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Mindfulness meditation and relaxation training increases time sensitivity

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ABSTRACT

Two experiments examined the effect of mindfulness meditation and relaxation on time perception using a temporal bisection task. In Experiment 1, the participants performed a temporal task before and after exercises of mindfulness meditation or relaxation. In Experiment 2, the procedure was similar than that used in Experiment 1, except that the participants were trained to mediate or relax every day over a period of several weeks. The results showed that mindfulness meditation exercises increased sensitivity to time and lengthened perceived time. However, this temporal improvement with meditation exercises was primarily observed in the experienced meditators. Our results also showed the experienced meditators were less anxious than the novice participants, and that the sensitivity to time increased when the level of anxiety decreased. Our results were explained by the practice of mindfulness technique that had developed individuals' abilities in devoting more attention resources to temporal information processing.

1. Introduction

Time and consciousness are intimately entwined (James, 1890). However, few studies have examined the effect on time perception of meditation as a practice that alters the "stream" of consciousness. Some studies suggest that the practice of meditation changes our subjective experience of time, i.e., our attention to the passage of time (Block, 1979; Glicksohn, 2001). However, does it fundamentally modify our perception of time?

There are a wide variety of different meditation techniques. Mindfulness-based meditation is one of the most widely used techniques (Kabat-Zinn, 2003). In the practice of mindfulness, individuals must focus their attention on a chosen object (one-pointed attention), usually on the sensation of breathing. Mindfulness training has two major goals. The first is to access a deep state of calm. The second is to focus attention and awareness on what is happening in one's own body and mind as it happens, that is, in the present moment. Mindfulness therefore changes the relationship with time by focusing individuals' attention on the present moment, by encouraging them to live in the now. Using magneto-encephalography (MEG) recordings, Berkovich-Ohana, Dor-Ziderman, Glicksohn, and Goldstein (2013) recently showed that the change in the sense of time in meditators attempting to be outside of time ("timeless") is associated with a high level of theta activity in the brain (4–13 Hz). This slow cortical activity has often been observed during meditative states (Shapiro, 1980). It is characteristic of a state of deep relaxation, such as a period of light sleep. Individuals' feeling of being outside of time when meditating

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is thus explained by the reduction in arousal level (hypo-arousal). However, the cortical oscillation found in the brain depends on the meditation technique used. When meditators use a mindfulness technique, which consists in concentrating attention on a single object (internal state) while resisting distractors (irrelevant stimuli, anxious memories, negative moods) (Cahn & Polich, 2006), some high-amplitude gamma oscillations (25–42 Hz) are found over the frontal and parietal areas of the brain (e.g., Berkovich-Ohana, Glicksohn, & Goldstein, 2012; Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004). These modulations in gamma activity are interpreted as reflecting an increase in selective attention (Fries, Reynolds, Rorie, & Desimone, 2001). The practice of the mindfulness technique has indeed been shown to improve individuals' attentional control skills, with meditators performing better on different attentional tasks than other participants who have never experienced meditation (e.g., attentional blink paradigm, d2) (e.g., Jha, Krompinger, & Baime, 2007; Moore & Malinowski, 2009; Sauer et al., 2012; Slagter et al., 2007). The question that we need to answer is therefore that of the real nature of the mechanisms (arousal or attention) underlying the effects of meditation on the perception of time.

There is now ample evidence that the perception of time changes as a function of the mechanisms involved, i.e. arousal or attention. According to the internal clock models (Gibbon, 1977; Gibbon, Church, & Meck, 1984; Treisman, 1963), the representation of time results from the number of time units (pulses, temporal oscillations) emitted by an internal clock system and accumulated during the stimulus duration. A slowing down of the internal clock system produced by a decrease in arousal level thus results in a temporal shortening effect. Indeed, when the clock run slower, fewer pulses are accumulated and time is judged shorter. This has been demonstrated in pharmacological studies in which sedatives (e.g., secobarbital, alcohol) have been administered to animals and human adults during time estimation tasks (for a review see Meck, 1996). In contrast, when the amount of attentional resources available for the processing of temporal information increases, time is judged longer and less variable (Brown, 2008; Zakay & Block, 1997). Numerous studies using the dual-task paradigm have demonstrated that time is indeed judged longer when the amount of attention allocated to time processing increases. Stimulus durations are thus judged longer in a single temporal task than in a dual-task, in which the participants must judge the duration of a stimulus while performing another non-temporal task (e.g., Macar, Grondin, & Casini, 1994). The attention-based models (Brown, 2008; Zakay & Block, 1997) explain this lengthening effect in terms of a reduction in the number of temporal units lost when attention is distracted away from time. In summary, an arousal-related slowing down of the clock and an increase in attention resources would have opposite effects on the perception of time.

Only three recent studies have examined the effect of meditation on the ability to process stimulus durations. Recently, Berkowitch-Ohana and her colleagues asked practitioners of mindfulness meditation and control participants to produce long durations (4, 8, 16 and 32 s) before and after a 15-min meditation session (Berkovich-Ohana, Glicksohn, & Goldstein, 2011; Berkovich-Ohana et al., 2012). The results showed that the meditators produced longer durations than the control participants. The authors therefore explained their findings in terms of a change in the meditators' subjective experience of "now" which was linked to a dilatation of the passage of time. However, in this study, there was no effect of the meditation exercise *per se*, thus suggesting that the difference between the temporal productions of the meditators and the other participants resulted from a "personality trait" specific to the meditators rather than from the activation of a meditative state during the session which would have affected the subsequent processing of time. However, if this is indeed the case, then the mechanisms underlying the production of longer durations in the meditators are far from clear. These results cannot be explained in terms of a lower rate of functioning of the meditators' internal clocks because the internal clock is recalibrated over time (Droit-Volet & Meck, 2007).

Other processes, probably related to consciousness, must therefore be considered as Glicksohn (2001) has argued. However, consciousness is closely linked to attentional processes. The practice of meditation has been shown to develop individuals' awareness, defined as an individual ability to voluntarily orient attention toward specific ongoing information (internal-oriented attention). Using a temporal bisection task, Kramer, Weger, and Sharma (2013) recently showed that the practice of a 10-min mindfulness exercise lengthened the perception of time in participants who had no prior experience of meditation. In their study, the participants were initially presented with a short (S) (0.4 s) and a long standard duration (L) (1.6 s). They then had to judge whether comparison durations of the same or of intermediate values were more similar to S or L. The participants performed this temporal bisection task before and after the mindfulness exercise. The results showed that the psychophysical function was shifted toward the left in the bisection task performed after the meditation exercise compared to that before the meditation exercise, thus lowering the point of subjective equality (Bisection Point) in a way which is consistent with a lengthening effect. The authors logically attributed their results to the meditation exercises which would have induced attentional control activities in their participants, who would consequently have paid more attention to time after than before the meditation exercise. The hypothesis is therefore that attention-related mechanisms account for the effects of meditation on the perception of time. To further test this hypothesis, we decided to examine the effect of a mindfulness exercise on the perception of time in a bisection task with longer durations (S = 4 s) than those used by Kramer et al. (2013) and whose processing requires a higher level of attention. In addition, we used a difficult temporal discrimination task, with a small ratio between S and L of 2:3 (S = 4, L = 6 s) as well as an easier temporal discrimination task with a larger ratio of 1:2 (S = 4, L = 8 s). Moreover, the mindfulness exercise was compared with a relaxation exercise in order to test the specificity of the effect of the mindfulness technique on the perception of time. The levels of arousal and anxiety induced by these two types of exercises were also assessed using self-reported scales at the beginning and the end of the experimental session. Our hypothesis was that the meditation exercise should lengthen time estimates and reduce their variability, especially in the difficult temporal discrimination condition.

2. Experiment 1

2.1. Method

2.1.1. Participants

Forty-two undergraduate students from the University of Clermont-Ferrand, France (mean age = 22.5, *SD* = 5.5) participated in exchange for course credits. They signed a formal agreement to participate in this experiment, which was approved by the Sud-EST VI statutory Ethics Committee (Comité de protection des personnes, CPP), according to French legal requirements L. 1121-1-2 and R 1121-3.

2.1.2. Material

Participants were tested individually in a quiet laboratory room where they were seated in front of a PC computer. An E-prime program (1.2 Psychology Software Tools, Pittsburg, PA) controlled the experiment and recorded the data. An auditory stimulus was used in the temporal bisection task and the participants gave their "Short" or "Long" responses by pressing the corresponding key (*D vs. K*) on the computer keyboard, with the button-press assignment being counterbalanced across subjects. The participants in the meditation and the relaxation group performed the meditation and relaxation exercises, respectively, described in two 10-min audio recordings (20 min total) that they were listening through headphones. For the meditation group, the audio recording presented two mindfulness meditation exercises: a body scan meditation of 10 min, in which the participant focuses attention on each part of the body in order to become aware of sensations that arise there; and a 10-min sitting meditation exercise in which the practitioner focuses attention on natural breathing moment by moment and without judgment. For the relaxation group, the exercises were taken from the standardized version of Jacobson's relaxation techniques, which are often used in relaxation protocols (Arena & Blanchard, 1999). The participants had to tense and relax their muscles one by one and be aware of the accompanying sensations. The aim of these exercises was to relax the muscles in the participant's body.

2.1.3. Procedure

The participants were assigned to the meditation ($N = 21$) or the relaxation group ($N = 21$). All the participants in each group performed two bisection tasks, one with an easy temporal discrimination ratio (ratio of 1:2 between *S* and *L*) and the other with a more difficult temporal discrimination ratio (ratio of 2:3). *S* and *L* were 4.0 and 8.0 s for the easy and 4.0 and 6.0 s for the difficult temporal discrimination task, respectively. The 7 comparison durations were 4, 4.67, 5.33; 6.0, 6.67, 7.33, 8 s, and 4, 4.33, 4.67, 5.0, 5.33, 5.67, 6 s, respectively. The presentation order of these 2 temporal bisection tasks was counterbalanced between subjects. A break of 15 min separated these two bisection tasks. To prevent the participants from counting, they were instructed not to count before each temporal task because this could distort the scientific data and make it impossible to analyze (see Rattat & Droit-Volet, 2012).

Each temporal bisection task was divided into 2 successive phases: pre-exercise and a post-exercise bisection. In pre-exercise bisection, the participants were alternately presented with the 2 anchor durations for 4 trials (2 *S*, 2 *L*). They were then presented with the comparison durations and had to judge whether these were more similar to *S* or *L*. Each participant performed 8 blocks of 7 trials each (56 trials), i.e. one trial for each comparison duration. Each trial started when the participants pressed the space bar after the work "ready!" had been displayed in the center of the computer screen following an inter-trial interval randomly chosen between 0.5 and 1.0 s. The presentation order of trials within each block was random. In post-exercise bisection, the procedure was similar to that used in the pre-exercise bisection, although *S* and *L* were only presented once to remind the participants of the bisection instructions. In addition, as in Droit-Volet, Fayolle, and Gil (2011) study, the 8 blocks of trials were divided in two series of 4 blocks (28 trials) in order to reduce the testing length. Before each trial series, the participants performed a 10-min exercise (20 min total), i.e., mindfulness meditation exercise for the meditation group and relaxation exercise for the relaxation group.

In addition, the participants twice completed 3 different scales, at the beginning and the end of the experimental session, i.e., before and after the two bisection tasks. The first scale was the French version of the Brief Mood Introspective Scale (BMIS, Mayer & Gaschke, 1988) which assessed the subjective arousal level experienced by the participants in the meditation and relaxation groups. In the BMIS, the participants rate the intensity of their experienced mood in response to 16 mood adjectives (Lively, Happy, Sad, etc.) using a 4-point scale from "definitely do not feel" to "definitely feel". The second scale measured the anxiety state before and after the experimental session by means of the State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). In the STAI, the participants rate their agreement concerning 20 different items such as "I feel calm" or "I feel secure" on a 4-point scale. The third scale, called the mindfulness attention and awareness scale (MAAS; Brown & Ryan, 2003), measured the level of attention to and consciousness of what is currently occurring.

2.2. Results and discussion

Fig. 1 shows the mean proportion of long responses – *p*(long) – for the bisection phase before (pre-exercise) and after (post-exercise) the meditation or the relaxation exercises in the difficult (ratio 2:3) and the easy (ratio 1:2) temporal

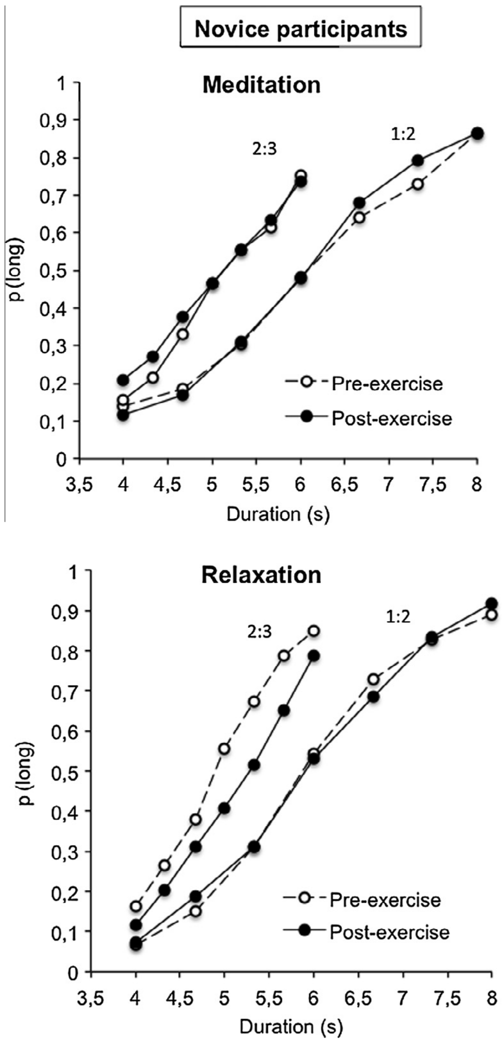

Fig. 1. Proportion of long responses plotted against stimulus durations (s) in the meditation and the relaxation group for the pre- and the post-exercise bisection task in Experiment 1 with novice participants who had never practiced meditation or relaxation.

discrimination tasks. The ANOVA run on p(long) with 1 between-subjects factor (meditation *vs.* relaxation group) and 3 within-subjects factors (comparison durations, pre–post exercise, easy-difficult discrimination) showed a main effect of comparison durations indicating that p(long) increased with the stimulus duration values, $F(6,240) = 282.99$, $p = .0001$. However, there was a significant ratio × duration interaction, $F(6,240) = 14.40$, $p = .0001$, suggesting that the psychophysical functions were flatter when the temporal discrimination task was more difficult, regardless of group. In addition, there was a significant group × ratio × pre–post exercise interaction, $F(1,240) = 4.68$, $p = .04$, as well as a significant group × pre–post exercise interaction $F(1,40) = 4.82$, $p = .03$. No other effect was significant. To analyze this significant 3-way interaction, an ANOVA was conducted on p(long) for each group taken separately and with ratio and pre–post exercise as factors. For the meditation group, there was no main effect of ratio, no main effect of pre–post exercise, and no interaction between these two factors (all $p > .05$). This suggests that meditation did not change the proportion of long responses. In the relaxation group, by contrast, we observed a significant interaction between pre–post exercise and ratio, $F(1,20) = 4.97$, $p = .04$, with the main effect of exercise just failing to reach significance, $F(1,20) = 3.93$, $p = .06$. The main effect of ratio was not significant ($p > .05$). This significant 2-way interaction in the relaxation group suggests that the participants responded short more often after than before the relaxation exercise in the difficult temporal discrimination condition, $t(20) = 2.71$, $p = .01$, but that this behavior was not replicated in the easier condition, $t(20) = .12$, $p = .91$.

To further analyze the results, we calculated two other indexes of performance: the Bisection Point (BP) and the Weber Ratio (WR) (Table 1). The Bisection Point is a point of subjective equality, i.e. the stimulus for which the participant responds short and long with equal frequency ($p(\text{long}) = .50$). When individuals obtain a lower BP value in one condition than in another, this suggests a lengthening effect, with the participant responding long more often for one and the same stimulus

Table 1
Mean and error standard for the Bisection Point and the Weber Ratio in the meditation and the relaxation group for the pre- and the post-exercise bisection phase in Experiment 1 with participants who had never practiced meditation or relaxation.

	Meditation		Relaxation	
	Pre-exercise	Post-exercise	Pre-exercise	Post-exercise
Bisection Point				
2:3 ratio				
Mean	5.22	5.09	4.74	5.13
E.S.	0.14	0.12	0.14	0.12
1:2 ratio				
Mean	5.82	6.20	5.86	5.86
E.S.	0.22	0.26	0.22	0.26
Weber Ratio				
2:3 ratio				
Mean	.24	.23	.27	.24
E.S.	.07	.05	.07	.05
1:2 ratio				
Mean	.24	.20	.13	.14
E.S.	.02	.03	.02	.03

duration. Conversely, a higher BP suggests a shortening effect. The WR is an index of time sensitivity, i.e. the Difference Limen ($D(p(\text{long})) = .75 - D(p(\text{long})) = .25)/2$) divided by BP. The lower the WR, the steeper the psychophysical function and the higher the level of time sensitivity. These two indexes were derived from the significant fit of the individual data with the pseudo-logistic functions (Killeen, Fetterman, & Bizo, 1997), which provided good fits for the bisection data in different conditions (Allan, 2002). The pseudo-logistic fit was not significant for 4 participants in the difficult temporal discrimination task (2:3 ratio) because their bisection curves were totally flat. The results of these participants were thus excluded from the statistical analyses run on BP, and the maximum value of 1.0 was given for the WR (for the method, see Droit-Volet, 2008; Droit-Volet & Zélanti, 2013).

The ANOVA run on the WR with 3 factors (groups, pre–post exercise and ratio) did not show any significant effect apart from a trend for the main effect of ratio, $F(1,40) = 2.97$, $p = .09$ (2:3 ratio = 24; 1:2 ratio = 18). The ANOVA run on the BP with the same factor design showed a significant 3-way interaction between group, ratio and pre–post exercise, $F(1,36) = 4.6$, $p = .04$. In the meditation group, there was only a significant main effect of ratio, which indicated that the BP value was higher for the 4/8-s than for the 4/6-s bisection task (6.01 *vs.* 5.15), $F(1,18) = 16.76$, $p = .001$. In the case of the relaxation group, there was also a significant main effect of ratio, $F(1,18) = 33.82$, $p = .001$. However, ratio also significantly interacted with pre–post exercise, $F(1,18) = 4.12$, $p = .05$. The BP was indeed higher after than before the relaxation exercises in the difficult discrimination condition, $t(18) = 2.43$, $p = .03$, but not in the easier one, $t(18) = 0.03$, $p = .98$.

In addition, we measured[1] the mindfulness score, the anxiety state score, as well as an "arousal-calm mood" score on the BMIS (for the method, see Mayer & Gaschke, 1988). The ANOVA run on mindfulness and anxiety state with 2 factors (pre–post exercise and group) did not reveal any significant effects (all $p > .05$). The ANOVA on arousal scores revealed a significant main effect of pre–post exercise, $F(1,39) = 11.88$, $p = .001$. The main effect of group and the group × exercise interaction were not significant ($p > .05$). The arousal scores were therefore lower after than before the exercises, irrespective of the type of exercise performed, i.e., meditation or relaxation. Consequently, for the relaxation group, in which a significant exercise effect on BP was observed in the difficult bisection condition (2:3), we decided to examine the correlations between the arousal scores and the BP values for the pre- and the post-exercise bisection phase in this bisection condition. No significant correlation was observed (all $p > .05$). Since there was a significant effect of ratio on the WR, we also verified the correlations between the arousal score and the WR for all subjects in the difficult and the easier ratio condition. No significant correlation between the WR and the arousal scores was found ($p > .05$). The only significant correlation that was observed was between the WR and the anxiety level ($R = .49$, $p = .009$), thus indicating that sensitivity to time (lower WR) increased as anxiety level decreased.

In sum, the results of the bisection task reported above revealed a shortening effect after the relaxation exercises, with the proportion of long responses decreasing and the BP value increasing significantly. However, this shortening effect was observed in the difficult (2:3 ratio) but not in the easy temporal discrimination condition. In addition, this shortening effect was not significantly related to the decrease in the subjective arousal level induced in the participants by relaxation practice. This suggests that the shortening effect observed in the relaxation group in our study was not due to a decrease in the level of arousal induced by the relaxation exercise. Moreover, a decrease in the arousal level would have produced a shortening effect in both the 4/6-s and the 4/8-s bisection task, and not only in the 4/6-s condition as was found in our study. We may therefore assume that this shortening effect specifically observed in the 2:3 ratio condition was linked to attentional processes. Firstly, as we discuss below, the scalar timing theories (Gibbon, 1977; Gibbon et al., 1984) predict an "additive effect" with the stimulus durations if attentional processes are involved, and a multiplicative effect if the clock-based hypotheses are correct, with the clock effect increasing with the stimulus duration values. Our results showing a constant exercise effect on p(long)

[1] One participant did not complete the BMI scale.

irrespective of stimulus durations are thus consistent with an attention-based hypothesis rather than a clock-based hypothesis. Secondly, it is obvious that the attentional effort required to process time accurately was greater in the difficult than in the easy temporal discrimination task. Consequently, if attention was required in order to perform the relaxation exercises properly, then less attention was available to be directed to the subsequent temporal discrimination task, thus producing a shortening effect. In line with this reasoning, this shortening effect on time judgment only emerged in the difficult temporal discrimination task (2:3 ratio), which was more attentionally demanding than the easier task.

Unlike in the relaxation group, the 10-min exercise had no effect on temporal bisection performance in the meditation group. One explanation might be that the practice of meditation improved the participant's ability to orient their attention toward the processing of time. Consequently, the shortening effect observed in the difficult temporal discrimination task for the relaxation group would not be found in the meditation group. However, an alternative explanation is that the meditation exercise was ineffective for the participants who were new to meditation. Or in other words, it did not work. Our findings were thus opposite to those found by Kramer et al. (2013) who revealed a meditation effect on bisection performance with the same conditions as those used in our study. It is, however, the case that many people find it difficult to meditate the first time they attempt to perform meditation exercises. The benefits of meditation on behavior are often observed only after more extended practice. Therefore, in the second experiment, the participants were trained to meditate every day over a period of several weeks (5 weeks). The aim of the second experiment was thus to test the effect of relaxation and meditation exercises on temporal discrimination behavior in bisection in participants who have been trained in meditation or relaxation.

3. Experiment 2

3.1. Method

3.1.1. Participants

The sample consisted of 31 new participants (mean age = 23.66, *SD* = 6.33) who received 40 euros for their participation (16 in the meditation group and 15 in the relaxation group). Three additional participants were recruited (2 in the relaxation group and 1 in the meditation group) but subsequently dropped out of the study. All participants signed a formal agreement for this experiment which was approved by the Sud-EST VI statutory Ethics Committee.

3.1.2. Material and procedure

The material and the procedure were similar to those used in Experiment 1 and the same bisection task and meditation or relaxation exercises were used. The only difference was that the participants were trained to perform either meditation or relaxation exercises as a function of their group (meditation *vs.* relaxation) before performing the temporal task. The participants in both groups practiced these exercises for 20 min every day at home over a period of five weeks. The exercises were recorded on an audiotape and were listened to by the participants via headphones. An exercise book indicated the exercises to be performed on each day. In the relaxation group, the participants had to tense and relax their muscles one by one (e.g., lips, neck, shoulder, back, legs) and pay attention to the accompanying sensations in accordance with a standardized Jacobson's relaxation technique (Arena & Blanchard, 1999) for a period of four weeks. In the fifth week, the exercises involved muscular grouping (i.e. the participants had to tense and relax two regions of the body simultaneously). The mindfulness meditation training used in this study was modeled on the Mindfulness-Based Stress Reduction (MBSR) program developed by Kabat-Zinn (1982). Our program consisted of formal techniques utilized in MBSR such as body scan meditation (week 1), body scan and breath meditation (week 2), breath meditation with attention focused on body feeling (week 3), breath meditation with attention focused on emotions (week 4), and breath meditation with attention focused on thoughts (week 5). The participants were instructed to adhere to the exercises as well as they could and the experimenter calling them at the end of each week to verify that they had performed their exercises every day.

In addition, the participants performed a series of neuropsychological tests before and after these 5 training weeks in order to examine whether working memory and attentional capacities had improved in response to the practice of meditation or relaxation. In the case of memory capacities, two tests were used: the forward and the backward Corsi span test. The first assesses visuo-spatial short-term memory, and the second visuo-spatial working memory. Two other tests were used to assess attentional capabilities: the d2-test of attention (Brickenkamp, 1981) and the Victoria Stroop test (Spreen & Strauss, 1998). Although both these tests assess selective attention capacities, the former focuses more on attention concentration capacities and the latter on attention inhibition capacities. The participants also completed the Mindfulness Attention Awareness Scale (MAAS; Brown & Ryan, 2003) before the meditation-relaxation training and after the bisection tasks. The BMIS and the STAI were also used as in Experiment 1.

3.2. Results and discussion

Fig. 2 shows the psychophysical functions in the pre- and the post-exercise bisection phase of the participants who were trained to practice meditation and relaxation. The shape of their bisection curves differed from those of the novice participants in Experiment 1, with a leftward rather than a rightward-shift of the psychometric functions in post- compared

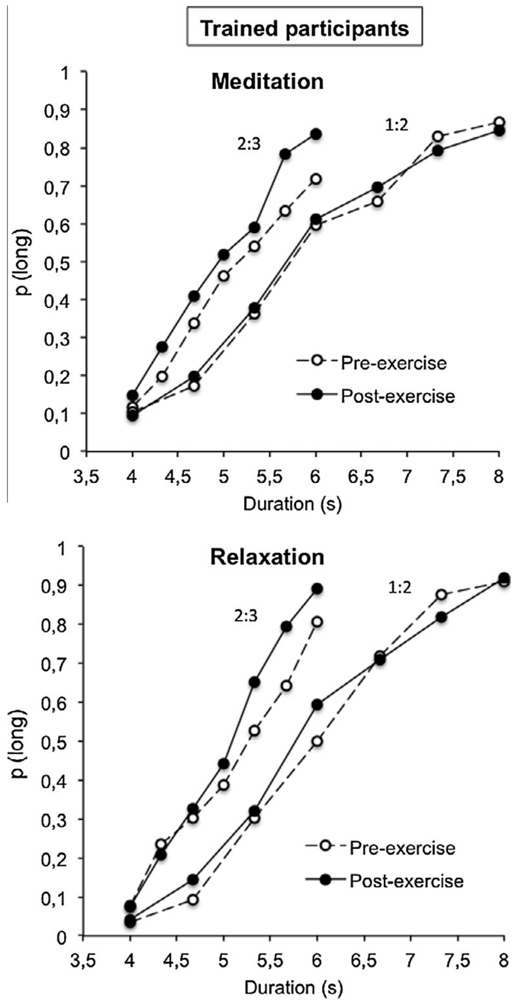

Fig. 2. Proportion of long responses plotted against stimulus durations (s) in the meditation and the relaxation group for the pre- and the post-exercice bisection task in Experiment 2 with trained participants who had practiced meditation or relaxation.

to pre-exercise bisection. The ANOVA on *p*(Long) with 1 between-subject factor (group) and 3 within-subjects factors (comparison duration, ratio, pre–post exercise) showed a significant comparison duration × ratio interaction, $F(6,174) = 9.55$, $p = .0001$, which subsumed a significant main effect of ratio, $F(1,29) = 6.97$, $p = .01$, and comparison duration, $F(6,174) = 216.61$, $p = .0001$. This suggests that the psychophysical functions were flatter in the difficult than in the easier temporal discrimination condition. In addition, there was a significant main effect of pre–post exercise, $F(1,29) = 5.36$, $p = .03$. The interactions involving this factor did not reach significance (all $p > .05$). Consequently, the participants produced a greater proportion of long responses after than before practicing meditation or relaxation (.47 *vs.* .50).

As in Experiment 1, the BP and the WR for each participant were derived from the significant fits of individual bisection curves with the pseudo-logistic function (Table 2). This fit was not significant for 2 participants (1 in each group). The ANOVA on BP with 3 factors (group, ratio, pre–post exercise) showed a significant main effect of ratio, $F(1,27) = 25.10$, $p = .0001$. The BP value was indeed longer in the 4/8-s than in the 4/6-s duration condition. The main effect of pre–post exercise failed to reach significance, $F(1,27) = 3.60$, $p = .07$. However, post-hoc analyses in each ratio condition taken separately showed a significant effect of pre–post exercise in the difficult temporal discrimination condition, $t(29) = 2.18$, $p = .04$, but not in the easier one, $t(29) = 0.29$, $p = .78$. The ANOVA on the WR with the same factors showed a significant interaction between pre–post exercise and ratio, $F(1,29) = 4.94$, $p = .03$, but no other significant result. The exercise effect on the WR was significant in the difficult temporal discrimination condition, $t(30) = 2.13$, $p = .04$, while it was not significant in the easier one, $t(30) = 0.76$, $p = .45$. Neither the main effect of group nor any interaction involving groups was significant for either BP or WR (all $p > .05$). In sum, the relaxation and meditation training increased sensitivity to time and the proportion of long responses, thus tending to lower the BP. However, this pattern of results only occurred when the processing of time was difficult (ratio 2:3).

Table 2
Mean and error standard for the Bisection Point and the Weber Ratio in the meditation and the relaxation group for the pre- and the post-exercise bisection phase in Experiment 2 with participants who had practiced meditation and relaxation.

	Meditation		Relaxation	
	Pre-exercise	Post-exercise	Pre-exercise	Post-exercise
Bisection Point				
2:3 ratio				
Mean	5.67	4.94	5.16	5.02
E.S.	0.34	0.11	0.35	0.12
1:2 ratio				
Mean	5.77	5.75	5.92	5.83
E.S.	0.16	0.19	0.17	0.20
Weber Ratio				
2:3 ratio				
Mean	.21	.15	.18	.10
E.S.	.05	.02	.06	.02
1:2 ratio				
Mean	.20	.22	.13	.15
E.S.	.03	.04	.03	.04

The two-factor (group and testing period) statistical analyses of the MAAS score showed a main effect of testing period, $F(1,28) = 9.76$, $p = .004$, thus indicating that the participants' mindfulness performance improved following the training of meditation or relaxation. However, further analyses of the correlations between the MAAS scores and the temporal performance indexes did not reveal any significant result (all $p > .05$). In addition, despite this increase in the mindfulness scores, there was no change in the individual scores on the different cognitive tests assessing either working memory (Forward and Backward Corsi) or attentional capacities (d2, Stroop victoria) (all $p > .05$). Consequently, practicing relaxation or meditation for 5 weeks did not change the basic level of cognitive capacities.

Similarly, the statistical analyses of the subjective arousal-related scores on the BMIS with group and pre–post-exercise as factors did not reveal any significant effect ($p > .05$), thus indicating that there was no change in affective mood after the exercises performed by the trained participants for the purposes of the bisection task (all $p > .05$). Compared to the participants in Experiment 1, this suggests greater within-session stability of the affective state in the participants who had practiced meditation or relaxation. However, post-hoc comparisons of the arousal scores of the participants in Experiment 1 and those in Experiment 2 using a 3-factor design (experiment, meditation/relaxation group, pre–post exercise) showed a main effect of pre–post exercise, $F(1,68) = 12.59$, $p = .001$, with no other significant effect, thus suggesting that the exercises performed during the bisection task tended to reduce the arousal level in all participants. In Experiment 2, the anxiety level was also similar before and after the exercises performed for the bisection task (all $p > .05$). However, the post-hoc comparisons of the anxiety scores of the participants in Experiment 2 with those in Experiment 1 using a 3-factor design (experiment, meditation/relaxation group, pre–post exercise) showed that the level of anxiety was lower for the meditation and relaxation "experts" (Experiment 2) than for the "novices" (Experiment 1) who practiced the exercises for the first time in the bisection task (34.02 *vs.* 39.04, $F(1,63) = 4.07$, $p = .048$). The level of anxiety also tended to be lower in the meditation than in the relaxation group (34.11 vs. 38.95, $F(1,63) = 3.78$, $p = .056$). The interaction between these factors was not significant and neither was the main effect of the pre–post exercise ($p > .05$). Consequently, the differences in anxiety level between trained (Experiment 2) and non-trained (Experiment 1) participants can account for the differences in the processing of time. Consequently, as can be seen below, we decided to compare *a posteriori* the results of Experiment 2 with those of Experiment 1.

3.2.1. Comparison between Experiment 1 and 2

An ANCOVA was run both on the BP and the WR with 8 different factors (experiment, group, ratio, pre/post-exercise, pre- and post-exercise anxiety level, and pre- and post-exercise arousal scores), with the latter factors being entered as co-variates. As far as the index of time sensitivity (WR) is concerned, the statistical analyses did not reveal any effect involving the arousal scores ($p > .05$). The main effect of the pre–post exercise failed to reach significance, $F(1,54) = 3.17$, $p = .08$. However, the analyses conducted on each ratio taken separately revealed a significant pre–post exercise effect for the difficult temporal condition, $F(1,72) = 4.03$, $p = .04$, but not for the easier one, $F(1,72) = .009$, $p = .93$. Sensitivity to time therefore improved after the exercises in the difficult temporal discrimination condition, irrespective of the experiment. However, there was also a significant main effect of experiment, thus suggesting that sensitivity to time was systematically higher for the trained participants (Experiment 2) than for the novice participants (Experiment 1) (.14 *vs.* 22, $F(1,54) = 4.66$, $p = .03$). Moreover, the main effects of level of anxiety before, $F(1,54) = 3.90$, $p = .05$, and after the exercises, $F(1,54) = 5.14$, $p = .03$, were significant. In sum, sensitivity to time increased when the level of anxiety decreased, with the trained participants being less anxious than the non-trained participants. There was also a significant interaction between the ratio and the anxiety level assessed before the bisection task, $F(1,54) = 5.69$, $p = .02$, thus suggesting that sensitivity to time increased as anxiety level decreased, and especially in the difficult temporal discrimination condition. The effects involving the type of exercise were not significant. Finally, our results suggested that the differences in time sensitivity between the individuals in the experiments were, to a large extent, linked to the fact that anxiety levels were generally lower in the participants trained in meditation or relaxation than in the novice participants.

Unlike in the case of the WR, the statistical analyses run on the BP showed that the value of the BP was not significantly related to anxiety level (all $p > .05$). In line with previous results, there was a tendency toward an interaction between ratio, group and pre–post exercise, $F(1,49) = 3.36$, $p = .07$, which subsumed a significant main effect of ratio, $F(1,49) = 5.48$, $p = .02$. When each ratio was considered separately, there were indeed non-significant effects involving the factors of group and pre–post exercise for the easy temporal discrimination task (all $p > .05$), while the group × pre–post exercise interaction reached significance for the difficult temporal discrimination task, $F(1,66) = 6.99$, $p = .01$, with no significant main effect of pre–post exercise being observed. This significant interaction in the difficult temporal discrimination task showed that the BP was lower after than before the meditation exercises, $t(36) = 2.22$, $p = .03$, while no difference was observed between the pre- and the post-exercise in the case of relaxation, $t(35) = 1.02$, $p = .31$. In other words, the accumulated individual data of our 2 experiments shows that the meditation exercises produced a lengthening effect, while the relaxation exercises had little effect on bisection performance. In addition, the pre–post exercise × experiment interaction was significant, $F(1,49) = 5.59$, $p = .02$. This suggests that the effect of exercise on temporal performance was more efficient in the trained (Experiment 2) than in the non-trained participants (Experiment 1). Indeed, the PB value was lower after than before the exercise performed for the bisection task in the trained participants, $t(30) = 2.08$, $p = .04$, while it remained similar in the non-trained participants, $t(41) = 1.16$, $p = .25$. In addition, and surprisingly, the analyses on the BP also showed a general effect of arousal scores assessed at the end of the bisection session, $F(1,49) = 6.23$, $p = .02$, as well as a significant interaction between ratio and post-arousal score, $F(1,49) = 5.22$, $p = .03$. Further analyses of correlations revealed only a significant relationship between the BP value and the arousal scores in the easy temporal discrimination task, $R = 31$, $p = .05$, with the BP value increasing with the arousal level assessed using the BMIS.

4. General discussion

The present study showed that mindfulness meditation exercises increased sensitivity to time and lengthened perceived time, as the fact that the WR and BP were lower in the post- than in the pre-exercise bisection task indicates. However, this improvement in temporal performance with meditation exercises was primarily observed in the participants who had previously practiced meditation, i.e. every day for a period of 5 weeks. Indeed, in our study, the mindfulness exercise had little effect on the temporal performance of individuals new to meditation in Experiment 1. Our results in novice participants were therefore inconsistent with those found by Kramer et al. (2013) who observed a lengthening effect in non-practitioners of meditation under the same conditions. This may be due to the durations (<1.6 s) used by Kramer et al. (2013) that were shorter than those used in our experiment (>4 s). The effect of meditation on subjective time in naïve subjects might thus emerge with short durations close to the present moment rather than with longer durations, above the present moment. However, this lack of effect in the novice participants may be also due to the inefficiency of meditation exercises when performed for the first time. Many people have reported that it is difficult to practice meditation without prior experience. There is indeed a great inter-individual variability in subjects' ability to maintain continuous awareness and therefore to follow the meditation exercises. As Kabat-Zinn (2003) stated, "we are all mindful to one degree or another, moment by moment" (p. 146). This ability may thus come more easily to some individuals than to others (Brown & Ryan, 2003). The fact that the main effect of the meditation exercise reached significance in our study when the results of the participants in Experiment 1 were combined with those of the participants in Experiment 2 provides support for this idea. Nevertheless, our study suggests that it is difficult to examine the effect of meditation on the perception of time when the participants involved are performing a meditation exercise for the first time. A simple instruction to perform a mindfulness exercise is thus not efficient enough to make it possible to investigate the role of meditation in time perception. In other words, mindfulness is not a simple method that can be easily tested over a brief period because it requires training in mindfulness skills.

The results concerning participants who had already experienced meditation clearly revealed that a meditation exercise both increased sensitivity to time and lengthened the perception of time. The difference in the meditators' temporal performance between the pre- and the post-exercise suggests that the practice of meditation during the bisection session might have reactivated the participants' attentional strategies and/or induced a state of attentional concentration. Several studies have shown that the practice of mindfulness increases individuals' attention control skills (see, for example, Chambers, Lo, & Allen, 2008). Subjects are indeed trained to focus their attention on an object and to resist distractors. They have thus learned to voluntarily control their attention. We can therefore suggest that the reduction of the variability of temporal judgment and the lengthening of time estimates were due to the fact that the meditators were able to devote more attention to the processing of incoming temporal information than the other participants, or at least the novice participants. As suggested in Section 1, our results are consistent with those of experiments that have used attentional paradigms showing that the continuous allocation of attentional resources to temporal information processing reduces the variability of time judgments and makes these judgments longer. According to the internal clock-related attentional models, this is due to the fact that fewer time units (pulses) are lost when the participants are more absorbed in the processing of time (Zakay & Block, 1997). However, in our study, the amount of attentional resources allocated to time was not determined by external factors (e.g. dual-task) but by internal factors, i.e., the ability of meditators to voluntarily orient their attention toward time (internally oriented attention). Our results thus confirm the idea that meditation practitioners can allocate attention more efficiently than other participants (Glicksohn, 2001). Furthermore, in our study, the effect of meditation exercises mainly occurred in the difficult temporal discrimination task. This suggests that this effect emerges when temporal processing is more attentionally demanding and provides additional support for the idea that individual attention capacities play a crucial role in the effects of meditation on time perception.

Our study nevertheless also suggests that the effect of meditation on the perception of time differed only slightly from that of relaxation. Progressive relaxation differs from mindfulness meditation because there is an intentional focus on relaxing during the practice of relaxation (Jain et al., 2007). However, the participants who performed the relaxation exercises were also trained to control their attention by trying to relax a series of specific muscles in sequence. Consequently, a simple attention-based approach, in which the participants train their attentional control skills, could improve temporal performance in bisection irrespective of the type of exercise performed. In other words, the practice of attentional control exercises (meditation or relaxation) would make individuals better able to direct their attention to the processing of temporal information. It is also possible that the Jacobson's relaxation technique used in our study based on muscle relaxation produced a conscious awareness of body states close to those induced by the body scan in the mindfulness-based meditation. Meissner and Wittmann (2011) showed that individuals, who were more sensitive to proprioceptive feedback (heart beat), i.e. who more accurately count the number of heart beats for a given interval, were also more accurate in their time estimation. Indeed, as explained Wittmann and Schmidt (2014), the state of mindfulness changes not only attentional control but also body awareness. The feeling of passage of time has been suggested to be strongly influenced by the awareness of body processes (Droit-Volet, 2014; Droit-Volet & Gil, 2009; Droit-Volet, Fayolle, Lamotte, & Gil, 2013; Wittmann, 2009). Consequently, relaxation exercises may have influenced the judgment of time in the same way as meditation exercises did, although to a lesser extent due to the lower efficiency of this technique on body awareness. This hypothesis suggested by a reviewer is nevertheless unlikely because the effect of exercises on the time judgment was only observed for the difficult temporal task in our study, whereas a body awareness-related effect would have been observed for all temporal tasks.

However, our results do not allow us to reject the idea that meditation does not have any specific effect on the perception of time distinct from that of relaxation. When the results of Experiments 1 and 2 are aggregated, the lowering of the BP between the post- and pre-exercise bisection phase was significant in the meditation group but not in the relaxation group. This suggests that the attention-related lengthening effect is greater in the case of meditation than in that of relaxation. Finally, the small difference in bisection performance between the meditation and the relaxation group might have been due to the training program followed by our participants over a period of 5 weeks. Some clinical studies which have investigated the effect of mindfulness-based therapies on a variety disorders have involved clinical programs conducted over a longer period lasting between 8 and 12 weeks. The Mindfulness-Based Stress Reduction (MBSR) program developed by Kabat-Zinn (1982) originally lasted 8 weeks. Other researchers prefer to work with highly trained meditators, such as Tibetan monks, who are continuously engaged in meditation activities in their everyday life. The degree of practice is thus important in determining the effectiveness of meditation for performance in different tasks. Recent studies have shown that attention and working memory capacities change over time in highly trained meditators to become a sort of personality trait (Jha et al., 2007; Moore & Malinowski, 2009). Glicksohn (2001) speaks of an individual capacity of attentional deployment. In our study, the scores on the working memory and attention tests did not change significantly after 5 weeks of mindfulness training. It is therefore possible that 5 weeks of training was insufficient to fundamentally alter the participants' cognitive capacities. It therefore seems important to replicate our experiment with meditators who practice and cultivate mindfulness at all times throughout their lives. Nevertheless, our results show that the experience of controlling one's own attention, in particular by means of a mindfulness-based technique, develops attentional strategies that consist in devoting more attentional resources to temporal information processing.

In addition, our study showed that the difference in temporal performance between the experienced meditators and the novice participants was observed as of the beginning of the bisection session. Indeed, the participants in Experiment 2 exhibited a greater sensitivity to time (i.e., lower WR) than those in Experiment 1, irrespective of the bisection phase. In addition, the WR was significantly correlated with the individual level of anxiety: The lower the anxiety level, the higher the sensitivity to time was. Moreover, the participants in Experiment 2 were significantly less anxious than those in Experiment 1. As the MAAS scores did not interact with the bisection performance, and there was no change in attentional capacities in the meditators in our study following mindfulness training, it seems reasonable to assume that the difference between the participants in Experiments 2 and 1 was, to a large extent, related to the lower level of anxiety in the former. This finding is consistent with studies which have shown that mindfulness practice reduces anxiety and stress, and eliminates their negative impact on performance (Delmonte, 1985; Kabat-Zinn et al., 1992; Roemer & Orsillo, 2002). Jensen, Vangkilde, Frokjaer, and Hasselbach (2012) recently revealed the major impact mindfulness has on reducing stress in a range of tasks. Mindfulness-based therapy is indeed particularly fruitful in treating various affective disorders (for a review, see Baer, 2003). Finally, our study showed that the reduction in anxiety was associated with an improvement in sensitivity to time. Bagana and Raciu (2012) and Siegman (1962) found the same positive correlation between anxiety trait and time judgments. Similarly, Sévigny, Everett, and Grondin (2003) showed that time discrimination was better in non-depressed than in depressed participants, but only for the long durations whose processing demanded a higher level of attention. As explained by Hancock and Weaver (2005), stress drains attentional resources and the resources that remain are insufficient to estimate time correctly. In conclusion, our study demonstrates that the practice of attention control exercises, such as mindfulness exercises that develop individual attentional skills, improves the judgment of time. However, this improved time judgment in mindfulness meditators does not contradict the fact that they can experience timelessness when in the meditative state.

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