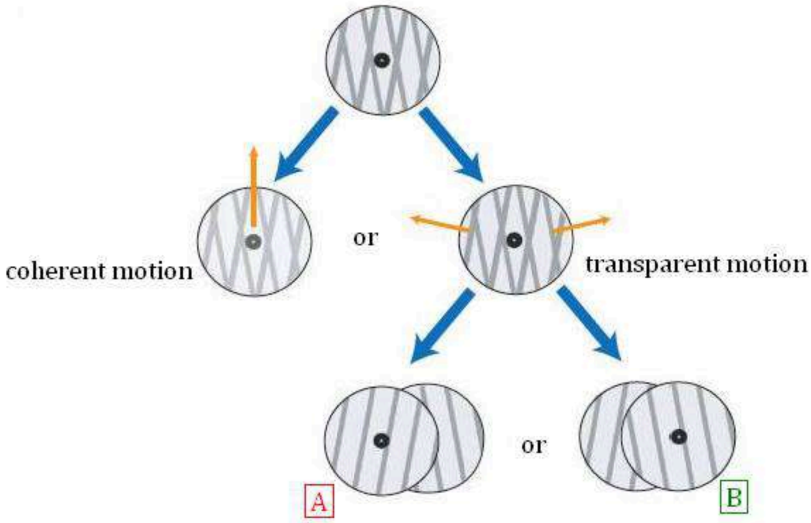


Figure 3 illustrates the motion plaid stimulus that is composed of two superimposed grating patterns displayed behind a circular aperture. The stimulus is ambiguous, or bistable, in that the gratings' motions can be perceived in various ways: firstly, in the sense of coherent or transparent motion (top panel), and secondly, in terms of the gratings' depth ordering (lower panel). In reference to the latter, figure 3 depicts the possible interpretations of a dominant percept: in percept A the grating in front moves to the left whereas in the alternative percept, B, the ordering is reversed with the grating in front sliding to the right. In case of this thesis, only the second type of ambiguity is of relevance.

As illustrated in figure 3, the stimulus consists of a plaid pattern comprised of two superimposed rectangular wave gratings. When set in motion, the stimulus becomes ambiguous, or bistable, in that observers perceive fluctuations between a unified grid-like pattern that moves upwards (coherent motion) and two separate gratings that drift in opposite directions (transparent motion). This ambiguity is illustrated in the top panel of figure 3. Furthermore, the motion plaid stimulus contains an additional type of ambiguity: When the angle between the two gratings is set sufficiently large, transparent motion is perceived almost all the time (Rubin & Hupé, 2003; 2004; Moreno-Bote et al., 2008) leading to the emergence of the second kind of perceptual bistability that concerns the perceived depth ordering of the two superimposed gratings (lower panel, fig.3). More specifically, in prolonged viewing conditions, the stimulus alternates between the two possible interpretations of depth ordering where the grating oriented to the left appears to slide over the right-ward oriented grating (percept A), or vice versa (percept B; see fig. 3, lower panel). In the current study, the grating that appears in front of the other is considered the dominant percept. For the sake of completeness the existence of the first ambiguity should be acknowledged, however, solely the second type concerning the depth ordering is germane to the current study.

Instead of referring to specific physical parameters (e.g. contrast) and 'stimulus strength' that results from their modulation, a dynamics-based measurement called *fraction of dominance duration* (fDD) will be calculated here. It can be seen as a proxy to stimulus strength and has been proved beneficial for generalisation across various phenomena of perceptual bistability (Hupé & Rubin, 2003; Rubin & Hupé, 2004, Moreno-Bote et al., 2010; Brascamp et al., 2015). Fraction of dominance duration (fDD) is the relative time a percept was reported to dominate (T) in relation to the cumulative dominance times of both percepts and is thus defined as $fDD_A= T_A/[T_A+T_B]$, and $fDD_B= T_B/[T_A+T_B]$, respectively. Consequently, fDD is a value that falls between zero and one, with 0.5 indicating an equal proportion of perceived dominance duration across interpretations. This point is termed *equidominance* in the relevant literature and implies that both percepts are equally likely to be seen, that is, $fDD_A= fDD_B= 0.5$. Most importantly, stimulus parameters in the current study have been chosen to elicit such equidominant percepts. Furthermore, the alternation rate (AR) is the number of perceptual switches per unit time and mean dominance durations (mDD) are the averaged dominance times of one percept in a given trial.

Moreno-Bote and colleagues (2008) varied the parameters of one grating (e.g. wavelength, speed) to measure their effect on the fraction of dominance time, as well as alternation rate (Moreno-Bote et al., 2010). They found that certain parameter settings resulted in equidominance. In their more recent study (2010), they showed that ARs peak and are symmetric around this point of equidominance. Their results are compatible with the modified propositions as shown in fig. 2 (left panel): ARs decrease when moving from the point where percepts were equally strong, and thus, equally likely to dominate. Interestingly, the results of Moreno-Bote's, Hupé's and Rubin's research have not proved entirely satisfactory. Their data shows that there is great variability in AR between phenomena of perceptual bistability for the same subject, as well as individual differences between subjects. The question therefore is, what aspect could be responsible for the degree of freedom that seems to exist separately from the fraction of dominance, from the relative, which is the *rate of alternations* at the point of equidominance. In other words: what is the driving force that leads to the switches in perception?

The prevalent view in the literature emphasises adaptation as the main underlying cause of perceptual alternations. However, this approach constitutes an assumption rather than relying on evidence and in addition appears as widely inconsistent with empirical findings of human psychophysics. That is, adaptation does not appear in the actual results of the experiments.

In previous studies dominance durations have been frequently fitted according to a gamma distribution (Leopold & Logothetis, 1996; O'Shea, Parker, La Rooy & Alais, 2009; van Ee et al., 2005). However, alternative theoretical distributions have been proposed elsewhere and seem to be (at least) equally appropriate (Brascamp et al., 2005; Moreno-Bote et al., 2007; Shpiro, Moreno-Bote, Rubin & Rinzel, 2009; Zhou, Gao, White, Merk & Yao, 2004). The shape of the dominance distribution revealing a peak rather than a monotonic decrease is crucial with respect to the role of adaptation and noise. Especially when regarded together with a second caveat present in the literature, namely, the lack of serial correlation of dominance periods of a certain percept within a trial. Accordingly, research failed to demonstrate a correlation between the duration of one dominance period and the successive one (Carter & Pettigrew, 2003; Brascamp et al., 2005; Holcombe & Seizova-Cajic, 2008; van Ee, 2009; Brascamp et al., 2015), a finding that stands in direct contrast to predictions of adaptation-based models. If adaptation played a role, one would expect correlations between successive dominance periods, contrary to what physicists call a "renewal process". The empirical data instead is more consistent with a renewal process (i.e. the system resets immediately after the alternation and the consecutive periods of dominance durations are independent of each other). So, these findings stand in contrast to the commonly held view that perceptual alternations are based on adaptation processes (such as slow negative feedback, and synaptic depression, for example). But what is the alternative suggestion for the primary driving force that results in perceptual alternations? The answer is *noise* (Moreno-Bote et al., 2007; 2010; Shpiro et al., 2009, van Ee, 2009; Pastukhov, García-Rodríguez, Haenicke, Guillamon, Deco & Braun, 2013).

The presence of noise in bistability is obvious as perceptual alternations are stochastic. Significantly, however, adaptation-based models are, in essence, oscillatory models. And regular oscillation-type models suggest "slow processes" (e.g. adaptation) as being the primary drive whereas noise is added on afterwards. In contrast, recent studies brought forward alternative approaches, of main interest here is an attractor-based model according to which the two competing interpretations are basically fixed points, or attractors, in state space (= the space of neuronal activities) and the alternations between them is driven (almost) entirely by noise (Moreno-Bote et al., 2007; 2010).

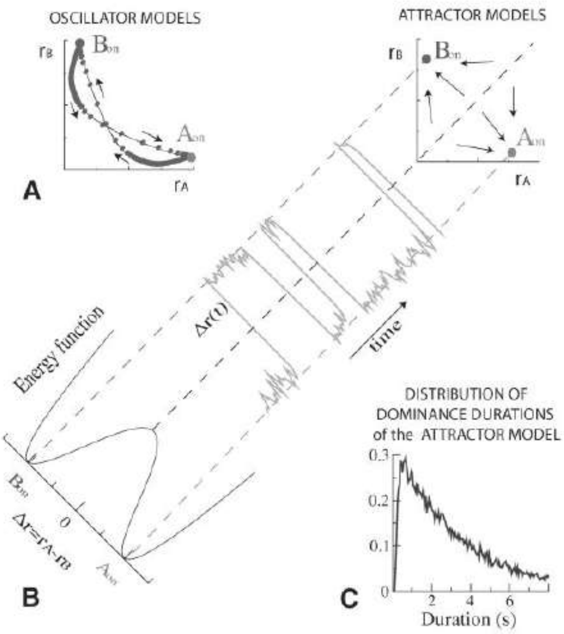
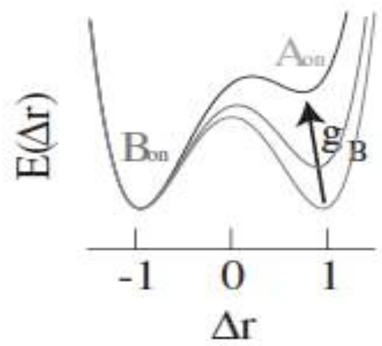


Figure 4 refers to the predicted behaviour of bistable perception as suggested by two types of computational models: oscillatory models and attractor models (based on a double-dwell energy function).

One of the most interesting questions, albeit difficult to explore experimentally, is therefore: What happens if one takes the noise out of the equation? According to oscillatory-based models, the prediction would be entirely regular alternations that are fluctuating at the average rate previously obtained (see fig. 4, inset A). Conversely, the attractor-based model deriving from a simple energy-dwell model predicts that the system will settle down in one of the two possible percepts and stay there indefinitely, thus, eliminating alternations entirely (see figures 4, 5).

Figure 5 shows the energy function for three values of g_B (0.1, 0.2, 0.4) with g_A being fixed at 0.1. The figure shows a decrease in stability of percept A is paralleled by an increase in stability of percept B as suggested by the model when moving away from equidominance.



In this context, the attractor-based model seems to satisfy several observations that have been known about the dynamics of perceptual bistability and appears to behave – to at least a first approximation – like perception behaves as demonstrated in miscellaneous experimental results (Moreno-Bote et al., 2007; 2010; Brascamp et al., 2015). For instance, compatible with the proposed model is the observation that ARs peak at the point of equidominance. Accordingly, this point of minimum stability would be represented with dwells of equal sizes in the energy function (fig. 4, 5). Conversely, moving away from this point of equidominance will lead to increased perceptual stability as expressed in lower ARs and enhanced dominance durations.

Taken together, the above suggests that perceptual switches between competing interpretations are due to stochastic processes (noise) rather than adaptation as has been previously hypothesised (though the latter may still play a role in the dynamics of the alternations). In other words, the intermittent alternations in perception that occur during prolonged observation of bistable stimuli are driven primarily by noise (Moreno-Bote et al., 2007; 2010; Shpiro et al., 2009, van Ee, 2009; Pastukhov et al., 2013).

Neuronal noise arises from numerous physiological sources which vary in spatial and temporal scales, and it is generally hard to control experimentally, especially in the intact animal. Nevertheless, research suggests that 'relaxation' techniques, and in particular meditation training, can reduce certain sources of physiological variability (Tang et al., 2009), and hence may have the effect of reducing neuronal noise. Indeed, previous research suggests that certain types of meditation practice may entail perceptual benefits such as a greater degree of stability in attention regulation in tasks on binocular rivalry (e.g. Carter, Presti, Callistemon, Ungerer, Liu & Pettigrew, 2005). In their study, Carter and colleagues (2005) demonstrated that Tibetan Buddhist monks were able to decrease and even halt the perceptual alternations during a task on binocular rivalry when they were engaged in a focused style of meditation which is called "one-point".

Accordingly, a crucial component of meditation is the maintenance of an optimal degree of arousal or alertness that is achieved through a stable attentional and emotional regulation (Slagter, Davidson & Lutz, 2011; Lutz, Dunne & Davidson, 2007). For example, Takahashi and colleagues (2005) demonstrated changes in autonomic nervous activity measuring heart rate oscillation during meditation. It has been said that heart rate variability (HRV) serves as an indicator of heart-brain interaction reflecting parasympathetic nervous-system dynamics (Slagter et al., 2011).

Therefore, the current study aims to investigate the dynamics of perceptual bistability in relation to potential sources of noise. In particular, it will be assessed how certain "relaxation" techniques, but especially meditation training, affects the rate of alternations between stable percepts. Participants will be asked to perform a simple perception task on bistability followed by a 30-minute meditation/relaxation period during which physiological data will be collected, and a subsequent repetition of the bistable perception task.

The hypothesis of this thesis is that meditation/relaxation has an effect on alternation rates and dominance durations in the perceptual task. This is because relaxation is assumed to reduce neuronal noise, which will result in greater perceptual stability as indicated by the aforementioned measurements (AR, mDD). Furthermore, the second hypothesis is that the effect of relaxation on the bi-stability measures will be greater for experienced meditators as compared to controls.

III. Methods

III.I. Participants

A total of 20 participants, aged 23-54 years (M=34.75; *SD*=10.15), took part in the study. There were two groups, namely, the experimental group composed of 10 long-term meditation practitioners[1] (7 female) defined as having practiced meditation regularly for at least two years and a control group of 10 subjects (5 female) with little or no meditation experience. The average age differed among these groups: the mean age of the meditation group was 39,9 (*SD*= 11.8) whereas for the control group the average age was 29.2 (*SD*=4.48). This difference in age was also reflected in the medians: the control group revealed a median of 30 years contrasting 41.5 years of median age in the meditation group. All subjects had normal or corrected-to-normal vision. There were 3 male control subjects with a red/green colour deficiency in the current sample. However, the deficiency did not affect their performance. Results were congruent with those of the remaining subjects and detection of induced alternation in the forced mode (description below) was accurate for these three observers.

Participants were recruited through word-of-mouth and gave written informed consent prior to their participation. Furthermore, they were kept blind regarding the hypothesis of the study until after their completion of the experiment. The study was approved by the school ethics committee. Participation was reimbursed with 10 Euros per testing session/hour.

III.II. Materials: Apparatus and Stimuli

All stimuli were created using Python 2.7 and the pyglet library (www.pyglet.org). They were presented on a 19-inch cathode ray tube monitor (Philips 109B2) with a resolution of 1600x1200 at a refresh rate of 60Hz. The display was 36.5x27.5 cm in size. Subjects' responses were collected using the buttons and the wheel of a computer mouse. Red-green 3D anaglyph goggles were used. Darkening luminance filter were attached to the green glass in order to reach equal luminance between the two glasses and thus counteract the Pulfrich effect.

The computer-based biofeedback software called emWave Pro (HeartMath LLC) has been used to monitor and display physiological measurements in real-time. It contains a small infrared sensor which is attached to the subject's skin and connected to a computer with cable and a USB port as shown in figure 6.

Fig. 6: Infrared sensor attached to the ear lobe

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1 *Further information on meditation techniques plus the exact nature and extent of experience is enclosed in the supplementary material (unpublished).*

Fig. 7 illustrates one frame of the plaid stimulus which consists of two superimposed rectangular-wave gratings that drift in opposite, oblique directions when set in motion. The stimulus is ambiguous, or bistable, in the sense of the gratings' depth ordering.

The stimulus appeared within a circular aperture of diameter 12.5° (fig.7). Luminance of the background area outside the aperture as well as of the aperture itself was 78cd/m^2. The luminance of the superimposed gratings was 64cd/m^2. There was white central fixation point with 88cd/m^2 (radius = 0.18°) which was superimposed on a small homogeneous black surrounding area (radius 0.9°) presented in the middle of the screen (fig.7). All lines were anti-aliased (i.e., intermediate luminance values were applied for the pixels at their edges). The following parameters were set equal for both gratings: a duty cycle (can be defined as the proportion of the surface covered by each grating and is calculated as follows [(width of dark bar)/(total cycle)]) of 0.2 and a wavelength (or spatial frequency) of 2.7°. All bars were moving at a speed of 5.4°/s. The total duration of one trial was 10 minutes.

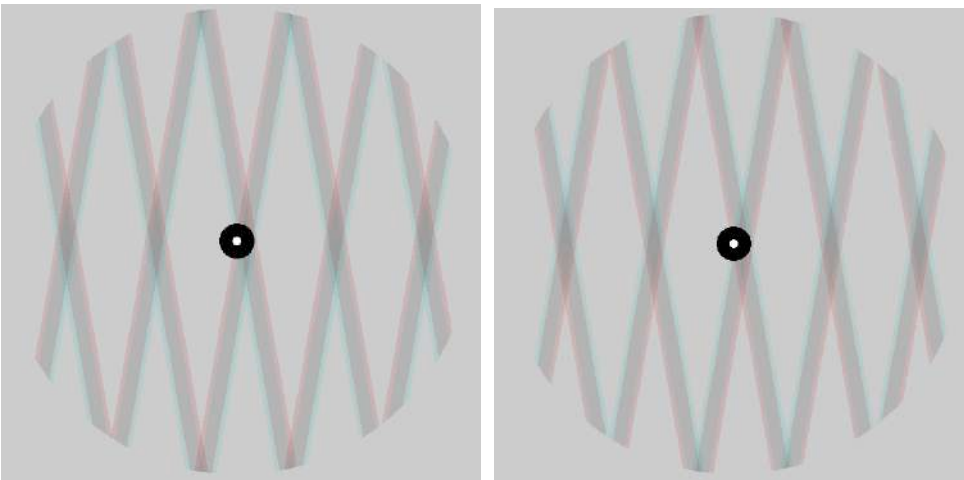

Fig. 8a *Fig. 8b*

Fig. 8 illustrates the plaid stimulus when set in forced mode. The both panels (a and b) show the two possible percepts. The dislocation of the two colours adjacent to the bars determines which grating is seen in front and which in the back (the reader might look at this figure with red-green glasses in order to better see the stereoscopic disparity in the forced stimulus).

In the forced mode, stereoscopic disparities were incorporated in the stimulus as shown in figure 8. Each bar of the grating is composed of two bars of cyan and red colour. When set to the spontaneous mode (fig.7), as opposed to the forced one (fig.8), these two bars overlap completely and blend into a grey colour. When using forced mode, a displacement is applied to these bars. In consequence, they do not overlap on their sides, thus, the cyan and red colours are visible. The luminance levels for the red and cyan regions were 90cd/m^2 and 94cd/m^2, respectively. So, stereoscopic disparities were implemented to the gratings by relocating their red and cyan coloured components (shifted by 0.37°along the horizontal axis).

Figures 7 and 8 show that the sites where the gratings cross each other, that is, their intersections, were slightly darker with a luminance of 43cd/m^2 in order to foster transparent motion (lower luminance than the rest of the bars; Stoner, Albright & Ramachandaran, 1990). In addition, the angle between the gratings was set to 160° between their global directions of motions, that is, +/-80° from the vertical. This decision was taken due to the results of previous research demonstrating that transparent motion is predominant when the angle between the two gratings is large enough (from ~140° onwards), (e.g. Hupé & Rubin, 2003; Moreno-Bote et al., 2008). The aforementioned manipulations yielded perceptual alternations regarding only the relative depth ordering of the bars. Consequently, alternations concerned with the other ambiguity inherited in the plaid stimulus, namely that of coherency, were attenuated almost completely in the current study.

III.III Procedure

The experiments took place in a dimly-lit, sound-isolated room in the experimental laboratories of the Center for Brain and Cognition of the university Pompeu Fabra (UPF) located in the -1 level of the Tanger building in the Department of Information and Communication Technologies. One testing session took approximately one hour in total. Each participant performed four sessions on different days in order to induce the forced mode (see below) and investigate a potential progress in performance, in particular with regard to controls' physiological data. There was one exception: the subject MBC completed all four sessions on two consecutive days due to travel reasons. The procedure of the four testing sessions remained exactly the same and were composed of two types of tasks (detailed description in the following paragraphs): Subjects performed a 10-minutes behavioural task on perceptual bistability before and after a 30-minute meditation/relaxation period during which physiological data was collected.

Perceptual task on bistability:

Participants were seated 70cm from the monitor with their heads placed on a chin rest and they were asked to look at the fixation point throughout all trials. For the purpose of familiarisation with the stimulus, all subjects completed at least one practice block, consisting of 3 trials of 20 seconds, prior to starting the actual experiment. Participants were given verbal instruction on how to complete the task additionally to a concise how-to-respond summary which was presented on the initial screen prior to each trial (appendix). Whenever the participant was ready he/she pressed the mouse wheel in order to start the trial.

During each trial, participants continuously reported the motion direction of the grating that appeared in front of the other one (dominant percept) by holding the according one of the two mouse buttons pressed for the duration of the respective percept. In other words, observers responded by pressing the left mouse button if the grating that seemed closer to them moved to the left, and the right button when they perceived the front grating drifting to the right, respectively. Particular emphasis was given to the *continuous report* of perception via mouse presses as well as the *passive viewing instructions* (i.e. not trying to intentionally perceive anything, but instead, report spontaneous alternations only) when briefing the participants and as a reminder in subsequent sessions. Once the subject reported to have understood the task, the experimental trials were initiated.

In order to control whether participants were reliably reporting the occurrence of perceptual alternation rather than just randomly pressing buttons, participants were partially tested in a “forced mode” of the perceptual task (stimulus in fig.8). Therefore, stereoscopic disparities were induced providing an additional depth cue that physically forced the stimulus to alternate between the two versions of the gratings’ depth ordering (as opposed to spontaneous fluctuations between percepts due to the bistable nature of the original, unforced stimulus). The timing of these physically induced alternations was determined by previously reported perceptual alternations from an earlier session. More specifically, so-called ‘transitions files’ which consist of event time stamps of perceptual alternations were used in order to deliberately reverse the depth ordering of the gratings. Therefore, individual transition files for each participant were created containing ~50% of the alternations (since using an entire 10-minutes trial just in order to check if participants were doing what they were asked to do seemed inefficient, or even wasteful). So, the newly created and individually tailored transition files were administered in two occasions: once in a trial before and once in a trial after the meditation/relaxation period. As differences in ARs between these two conditions were expected the transition files were matched accordingly. The forced mode turned off 10 seconds after the last induced physical alternation.

Subsequently, transition files were compared and controlled for congruency. In the case of major discrepancies between the alternations, data would have been excluded from the final analysis. However, this was not the case in the current sample. Exemplary for one observer (AIL), two transition files have been enclosed in the appendix. In general, subjects were informed about the existence of the forced mode, yet, they were naïve regarding the exact moment of application. Hence, observers wore red-green glasses for the entire experiment in order to perceive the stereoscopic disparities whenever induced.

In between the repetition of the perceptual task participants were asked to either relax or meditate for half an hour depending on the group. During this period physiological data was monitored and displayed as below in figure 9.

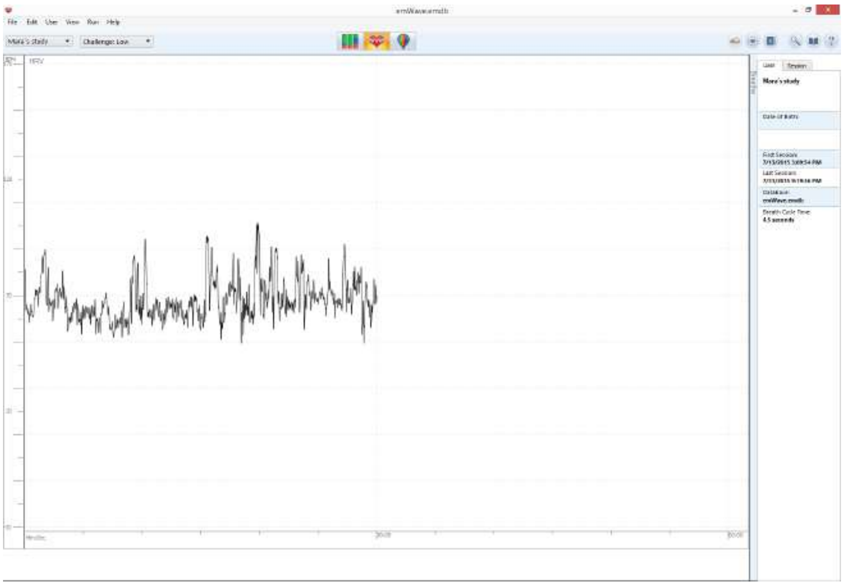

Fig. 9 depicts an example of the screen display after completion of a 30-minute relaxation session (control participant). During the session the breath pacer appears in the top right corner. In the current example the speed of the breathing cycle was set to 4.5 seconds. One cycle consists of an inhalation and an exhalation.

For the relaxation periods control subjects were instructed to relax for half an hour using emWave Pro software. Therefore, a breath pacer appeared in the right upper corner of the screen. Participants were asked to adjust this pacer individually, so that it would match their natural way of breathing. Afterwards they were given the free choice of closing or leaving their eyes open during relaxation. In the meditation condition, too, instructions were fairly liberal: By nature, the meditation period was highly individual and varied across participants regarding the exact style or position that was adapted. For instance, the majority of participants were seated on a pile of cushions on the floor whereas a few others remained seated on the chair. Another source of variation emerged with the monitor being switched off for several, yet, not all subjects of the meditation sample. More detailed information on the individual environmental conditions for each subject can be obtained from the supplementary material (unpublished).

Subjects were not told that the perceptual and the physiological task are connected in order to avoid expectation bias. However, after completion of the experiment subjects were given a full debrief on the study.

III.IV Analysis

The dependent variables in this experiment are alternation rate and dominance durations of percept A and B, respectively. The independent variables are the between-subjects groups (Meditation vs. Controls) and the repeated measurement conditions (Before vs After).

Due to technical issues (1), incorrect responding (1), and flawed parameter settings (6) a total of 8 sessions (= 16 trials of the perceptual task) had to be excluded from the final analysis. This results in a total sample set of 72 testing sessions 38 of these were performed by meditators, 34 by controls.

Subsequent data analysis was performed using MATLAB (MathWorks, USA) and the statistical software SPSS (IBM).

Dynamic-based measurement of percepts' strength

Perceiving one grating as sliding in front of the other, that is, the dominance time of one percept (A or B) has been quantified as the duration between the onset and offset of exclusive visibility of that percept. A dominance duration was required to be longer than 300ms. Hence, durations shorter than that have been excluded from the analysis. Furthermore, overlaps where both mouse buttons are pressed simultaneously have been removed (clean-up of overlaps). This was done by taking the successive frame as reference and adding the time of the overlap to the according press (i.e. removal of the relative other button press) whenever possible. In few occasions where the consecutive press was not available (e.g. end of trial) the previous was used for reference instead.

From the dominance durations, three dynamics-based measures of bi-stability were calculated: mean dominance duration (mDD), fraction dominance duration (fDD), and alternation rate (AR).

The mDD *of one percept* was calculated as the mean of all dominance durations for a given trial. The fraction of time that a percept dominated (fDD), that is, the relative time a percept was reported relative to the other percept was therefore defined as $fDD_A = T_A/[T_A+T_B]$, and $fDD_B = T_B/[T_A+T_B]$, for the two percepts respectively. An fDD value of 0.5 indicates an equal proportion of perceiving either of the two percepts.

The alternation rate (AR) was defined as the number of perceptual switches per time window, here, one minute. In this context, one should bear in mind that the AR is independent and cannot be expressed directly in terms of the other two measurements (fDD and mDD) as two successive dominance periods of the same percept may be reported. Hence, an alternation is only considered to occur when a switch occurs between percept A and B.

The Matlab code used for the analysis described above can be found online (https://github.com/ErBa508/analyzeButtonPresses).

Most importantly, on the incorrect assumption that individual trials will be set to either the spontaneous, *or* the forced mode but never consist of both, the code writer was not concerned with separating these two with a given trial. So, the code was not created for trials composed of both conditions which is why data from the spontaneous and the forced mode were pooled and analysed together, disregarding the fact that the alternations reported in the forced mode are not perceptual but physically induced.

IV Results

IV.I Alternation dynamics

The behavioural data obtained in the experiment, collapsing participants from the control and mediation groups, was generally consistent with the known key features of bistable perception: participants in the study alternated between perceiving the two relative depths ordering of the two gratings in the motion plaid (Fig. 10), with highly variable duration and alternation rates (Fig. 11).

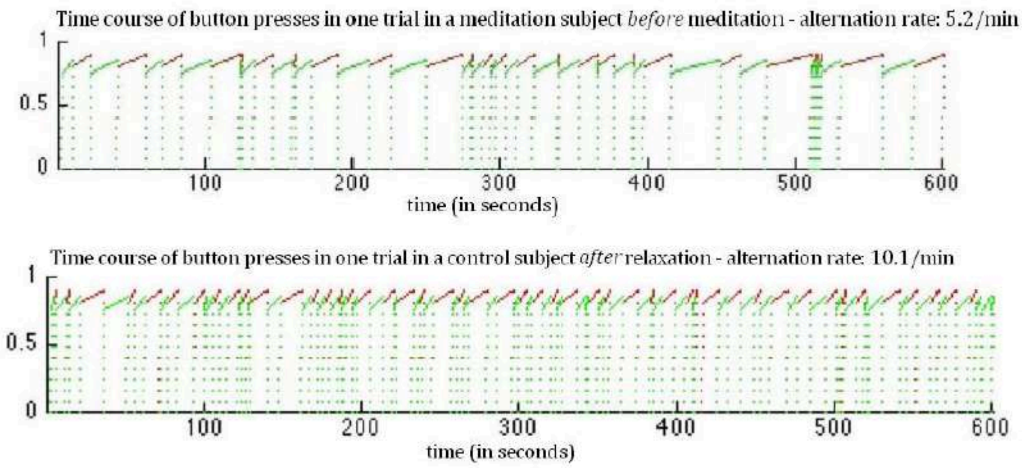

Fig. 10: Representative raw data from two subjects show the time course (in seconds) of the alternation between percept A and percept B in one trial each. Red diagonal lines mark the duration of one percept (A) and green diagonal lines mark the duration of the other percept (B). The y-axis displays arbitrary units and illustrates a shift in space to better emphasise the visualisation of the time course of two different dominance durations. The

top panel belongs to a subject from the experimental group and has been recorded before the meditation session. The number of alternations reported was 52 (AR: 5.2 per minute) and the bottom panel was obtained from a control subject after the relaxation period. This participant reported 101 switches during the trial, thus, yielding an AR of 10.1 switches per minute. Both time lines were created after a clean-up of the overlaps between button presses.

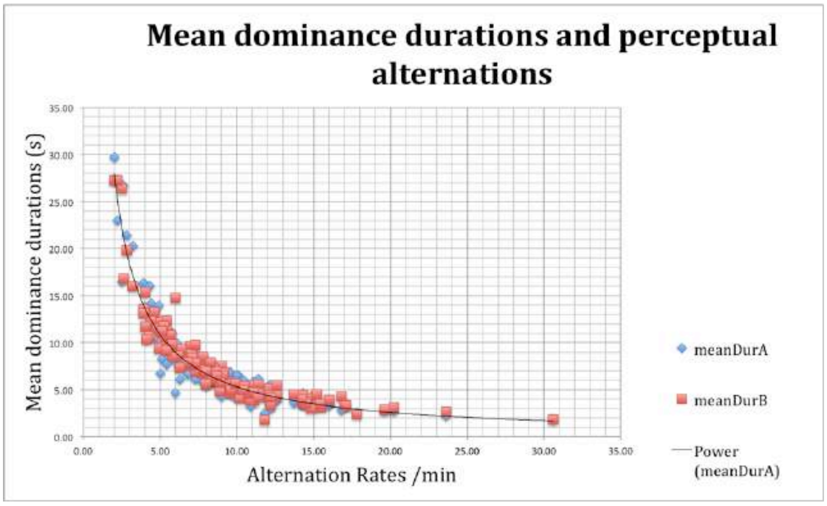

Fig.11 shows the relationship of two dependent variables: mean dominance durations (mDD) and mean alternation rates (AT) of percepts A and B. The depicted association is compatible with the modified propositions III and therefore by inference also with modified proposition II (although the equivalent measurement of stimulus strength, that is, fDD , is omitted here).

Histograms of frequency distributions are consistent with the overall literature: mDD of both percepts are distributed according to a positively skewed distribution (fig.12) and fDD lies around the point of equidominance, that is, fDD= 0.5, for either of the two percepts (fig. 13).

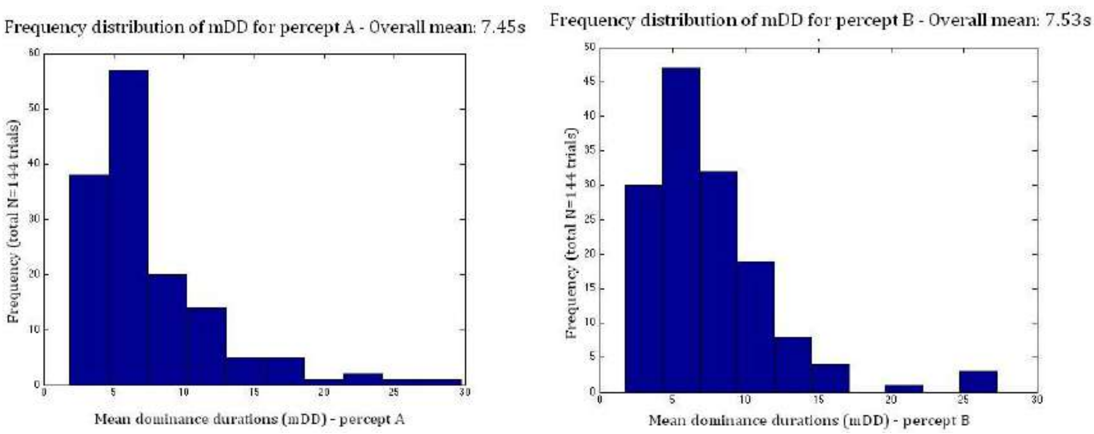

Fig 12 illustrates the histograms of mean dominance durations for percept A (left panel) and percept B (right panel) compiled for all participants and both conditions (before/after). Dominance durations were normalised by dividing them by the average duration in each given trial.

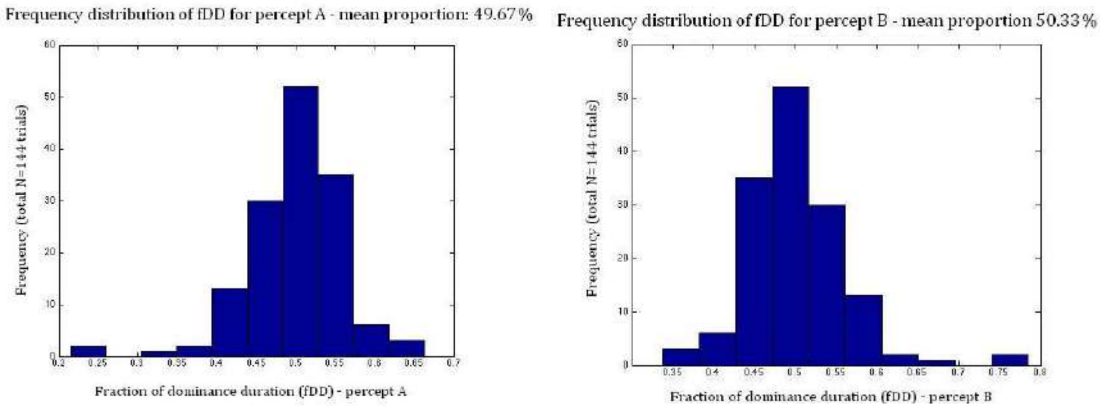

Fig. 13 show fDD for both percepts. It illustrates that values are clustered around 0.5 (equi-dominance). Mean proportion of percept A was 49.67% (B = 50.33%).

IV.II Testing alternation rates

The measure of interest for the rest of the analysis was the AR. In order to test differences in ARs across conditions using parametric tests, I tested if they complied with a Gaussian hypothesis.

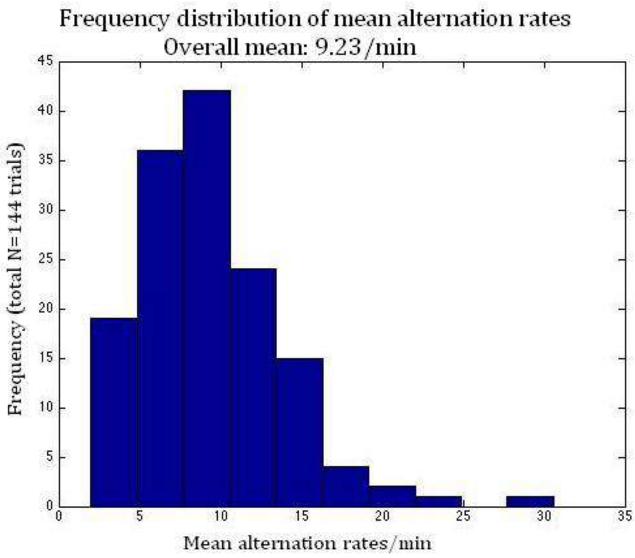

Fig 14 shows the histogram of alternation rates across all observers in both conditions (before/after). Alternation rates were normalised by the mean alternation rate of the corresponding trial.

Raw mean values of the AR did not exhibit a normal distribution (Fig. 14), so I transformed them to their natural log values. In order to check if the log transformation of the AR data is normally distributed, a Shapiro-Wilk test has been conducted. Results (W= 0.987, p-value= .212) supported the null-hypothesis, thus, they are assumed to be normally distributed. For the rest of the analysis I thus used these log-transformed AR values.

Next, I looked at the stability of AR measurements across successive sessions of the task. Training could induce a dynamics in AR that could be affecting my results.

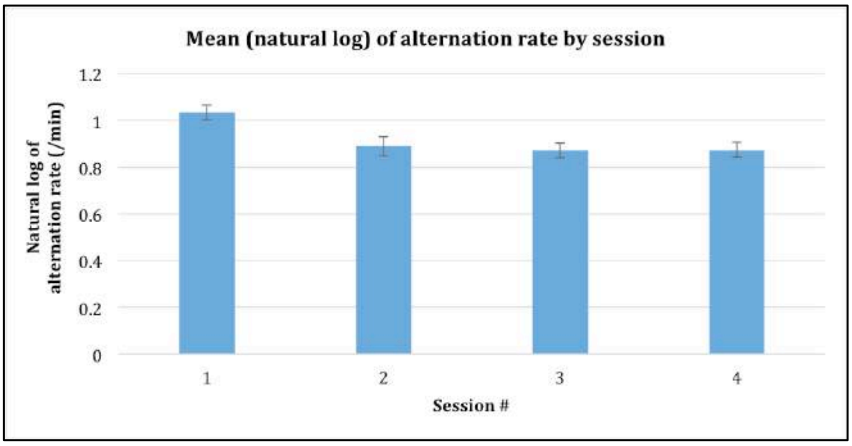

Fig. 15 illustrates the natural log transformations of mean AR (per minute) for all subjects across the four testing sessions (1-4). The first session was significantly different from the three latter ones. Error bars show the 95% confidence level.

In order to check for equality of variance in ARs across sessions a one-way ANOVA for the natural log-values was performed. The reason why this has not been assessed using a *repeated-measures* ANOVA was to avoid artefacts. Their emergence would have been due to some participants lacking one or two sessions' data (due to exclusion, for details see methods). Figure 15 indicates that the first session was significantly different from the remaining ones (session 2, 3, and 4). However, the last three sessions were not significantly different from each other. The one-way ANOVA revealed a significant effect of sessions: $F(3,140) = 5.484$, $p < .01$. Bonferroni's multiple pairwise-family comparison tests furthermore confirmed that the first session was significantly different from the others, but it did not show a significant difference between the remaining three sessions. In line with this, Barlett's test did not show a violation of homogeneity of variance: $\chi^2 = 2.418$, $p = .49$. Therefore, variances were judged to be equal. As a result, values from the first session were omitted from further analyses and log-ARs were averaged over the sessions 2 – 4 per subject and condition.

IV.III ARs and meditation

I applied a mixed model ANOVA with the between-subjects factor *group* (meditation/control) and the repeated-measure factor *condition* (before/after), and including the interaction group x condition. SPSS output tables have been enclosed in the appendix. There was a highly significant, and large effect of condition (before/after) for both groups: ANOVA results show that there was a significant effect of the before/after condition on AR: [$F(1,18) = 20.649$, $p<.001$], but no significant difference between controls and meditators: $F(1,18) = 1.351$, $p = .26$. This is consistent with the first hypothesis that meditation/relaxation has an effect on ARs in the perceptual task. Importantly, there was no significant interaction between groups and conditions: $F(1, 18) = 0.421$, $p = .524$. This is inconsistent with the second hypothesis that the effect of decreased ARs in the *after* condition will be more pronounced in meditators than in control subjects. In order to plot the AR values in the bar plot (fig 16), instead of using the transformed log values, the log inverse (also called the 'geometric mean') has been used. This was due to AR being plotted in more realistic numbers of perceptual alternations (reported per minute).

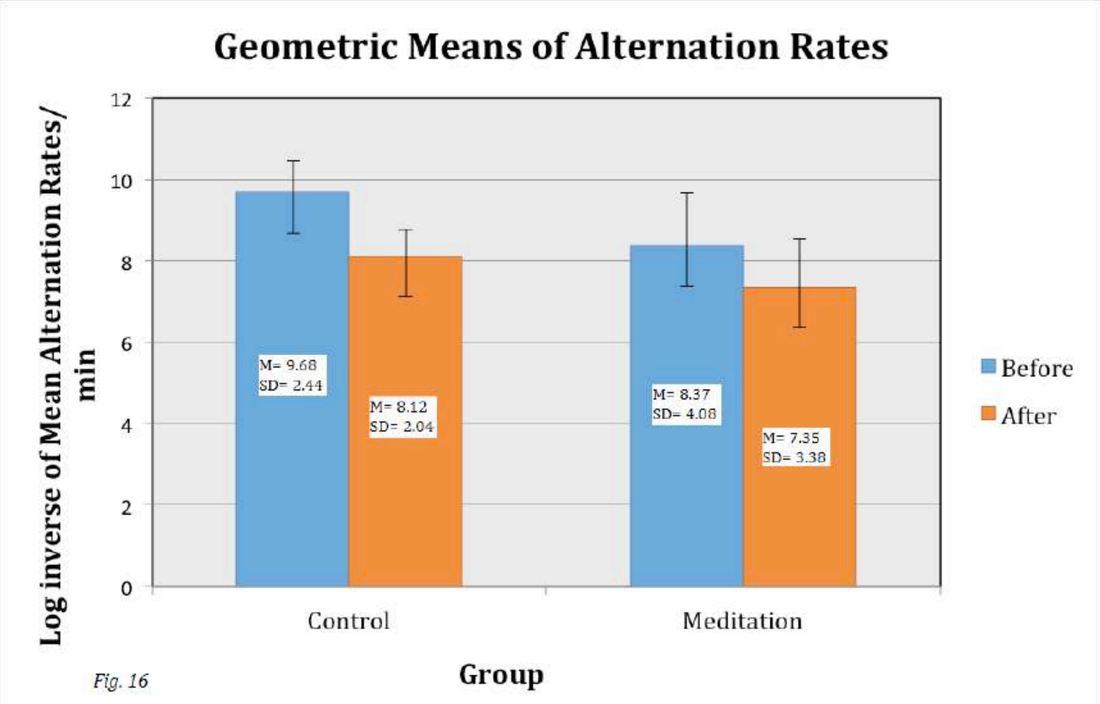

Fig. 16 presents the inverse log mean alternation rates per minute for both groups in the before and after condition, respectively. This bar chart demonstrates that, on average, there is a decrease in alternation rate obtained after the meditation/relaxation period as compared to before. Considering the two groups it shows that, on average, meditators yield lower mean alternation rates when compared to the control group (non-significant). Error bars show the SEM values. Note, this bar graph overestimates the size of the SEM because it does not take into account the fact that before/after is repeated measures.

V. Discussion

The first hypothesis of this thesis is that meditation/relaxation has an effect on the dominance durations and the alternation rate measured in the perceptual task. This is because relaxation is assumed to lead to a reduction in noise which results in greater stability in the perceptual task as expressed in lower alternation rates and increased dominance durations. The second hypothesis was that the effect of relaxation on the bi-stability measures might be greater for experienced meditators as compared to controls.

The results of the current study only partially support the postulated hypotheses: The findings demonstrate that ARs were indeed significantly lower after the

30-minute relaxation/meditation session. Consistent with my first hypothesis and as illustrated in figure 11, low alternation rates seem to come along with increased mean dominance durations, that is to say, representing an overall increased stability in the perceptual task. However, this association of increased mDDs and ARs has not been examined further in this study. Despite not being the focus of this thesis, it is however noteworthy that the obtained results fit in nicely within the overall literature on perceptual bistability coined by Levelt and his four propositions postulated fifty years ago. In line with this, we observe what almost seems like a tautology: increasing mDD of the two interpretations of the bistable stimulus alongside a decrease in AR (figure 11). As these two provide this obvious relationship, however assumed to be based on distinct underlying mechanisms, provide this obvious relationship, the current study concentrates on the latter measurement of the dynamics of perceptual bistability only in order to stay in the scope of this report.

In general, the effect of decreased AR between testing conditions (before vs. after) is compatible with previous research on noise and supports the theory that the perceptual data reflects a reduction in noise due to relaxation (Moreno-Bote et al., 2007; 2010, Shpiro et al., 2009). Based on Moreno-Bote et al.'s work and the results of the present study it is suggested here that this effect indicates a reduction in noise resulting from the 30-minute relaxation/meditation period. However, explicit inferences on the exact role of noise should not be made at this stage of analysis as they are mainly speculative. Instead, follow-up investigations should correlate the HRV data with results from the perceptual task (as was originally planned for this project). Along these lines it should be assessed if a reduction in physiological variability translates into a decrease in neuronal noise due to relaxation and how these two potential sources of noise are related.

In contrast, the second hypothesis that this "aftereffect" of condition might be more pronounced in meditators than controls was not found to be significant. Moreover, the opposite picture has been revealed by the obtained data: the bar graph (fig.16) shows that the difference in ARs for the two conditions was larger for control participants compared to meditators. However, this tendency was not confirmed by inferential statistics as demonstrated by the lack of interaction between conditions and groups. Even though the following is highly speculative, this difference between groups suggested by the trend in the bar chart, albeit non-significant, might be traced back to long-term effects from numerous years of mind control, in general, and attention regulation in particular, exercised by the meditation group whereas the control group seemed more susceptible to immediate effects of the relaxation period. In this context, the phenomenon of brain plasticity might have led to ARs in meditators being lower, in general (again, not significant, possibly due to small sample size and its high degree of variability). In line with the prevalent literature, an overall reduction of noise has been suggested to underlie various different effects related to attention regulation in a similar manner as other forms of meditation are, with enough practice, incorporated into numerous aspects of our everyday life. For example, people practicing mindfulness meditation are typically more aware in other areas of life as well (Slagter et al., 2011; Lutz et al., 2007).

Further and more carefully controlled research is needed to clarify this potentially distinct footprint of this specific population. In this context, the failure to reach significance of the tendencies of a potential interaction between groups/conditions, plus, the between-subjects difference in mean ARs (seen in fig.16), is possibly due to the great variability within the meditation group of the current sample. In addition, several other potential confounds and environmental factors might have influenced the results, as will be pointed out later on in this discussion. For now, it is interesting to see that the range of standard deviation is much larger in the experimental group (nearly doubled the range of the control group) and points towards a greater variability in this group.

And indeed, meditation in and of itself constitutes a very diverse object of research. It does not make much sense to regard it as something uniform or homogeneous. There is a vast variety of techniques, and traditions, no to mention individual differences. In a way, each meditation session is unique. The first-person experience, by definition, is impalpable for other people which is why Western science usually seeks to abandon the introspective approach wherever possible, commonly thought to be difficult to measure quantitatively. So, the high degree of variability of the meditation group in the current sample can – to some extent – be generalised to an overall diversity present in the meditation population as researchers face major challenges when choosing meditation as the object of scientific empirical investigation (Schmidt & Walach, 2014).

Consistent with the literature (Brascamp et al., 2005; Rubin & Hupé, 2004; Brascamp et al., 2015) the frequency histograms show that dominance durations are distributed according to a positively skewed probability distribution. They indicate a relative change of mean dominance durations (fig. 12) whereas the fraction of dominance (fig. 13) seems to settle around 0.5, that is, equidominance. This outcome is not surprising, as the stimulus parameters in the current study have been chosen to elicit equidominant percepts. However, it is important with respect to alternation rates which are assumed to peak and be symmetric around this particular point of dominance fraction (Moreno-Bote et al, 2010; Brascamp et al., 2015)

Furthermore, Figure 15 demonstrates that performance (as indicated here by means of AR) stayed fairly constant across sessions with the exception of the first one that differed significantly from the others. As this effect was only present at the beginning of the study but not towards the end, this strongly suggests a general factor of novelty or unfamiliarity of the testing situation.

That is, however simple the perceptual task might be, it is still entirely unfamiliar to the participants and they maybe have to get used to it at first (and apparently so much so that it goes beyond practice blocks of a few 20-second trials). Furthermore, various subjects (primarily belonging to the meditation group) reported that the current study was their first time participating in a scientific experiment, generally speaking. So, regardless of the particular plaid stimulus used here, there might have been an overall nervousness/primacy effect that led to these results. At the same time, the observed findings justify that participants have been invited for several days. Since the first session differed significantly from the remaining three, it has been excluded from subsequent analysis.

Nevertheless, the above-described effect of the first session (fig. 15) has major implications with respect to application of the forced mode. Forced mode is where the stimulus physically alternates (induced transitions) as opposed to *perceptual* alternations in the spontaneous mode. More precisely, for the vast majority of subjects (N=18) transition files have been created using time stamps of perceptual alternations obtained in this first session. Since it was unknown at that point of the study that the first experimental run would differed significantly from the others, inducing these ostensibly distinct alternations at a later point, might have led to biased results. Moreover, this potential bias is directly related to another limitation regarding the subsequent analysis: Because time did not allow it, the data for the induced alternations in the forced mode has *not* been taken out of the final analysis. Consequently, this might have resulted in artefacts as the data collected in the forced mode setting has been treated as spontaneously occurring performance which is simply not the case here, especially not with respect to the first session's effect. So, in order to attenuate this bias, further analysis of the current data set has to consider the above. Therefore, data obtained in the forced mode has to be excluded as it was originally thought of as a mere means of control and should not be treated as natural responses. Besides, the current study applied the forced mode exclusively at the beginning of all trials and then switched back to the spontaneous mode after 10 seconds of the last induced alternation.

This is crucially important to take into account since perceptual alternations are assumed to be stochastic. So, the lack of regularity in these fluctuations is one of the core arguments for the role of noise as the primary drive that results in these switches (Moreno-Bote et al., 2010). Since the current research adapts this approach, it is necessary to bear in mind this potential bias which, of course, would be abolished with exclusion of the affected data from the final analysis. All above-described limitations associated with the forced mode are quite problematic when drawing conclusions from the obtained findings and become immediately evident when looking at one subject's raw data of dominance durations in the spontaneous mode contrasted with those obtained in the forced mode (appendix IX.III)

In order to conclude the notion on the forced mode, one needs to mention that its administration leaves room for improvement in the experimental paradigm. More specifically, future research should concern a way to introduce these stereoscopic disparities in a less obvious manner since some participants noticed a clear change between the two settings. For example, one subject gave the following comment on the depth perception in the first forced trial of the perceptual task (HP02_Before): "Today, it was easier. At first I saw a proper gap between the gratings, later on they moved closer together and it became harder again…". This report is consistent with personal experience according to which the change between the two modes is still too prevalent in order to pass unnoticed (i.e. in the forced mode one of the grating appears even closer relative to the fixation point whereas the other one stays far behind). In this context, critical reflection on the current design reveals further limitations which will be discussed in the following paragraphs:

Firstly, there was a difference in age between the groups. It seems natural that people with several years of meditation experience tend to be older than postgraduate university students (such as the majority of the control group). However, as the average age between groups differed by approximately a decade in the current sample (indicated by the mean age of 29.2 years in controls versus 39.9 years in meditators) as well as the median of 30 years in the control group contrasting 41.5 years in the meditation group, there is a possibility that differences in age could contribute to the results of the between-subject measure, which in this case was found to be non-significant. Both median and mean were calculated to help interpreting the skewedness of the distribution. To follow-up with this unknown, new participants could be drawn from a "young" and "old" population to measure whether age has an effect on bi-stability measures in (a) the control group and (b) in the meditation group.

In case of the present study, the selection of control subjects, having occurred largely prior to the selection of meditation subjects, led to something like a trade-off situation since, on the one hand, the meditation group had to match the criteria of the control group while, on the other, more life and thus more meditation experience was, of course desirable to gather meaningful results. Therefore, the control group presented, in effect, a default in terms of age, life experience and social stratum, which the mediation group then had to adhere to. Generally speaking there was no apparent reason why age should have an effect.

More generally, the emergence of further environmental variability could be due to the overall fairly liberal instructions. For instance, while the vast majority of meditators had their eyes closed, and were sitting on the floor (on a couple of cushions) during the meditation period, a few others remained seated on the office chair, some of them with their eyes left open. Also, most control subjects had their eyes opened during relaxation since they (sometimes continuously) adjusted the breath pacer to their natural way of respiration, and frequently followed the biofeedback of their physiological data. So, there is an overall inconsistency in testing situation, and miscellaneous environmental factors might have affected the results. Furthermore, the instruction format could have contributed to the variability between meditators. Other particularly noteworthy aspects included the question of language and the participants' affiliation with the university. All control participants were fluent in English. Some of them even spoke English only (no Spanish). Moreover, several (6/10) of the control subjects were directly related to the university (UPF) and its research. Therefore, it can be assumed that those participants were more likely to be familiar with contributing to and participating in empirical research, as stated above (first session effect). In contrast, people in the meditation group were not only mostly unfamiliar with the participation in scientific experiments, they also did not necessarily speak English and could exclusively communicate in Spanish (5/10). One subject in each group communicated exclusively in German (2/20).

During this project I gained a lot of insight and probably would do several things differently if I had to conduct the same study again. For instance, the trial length of 10 minute for the perceptual task seems to be the absolute maximum you can expect a subject to put up with. Consequently, I would check if a reduction in trial lengths would lead to a qualitative changes in my data. Perhaps, this could be done by a division of the data at hand and subsequently compare the first 5/7 minute to the last 5/3 minutes in order to verify the assumption first. If it holds true, I would probably reduce it to a total duration of 5-7min/trial. Indeed, previous research has shown that the fraction and the mean dominance durations are independent of trial length (Hupé & Rubin, 2003, 2004). So, the output would be similar, yet, the experiment would be far more pleasant for the observer. And various specific examples demonstrate why: JC01 nearly fainted due to visual overstimulation, LH01 got nauseous because of the red-green glasses (this particular subject reported to generally struggle with the perceptual task due to its lengths and her lack of concentration for so long possibly rooted in her attention deficit hyperactivity disorder (ADHD) she has suffered from since her childhood). Furthermore, a frequent issue were dry, or watery eyes (e.g. AIL01-04, NB01). This is crucial as it might have result-altering implications in that it can lead to increased blinking which in turn may result in increased perceptual alternations.

An additional notion needs to be made on the exact nature of conditions between groups. Strictly speaking, the control group is not exactly a control group but instead another experimental group consisting of inexperienced meditators who were relaxing with help of stress-reduction software. So, in order to speak of actual controls, one would need a sort of baseline where subjects are not asked to do anything in particular. Moreover, future research could introduce an additional condition in which noise is deliberately induced. For example, a stressful task that provokes some kind of arousal would probably lead to an increase in noise and result in higher ARs in this condition. And indeed, there was one meditation subject who indicated this effect. Namely, this observer reported by far the highest mean AR of 8.7 per minute (relative to values of 5.1 and 4.4 obtained in *before* conditions of the previous sessions) on the day he encountered himself in a highly stressful and emotionally loaded situation. Even more remarkable (as directly related to the present study) is the finding that despite this high level of arousal, ARs were majorly reduced after the meditation period (mean AR dropped to 4.3). Moreover, a closer look at this subject's data reveals other highly interesting aspects: Firstly, there is a shift away from equidominance, it seems, as the fDDs for the two percepts are more unbalanced after meditation. That is, they shift away from an equal proportion of perceptual dominance as the observer favoured one percept over the other in order to gain stability (and thus decrease AR). These preliminary findings fit nicely into Moreno-Bote et al.'s noise-induced attractor model according to which the reduction of noise leads to greater perceptual stability which is achieved by settling down in one percept rather than the other. And finally, to round everything off, this participant's data also appears to be congruent with the modified propositions on mDDs whereas demonstrating a greater increase for the stronger (i.e. higher fDD) percept over the less preferred other when moving away from equidominance (Brascamp et al., 2015). Follow-up research should assess these preliminary implications further.

VI. Conclusions

To sum up, the current study aims at investigating the role of noise in the dynamics of perceptual bistability within the constraints of a small-sample study. Therefore, performance in a perceptual task using ambiguous motion plaids has been assessed in experienced meditation practitioners and contrasted to that of a control group untrained in meditative techniques. The findings confirm a decrease in mean alternation rates following meditation/relaxation, but not enhanced effects in the meditation compared to the control groups. Even though there are various limitations to the study, it still provides some indications and tendencies that encourage further research of mind control and the impact of neuronal noise as a key influencing factor: With noise getting more and more attention in miscellaneous areas of research on cognitive neuroscience, controlled empirical studies on the specific population of meditation practitioners seems to be a step in, what I believe, is the right direction.

VII. Acknowledgments

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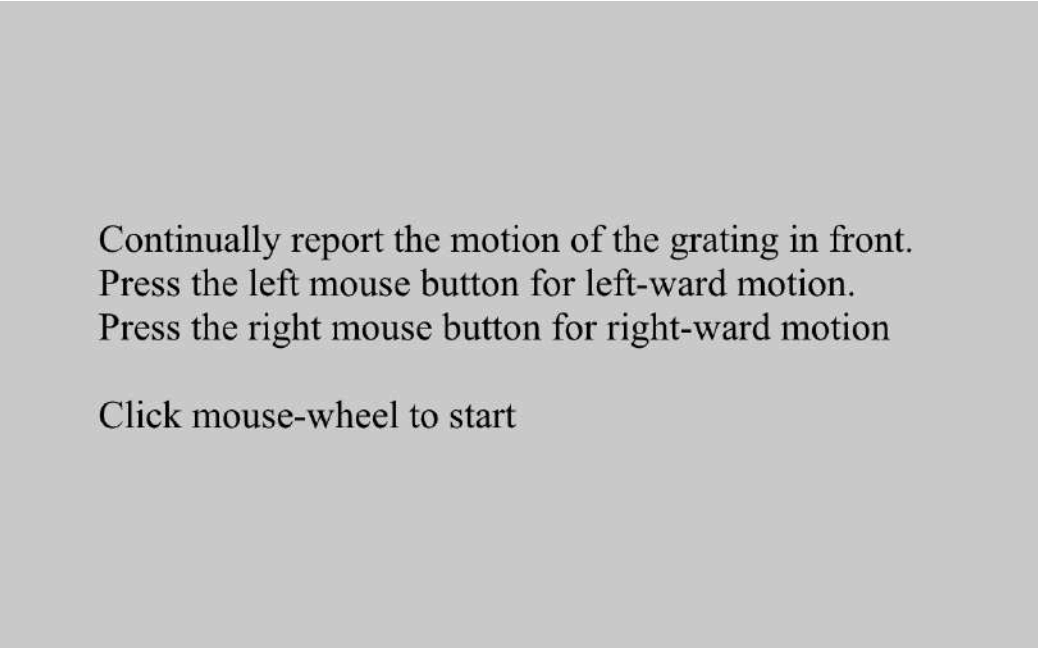
IX. Appendices

IX.I Instructions presented on the initial screen prior to each trial of the perceptual task:



IX.II Transition files

Exemplary for one observer (AIL) the time stamps of perceptual alternations derived from the two transition files used for comparison:

IX.II.I Below listed are the time stamps that correspond to left and right mouse button presses found in the newly created transition file that entails half of the alternations obtained in the **second** session *after* the 30-minute relaxation period. Transitions were recorded in the **spontaneous mode:**

L_item	R_item
8.39100003242	0.733999967575
26.6579999924	23.1270000935
39.7999999523	33.2680001259
67.8960001469	56.5670001507
96.3359999657	81.5690000057
109.837000132	101.430000067
128.338000059	119.400000095
151.996999979	140.69900012
165.170000076	158.857000113
179.296000004	176.35800004
194.312999964	190.094000101
206.18900013	203.110000134
243.285000086	221.252000094
268.615999937	260.146000147
278.148000002	271.990999937

IX.II.II Below listed are the time stamps that correspond to left and right mouse button presses found in the transition file of physically induced alternations obtained in the **third** session after the 30-minute relaxation period. Transitions recorded in the **forced mode:**

L_item	R_item
9.51699995995	2.54699993134
31.0489997864	22.2209999561
41.6129999161	35.2839999199
69.0529999733	53.0509998798
98.6169998646	81.1159999371
111.086999893	103.054999828
130.447999954	121.478999853
156.513000011	142.15199995
167.778999805	160.856999874
200.750999928	192.186999798
209.282999992	206.281999826
237.284999847	219.048999786
270.177999973	259.254999876
280.023000002	273.7099998

Note that the remaining alternations of this trial (namely those obtained in the spontaneous mode that was set back 10 seconds after the last induced alternation (i.e. ~288 seconds) is omitted here. Furthermore, time stamps obtained in the forced mode are, by nature, a few seconds later than those used for reference in the spontaneous mode simply reflecting observer's reaction times. However, there are cases (here as well as found in the other participants) where the reversed pattern is exhibited: the physical alternation is induced shortly after the perceptual, thus, kind of confirming subject's perception. Furthermore, it is important to bear in mind that the transition file obtained in the forced mode may contain spontaneously occurring perceptual alternations in between and in addition to those that were physically induced in the forced mode.

IX.III Mixed-model ANOVA output (SPSS)

Within-Subjects Factors

Measure: MEASURE_1

before_after	Dependent Variable
1	lnAR_before
2	lnAR_after

Between-Subjects Factors

		N
Group	1.00	10
	2.00	10

Descriptive Statistics

	Group	Mean	Std. Deviation	N
lnAR_before	1.00	.9728	.11326	10
	2.00	.8722	.22576	10
	Total	.9225	.18134	20
lnAR_after	1.00	.8962	.11624	10
	2.00	.8147	.22325	10
	Total	.8554	.17820	20

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
before_after	Pillai's Trace	.534	20.649[b]	1.000	18.000	.000
	Wilks' Lambda	.466	20.649[b]	1.000	18.000	.000
	Hotelling's Trace	1.147	20.649[b]	1.000	18.000	.000
	Roy's Largest Root	1.147	20.649[b]	1.000	18.000	.000
before_after * Group	Pillai's Trace	.023	.421[b]	1.000	18.000	.524
	Wilks' Lambda	.977	.421[b]	1.000	18.000	.524
	Hotelling's Trace	.023	.421[b]	1.000	18.000	.524
	Roy's Largest Root	.023	.421[b]	1.000	18.000	.524

Multivariate Tests[a]

Effect		Partial Eta Squared	Noncent. Parameter	Observed Power[c]
before_after	Pillai's Trace	.534	20.649	.990
	Wilks' Lambda	.534	20.649	.990
	Hotelling's Trace	.534	20.649	.990
	Roy's Largest Root	.534	20.649	.990
before_after * Group	Pillai's Trace	.023	.421	.094
	Wilks' Lambda	.023	.421	.094
	Hotelling's Trace	.023	.421	.094
	Roy's Largest Root	.023	.421	.094

a. Design: Intercept + Group
Within Subjects Design: before_after

b. Exact statistic

c. Computed using alpha = .05

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
before_after	Sphericity Assumed	.045	1	.045	20.649
	Greenhouse-Geisser	.045	1.000	.045	20.649
	Huynh-Feldt	.045	1.000	.045	20.649
	Lower-bound	.045	1.000	.045	20.649
before_after * Group	Sphericity Assumed	.001	1	.001	.421
	Greenhouse-Geisser	.001	1.000	.001	.421
	Huynh-Feldt	.001	1.000	.001	.421
	Lower-bound	.001	1.000	.001	.421
Error(before_after)	Sphericity Assumed	.039	18	.002	
	Greenhouse-Geisser	.039	18.000	.002	
	Huynh-Feldt	.039	18.000	.002	
	Lower-bound	.039	18.000	.002	

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
before_after	Sphericity Assumed	.000	.534	20.649	.990
	Greenhouse-Geisser	.000	.534	20.649	.990
	Huynh-Feldt	.000	.534	20.649	.990
	Lower-bound	.000	.534	20.649	.990
before_after * Group	Sphericity Assumed	.524	.023	.421	.094
	Greenhouse-Geisser	.524	.023	.421	.094
	Huynh-Feldt	.524	.023	.421	.094
	Lower-bound	.524	.023	.421	.094
Error(before_after)	Sphericity Assumed				
	Greenhouse-Geisser				
	Huynh-Feldt				
	Lower-bound				

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	31.610	1	31.610	514.868	.000	.966
Group	.083	1	.083	1.351	.260	.070
Error	1.105	18	.061			

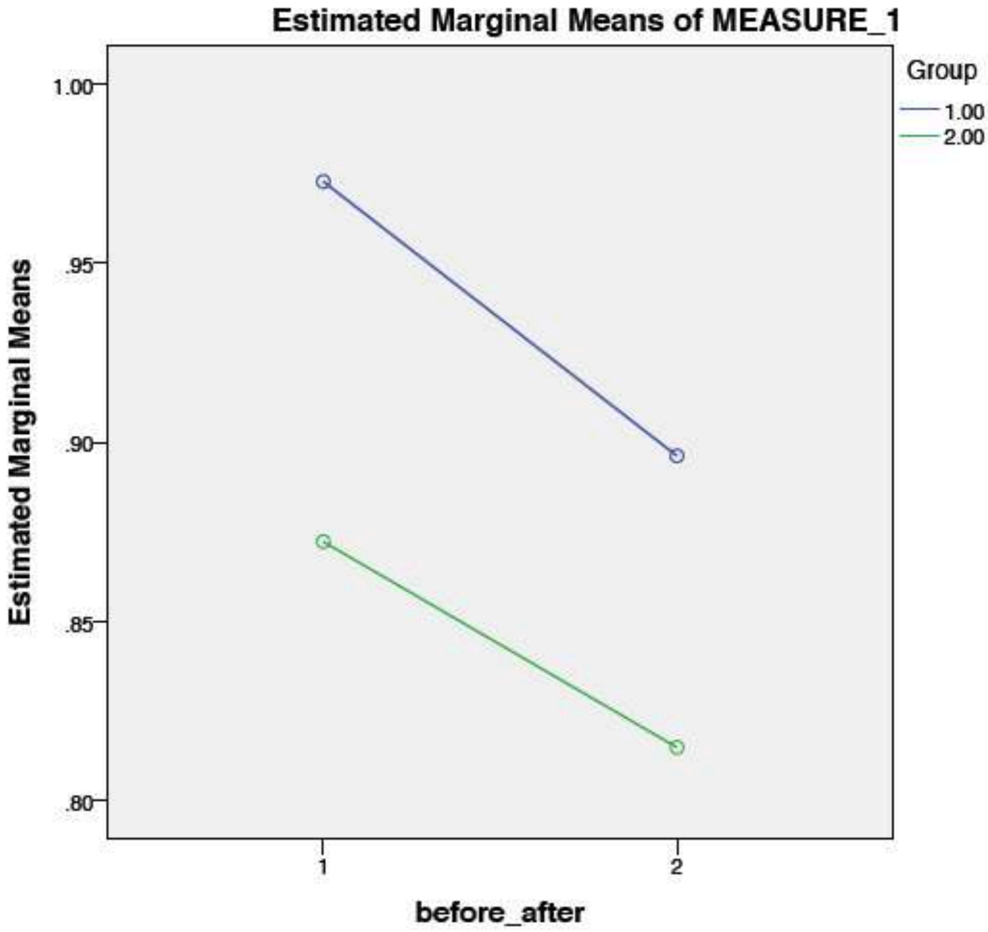
Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Noncent. Parameter	Observed Power[a]
Intercept	514.868	1.000
Group	1.351	.196
Error		

Profile Plots



IX.IV Raw data of the time course of dominance durations obtained in the spontaneous mode (top panel) contrasted with those obtained in the forced mode (lower panel) exemplary for one observer (AA01 vs. AA02 in the before condition, respectively):