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Perceived Control in the Lab and in Daily Life Impact Emotion-Induced Temporal Distortions

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Abstract

Prior research has shown that the arousal and valence dimensions of emotional images distort the perceived duration of those images. Further, these time distortions are eliminated when observers feel in control over the events in the experiment. The present study had two goals. The first goal was to replicate the effect of perceived control on time perception, using a design where perceived control was manipulated within subjects. The second goal was to evaluate whether the experimental manipulation of perceived control was related to feelings of control experienced in daily life, as assessed by the Desire for Control and Locus of Control scales. In all, 109 participants completed a time bisection task and evaluated the same emotional images under low and high levels of perceived control over the events. The results replicated the finding that the temporal distortions by emotional events observed under low perceived control were eliminated under high perceived control. Furthermore, individual differences regarding control in daily life modulated the effects of perceived control on time perception. Individuals with a high desire for control and a high degree of internality seemed to have an enhanced experience of positive events. These same individuals also benefited more from the experimental control manipulation, speeding the passage of time and perhaps making the task more enjoyable. The results are discussed in the context of current models of time perception.

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1. Introduction

1.1. Time Perception and Emotion-Driven Modulations in Time Perception

The last several decades have seen increased interest in understanding the mechanisms associated with the subjective experience of time. The most widely accepted models of time perception center on the concepts of a pacemaker and an accumulator (Gibbon, 1977; Gibbon et al., 1984; Lake et al., 2016). The general idea is that the pacemaker produces ticks (or pulses) that are delivered to an accumulator. Our representation of time duration arises from our perception regarding the number of pulses that have accumulated. The pulses are delivered to the accumulator through a 'switch' (Lejeune, 1998), controlled by attention, that starts and ends the flow of pulses into the accumulator (Zakay & Block, 1995). The more pulses flow into the accumulator, the longer events seem to last. Finally, the time it takes to start collecting pulses depends on when attention activates the switch, in other words, how quickly attention can be deployed from the event itself to the task of temporal judgement (the attentional-gate model of Zakay & Block, 1995, further expanded by Lake, 2016; Lake et al., 2016).

Emotions modulate time perception in multiple ways (Lake, 2016; Lake et al., 2016 for a review). In terms of the theoretical models of time perception, the emotional salience of an image or event impacts attentional orienting, which in turns impacts the speed at which an observer can engage the switch and start collecting pulses. In addition, performance on the time estimation task also depends on the degree with which controlled attention mechanisms remain engaged in the counting task (Lake et al., 2016). Furthermore, the arousal of an event impacts time perception by altering the behavior of the pacemaker: notably, highly arousing images increase the ticking rate of the internal pacemaker (Dirnberger et al., 2012; Droit-Volet et al., 2010; Fayolle et al., 2015; Gil & Droit-Volet, 2012; Gil et al., 2007; Kliegl et al., 2015; Tipples, 2015; Waits & Sharrock, 1984; but see, Folta-Schoofs et al., 2014) in a transient manner (Lake et al., 2016).

1.2. Time Perception and Experience of Control over Emotional Events

The subjective experience of control refers to when people feel that their choices or actions affect the events around them. Both humans and animals value the opportunity to choose, and the ability to exert control over the environment is associated with enhanced well-being (e.g., Buchanan-Smith & Badihi, 2012; Buetti & Lleras, 2012; Fujiwara et al., 2013; Kurtycz et al., 2014; Leotti et al., 2010; Presson & Benassi, 1996; Wulf et al., 2014). The experience of control may or may not be related to any *actual causal control* over the world. For example, a person may be given a choice between two keys and one of two outcomes (happy or sad face) may occur after their keypress. When the outcome is related to the choice selection, participants have real control over the outcomes: their actions control the world in probabilistic or deterministic fashion. Interestingly, an illusory feeling of control can be experienced when the outcomes are entirely independent of participants' choices, provided that their desired outcome occurs often (Alloy & Abramson, 1979; Jenkins & Ward, 1965; Presson & Benassi, 1996; Thompson, 1999). If a happy face appears in a larger number of trials irrespective of the participant's button press (e.g., in 75% of the trials), the participant will report having a high level of control over the experimental events.

Previous research (Buetti & Lleras, 2012; see also Mereu & Lleras, 2013) showed that a subjective experience of control over emotional events impacts the perceived duration of these events. Buetti and Lleras used a time bisection task (Penney et al., 2008) in which participants were shown images that vary in duration (between 400 and 1600 ms) and were asked to judge if the duration of the images was closer to the short standard they learned (400 ms) or to the long standard (1600 ms). Analyses of the point of subjective equality for the different images showed that when participants felt they lacked control over the experimental events (Experiment 4), they experienced distortions in their perception of time (see also Angrilli et al., 1997; Smith et al., 2011). Specifically, participants perceived highly arousing negative images (e.g., mutilated bodies) to last longer than arousal-matched positive images (e.g., erotic scenes). However, when they felt a sense of control over the events in the experiment (Experiment 3), such perceived temporal distortions were eliminated. Importantly, in Buetti and Lleras (2012), the feeling of control was illusory. In the two experiments, the stimuli, design, and procedure were identical and the critical difference resided in the instructions. In Experiment 4 (low-control condition), the trial begun with the computer telling participants which key to press (either "press the 1 key" or "press the 3 key"). In Experiment 3 (high-control condition), the trial begun with a screen asking participants to make a choice ("Choose key 1 or key 3"), and they were also told to find a good combination of keypresses across trials that would maximize the occurrence of positive images on the screen. Note that in both experiments, 75% of the images were positive. The sense of control over the images was evaluated with post-experimental questionnaires that assessed whether the participant reported sensing a feeling of control over the experimental events (54% in Experiment 3 vs 11% in Experiment 4).

1.3. Current Study

The findings reported in the present manuscript are part of a larger project that investigated the effects of experimental control on time perception of emotional events in individuals who vary in their emotional profile with regard to depressive and hypomanic symptoms (Fig. A1 in Appendix 1 shows the distribution of scores of the participants on the different questionnaires).

The present manuscript focuses on two of the four theoretical questions investigated in this project. The first question was methodological in nature and consisted of evaluating whether the temporal distortions of emotional events can be eliminated when the experience of control is manipulated within subjects. Buetti and Lleras (2012) found that temporal distortions of emotional events were eliminated when participants experienced a high feeling of control. In that study the experimental manipulation of control was performed between subjects. One group of subjects was led to experience low levels of control over experimental events and a different group of subjects was led to experience a relatively high level of control over those same events. The between-subject design was chosen initially to avoid potential carryover effects from one condition to the other. In the present study, the goal was to evaluate whether the same result could be observed when control is manipulated within subjects. The within-subject design used in the present research provides a much stronger test of the hypothesis that heightened levels of perceived control eliminate the temporal distortions associated with experiencing emotional events. A within-subject manipulation ensures that the differences observed between groups in Buetti and Lleras (2012) were not due to differences in characteristics of the groups (a failure of random assignment) nor to differences caused by the manner in which the experimenters interacted with the two control groups (experimenter degree of freedom).

The second theoretical question concerned a test of convergent validity regarding two different concepts of control: control as manipulated in the laboratory and control as experienced in daily life. Heightened levels of perceived control in daily life have been associated with positive psychological outcomes, such as reduced depression (e.g., Amoura et al., 2014; Burger & Arkin, 1980; DeNeve & Cooper, 1998; Gebhardt & Brosschot, 2002; Ghorbani et al., 2008; Kleftaras & Georgiou, 2014; Moulding & Kyrios, 2007), reduced anxiety (Gebhardt & Brosschot, 2002; Ghorbani et al., 2008; Goldstein et al., 2002; Ludwick-Rosenthal & Neufeld, 1993), increased adaptive functioning (Thompson, 2002), and improved coping with stress (Glass et al., 1993; Litt, 1988; Thompson et al., 1993). The finding that perceived control eliminates emotion-related time distortion begs an important question: is the feeling of control that is experimentally induced in the laboratory related to self-reported measures of control in daily life? If so, experimentally induced control would be meaningful with regard to predicting the positive psychological outcomes that have been associated with self-reported measures of control in daily life. If the cognitive mechanisms that give rise to the sense of control in the experimental setting share some mechanistic overlap with those that allow an individual to judge (or locate) the sense of control over events in their daily life, then these two factors *should interact* in modulating the perceived duration of emotional events. On the other hand, if these two factors affect entirely independent cognitive mechanisms, then they will have additive effects only (Sternberg, 1969, 1998).

Two self-reflection questionnaires were used to assess the first factor, control in daily life. The Desirability of control scale evaluated individuals' desire for experiencing control in their daily life (Burger & Cooper, 1979). The Locus of control scale assessed where individuals located the sense of control internally, in a powerful other or in chance (Levenson, 1981). The second factor, experimental control, was manipulated within subjects. Participants were invited to complete multiple experimental sessions in which the level of perceived control while performing a time perception task was varied. In one session, they were led to experience a high level of perceived control over the emotional content of the images they were judging. In a second session they were led to experience little to no control over those same images. The order of experimental control level was counterbalanced and the two sessions were run two weeks apart to minimize potential carryover effects from one condition to the other.

Information regarding the two other theoretical questions of the project and the planned analyses can be found in Appendix 2.

2. Methods

2.1. Participants

In all, 109 undergraduate students from the University of Illinois participated in the study (79 females, mean age 19.4 years old on average, and 30 males, mean age 19.5 years old) and were remunerated for their participation. Details about sample characteristics and recruitment can be found in Appendix 1. Participants were contacted in double-blind fashion to complete three sessions where the level of experimental control was manipulated. In other words, neither the participants nor the experimenters in the lab knew the participants' scores on the different questionnaires, nor did the participants know that they were being contacted because of their scores on those questionnaires.

2.2. Stimuli and Design

Participants were trained to discriminate between two standard durations, a short one (400 ms) and a long one (1600 ms; see Droit-Volet et al., 2004). The stimuli used to learn the standard durations were: a pink oval (participants saw alternations of short and long durations for a duration of eight trials) and neutral images from the Affective Picture System (short and long durations were randomized; this task lasted until participants reached 80% of correct answers). Afterwards, participants completed an experiment in which the images ($25.5° \times 21°$) to be judged varied (a) in their time duration (400, 600, 800, 1000, 1200, 1400 and 1600 ms), (b) in their arousal (high vs low) and (c) in their valence (positive vs negative). Images were selected from the International Affective Picture System (IAPS; Lang et al., 2008). The list of images as well as the mean arousal and valence for the four sets of pictures are presented in Appendix 3.

In both the high- and low-control conditions of time bisection task, we used the same 24 high-arousing positive images, 24 low-arousing positive images, 8 high-arousing negative images, and 8 low-arousing negative images. As in Buetti and Lleras (2012), to better estimate the Bisection Point in the psychophysical curve, all images were presented for the three central time durations (800, 1000, and 1200). To reduce the duration of the experimental session, fewer images were shown for the two shortest (400 and 600 ms) and for the two longest durations (1400 and 1600 ms). That is, 15 high-arousing positive images, 15 low-arousing positive images, 5 high-arousing negative images, and 5 low-arousing negative images were presented in those conditions. Images were presented on a white background at the center of the screen and image order was randomized. Participants completed a total of 352 trials.

Note that as in Buetti and Lleras (2012), the same stimuli and design were used in the high- and low-control conditions. The only difference between the two tasks was the instruction. Participants completed the high- and low-control conditions in separate experimental sessions. The order was counterbalanced across participants and two weeks elapsed between experimental sessions.

2.3. Procedure

The participants completed a set of tasks and questionnaires during three experimental sessions. Not all measures and tasks are analyzed in the current manuscript (see Appendix 2 for description of additional questionnaires and tasks that were not reported in the present manuscript; Session 3 is also described in Appendix 2). Here we only focus on individuals' scores at the Desire For Control and Locus of Control questionnaires as well as on the comparison between performance at the Time Bisection task under high- and low-control conditions (Sessions 1 and 2 below).

In the time bisection task participants were first trained to discriminate between two standard durations, a short one (400 ms) and a long one (1600 ms). They were then assigned to one of the two experimental control conditions. In the *high-control condition*, participants were instructed to try to maximize the occurrence of positive images by selecting one of two buttons at the start of a trial (keys 1 or 3 on the numerical pad). Participants were told that there were some combinations of keypresses across a series of trials that would increase the number of positive images presented on the screen. Because the desired outcome occurred often (75% of the images were positive), this instruction was expected to provide participants with an illusory feeling of control (Buetti & Lleras, 2012). In the *low-control condition*, participants were told that the computer was in control of picking the images. They were instructed to press whichever key the computer selected to start each trial (keys 1 or 3 on the numerical pad). This instruction was expected to provide little to no feeling of control in participants.

After the participants chose/pressed the key (1 or 3), there was a random time interval between 0 and 1000 ms that was followed by an emotional picture. The image was presented for 400, 600, 800, 1000, 1200, 1400 or 1600 ms. A random interval between 0 and 1000 ms followed the image offset. Then, participants were asked to judge whether the duration of the emotional picture was closest to the short or long standard. Using these data, we computed the Point of Subjective Equality (PSE) for each participant in each of the different experimental conditions. The PSE corresponds to the stimulus duration that gives rise to 50% 'long' responses.

In the first experimental session, participants started by completing the main experimental task — the Time Bisection task (35 minutes) under either the high- or low-control condition (counterbalanced). The other condition was completed during the second experimental session.

At the end of the task, participants answered the following questions: "How often did positive images appear?", and "Did you feel at any point of the experiment that you had control over the images?". In the low-control condition only, the following question was also asked: "How much did the computer choice influence the image content?". Participants used a 0 to 100% scale to respond to each question. A series of trait questionnaires were also administered in session one, including the Desire for Control scale (20-items version; Burger & Cooper, 1979) and the Locus of Control scale (24-items version; Levenson, 1981). One single score was obtained from the Desire for Control questionnaire while three scores were obtained from the Locus of Control questionnaire. The three scores reflect the extent to which control is located internally, in a powerful other, and in chance. Higher scores at both scales indicate a higher need for control in daily life and a higher locus of control.

3. Effects of a Within-Subject Manipulation of Experimental Control on Time Perception

The goal of the first set of analyses was to evaluate whether the interaction between control, arousal, and valence found by Buetti and Lleras (2012) can be replicated when experimental control is manipulated within subjects. A generalized linear mixed-effect model (GLMM) analysis was conducted with control, arousal, and valence as fixed effect factors and with participants as random factor on points of subjective equality (PSEs). Based on previous findings (Buetti & Lleras, 2012), we expected a significant interaction between arousal and valence in the low-control condition, with larger PSEs (i.e., times passes faster or time is underestimated) for high-arousing positive images compared to high-arousing negative images, and smaller PSEs for low-arousing positive images compared to low-arousing negative images (Angrilli et al., 1997; Smith et al., 2011). In the high-control condition, we did not expect this interaction to be significant.

3.1. Results

3.1.1. PSE

When testing for the distribution of PSEs (see Note 1), the Shapiro–Wilk test of normality indicated that the PSEs distribution was not normal ($W = 0.99014$, $p =$ 2.88e−5). A two-sample Kolmogorov–Smirnov test confirmed that PSEs followed a gamma distribution ($D = 0.056$, $p = 0.242$, two-sided). In the analyses below, we ran Gamma GLMMs with Identity link (using the function glmer from the lme4 R-package; Bates et al., 2015) with control, arousal, and valence as fixed factors and participant as random factor. As a reminder, when comparing PSEs, a smaller PSE corresponds to time being perceived as lasting longer (or time being overestimated) compared to a larger PSE (or time being underestimated). Statistics are reported in Table 1.

The results of the analysis (108 subjects, 812 observations) indicated that PSEs were significantly smaller in the high-control than the low- control condition (888 vs 893 ms). All the interactions including the variable Control were significant. Note that confirming the results from Buetti and Lleras (2012), the interaction between control, arousal and valence was significant. To better understand these

Table 1.
Statistics from the generalized linear mixed-effect model analyses (GLMMs) with control, arousal, and valence as fixed factors and participant as random factor on points of subjective equality (PSEs). Significant effects are highlighted in bold.

PSE	Estimate	SE	*t*-value	*p*-value
(Intercept)	907.876	16.988	53.443	<0.0001
Control	−22.402	10.049	−2.229	**0.0258**
Arousal	11.097	9.957	1.115	0.2651
Valence	−8.417	10.398	−0.81	0.4182
Control × Arousal	90.557	12.972	6.981	**<0.0001**
Control × Valence	29.976	14.4	2.082	**0.0374**
Arousal × Valence	−4.962	13.681	−0.363	0.7168
Control × Arousal × Valence	−92.703	18.715	−4.953	**<0.0001**
Follow-up analyses:				
Low-control condition				
(Intercept)	880.714	18.45	47.736	<0.0001
Arousal	102.986	9.384	10.975	**<0.0001**
Valence	24.301	8.998	2.701	**0.007**
Arousal × Valence	−99.706	12.855	−7.756	**<0.0001**
High-Control condition				
(Intercept)	917.238	20.709	44.292	<0.0001
Arousal	12.325	10.865	1.134	0.257
Valence	−4.395	10.751	−0.409	0.683
Arousal × Valence	−5.027	14.867	-0.338	0.735

significant interactions, separate analyses were conducted on the low-control and high-control conditions separately.

In the low-control condition (99 subjects; 396 observations), high-arousing images were judged as lasting longer than low-arousing images (868 ms vs 918 ms, respectively). Positive images were judged as lasting longer than negative images (880 ms vs 906 ms). Importantly, the interaction between arousal and valence was significant. As illustrated by the distributions on Fig. 1, high-arousing positive images were judged to last for a shorter time than high-arousing negative images (879 ms vs 856 ms), while low-arousing positive images were judged as lasting longer than low-arousing negative images (880 ms vs 956 ms). Follow-up analyses indicated that PSEs for positive and negative images differed both for high-arousing images ($p < 0.001$) and for low-arousing images ($p < 0.0001$).

In contrast, in the *high-control condition* (104 subjects, 416 observations), PSEs were not significantly different for high- and low-arousal images (885 ms vs 891 ms), nor for positive and negative images (884 ms vs 892 ms). The arousal × valence interaction was not significant (mean PSEs for high-arousing positive and negative = 883 ms and 888 ms; mean PSEs for low-arousing positive and negative = 885 ms and 897 ms). A Bayesian follow-up analysis was conducted to investigate the magnitude of this null effect. Using the 'hypothesis' function in the brms R-package (Bürkner, 2016), we computed the Bayes factor between the null hypothesis (the arousal by valence interaction effect is zero) and the alternative

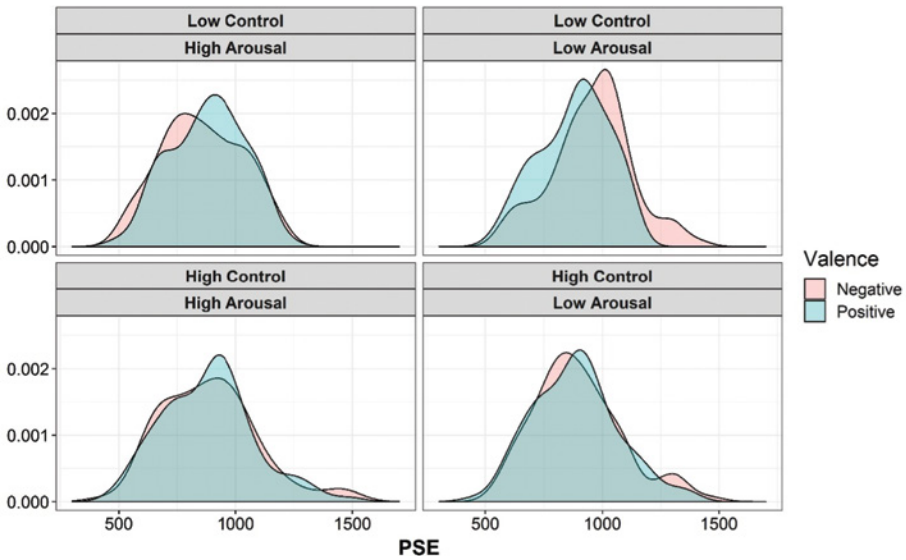

Figure 1. Density plots illustrating the effects of arousal and valence on Points of Subjective Equality (PSEs) as a function of experimental control (top row: low control; bottom row: high control). Participants judged the same images under the two control conditions.

hypothesis (the arousal by valence interaction effect is not zero) via the Savage–Dickey density ratio method. The Bayes factor is usually interpreted as the weight of evidence coming from the data (Good, 1985). When the Bayes factor for M_1 versus M_2 equals K, this shows that the data are K times as likely to have occurred under model M_1 than under model M_2 (Wagenmakers et al., 2010). Here, we found a Bayes factor of 5.32 when testing the model with no interaction against the model with interaction. According to a widely cited scale for interpretation of K provided by Kass and Raftery (1995), when $3.2 < K < 10$, the strength of evidence favoring the null hypothesis is substantial. Therefore, we found substantial evidence that the interaction between arousal and valence in the high-control condition does not exist.

3.1.2. Analyses on Other Parameters of the Psychometric Function

In addition to the analyses of the PSE, we also conducted analyses on the difference limen (dl) and Weber ratio. The dl corresponds to the semi-interquartile range of the function and was obtained by subtracting durations observed at the 25th percentile from the ones observed at the 75th percentile and then dividing by 2. The dl is a measure of variability and is specifically sensitive to the middle 50% of the psychometric distribution. The Weber ratio is obtained by dividing the dl by the PSE. The difference limen (dl) and Weber ratio are both indexes of temporal sensitivity and larger values indicate lower temporal sensitivity. Statistics are reported in Table 2.

A two-sample Kolmogorov–Smirnov test confirmed that a logarithmic transformation of dl follows a gamma distribution. Thus, we conducted a separate Gamma GLMM with Identity link on log(dl) (108 subjects, 812 observations). The means reported in the text below correspond to the untransformed dl values. The triple interaction between control, arousal and valence was significant. Below we present follow-up analyses for each control condition to better understand the main effects and interactions of these three factors. In the low-control condition the variability was larger with low-arousing images (137 ms) than with high-arousing images (131 ms). The variability was also larger with positive images (141 ms) than negative images (127 ms), and this was particularly the case for high-arousing images (143 ms vs 120 ms, difference = 23 ms) compared to low-arousing images (138 ms vs 134 ms, difference = 4 ms). In the high-control condition, only the main effect of arousal was significant, with a higher variability with high-arousing images (162 ms) than with low-arousing images (152 ms), the opposite pattern than what was observed in the low-control condition. In sum, experimental control eliminated the effects of valence and importantly, increased variability when judging high-arousing images.

A two-sample Kolmogorov–Smirnov test confirmed that Weber ratio (WR) follows an inverse gaussian distribution ($D = 0.044335$, p-value $= 0.402$). We conducted an Inverse Gaussian GLMM with Identity link on WR. The results indicated

Table 2.
Statistics from the generalized linear mixed-effect models (GLMMs) with control, arousal, and valence as fixed factors and participant as random factor (108 subjects, 812 observations) on variance, dl, and Weber ratio. Significant effects are highlighted in bold.

dl	Estimate	SE	*t*-value	*p*-value
(intercept)	4.979	0.052	96.621	**<0.0001**
Control	−0.289	0.049	−5.916	**<0.0001**
Arousal	−0.124	0.049	−2.535	**0.011**
Valence	0.001	0.049	0.021	0.983
Control × Arousal	0.249	0.069	3.621	**<0.0003**
Control × Valence	0.228	0.069	3.287	**0.001**
Arousal × Valence	0.098	0.069	1.416	0.157
Control × Arousal × Valence	−0.266	0.098	−2.708	**0.007**
Follow-up analyses on dl:				
Low-control condition				
(intercept)	4.674	0.052	90.047	**<0.0001**
Arousal	0.127	0.039	3.278	**0.001**
Valence	0.236	0.039	6.012	**<0.0001**
Arousal × Valence	−0.173	0.056	−3.105	**0.002**
High-Control condition				
(intercept)	4.972	0.058	86.006	**<0.0001**
Arousal	−0.123	0.045	−2.715	**0.007**
Valence	0.010	0.046	0.216	0.829
Arousal × Valence	0.096	0.064	1.493	0.136
Weber ratio				
(intercept)	0.180	0.007	24.047	**<0.0001**
Control	−0.038	0.008	−4.806	**<0.0001**
Arousal	−0.022	0.008	−2.649	**0.008**
Valence	−0.002	0.009	−0.268	0.789
Control × Arousal	0.022	0.010	2.168	**0.030**
Control × Valence	0.026	0.011	2.341	**0.019**
Arousal × Valence	0.013	0.012	1.119	0.263
Control × Arousal × Valence	−0.020	0.015	−1.331	0.183

that the main effect of control was significant: WR was larger in the high-control (0.18) than low-control condition (0.15), indicating lower time sensitivity under conditions of high control. The WR was larger in the high-arousal condition (0.17) than in the low-arousal condition (0.16). This effect was qualified by control: larger WR in high- vs low-arousing images was observed in the high-control condition (high arousal: 0.18, low arousal: 0.17) but not in the low-control condition (0.15 in both conditions). Finally, a heightened feeling of control increased the WR with negative images (low control = 0.14 vs high control = 0.18) more so than with positive images (0.l6 vs 0.18).

3.2. Discussion

The analysis on PSE successfully replicated the findings of Buetti and Lleras (2012) with a within-subject design. When participants experienced low levels of perceived control, their experience of time was impacted by the arousal level of the images. High-arousing images were perceived as lasting longer than low-arousing images. Furthermore, the valence of the images qualified the effect of arousal: for high-arousing images, negative images were perceived as lasting longer than positive images. This pattern of results reversed for low-arousing images.

In contrast, under high-control conditions, the same participants that exhibited large temporal distortions under low-control conditions, now demonstrated a similar experience of time across the four emotional categories. Noteworthy, the images that participants judged (and the occurrence of those images) were identical to the low-control condition. Numerically, it appears that all PSEs converged toward the PSEs observed for positive images in the low-control condition (about 880 ms, for both low- and high-arousal conditions).

The present findings also showed new results compared to Buetti and Lleras (2012). Experimental control affected the variability and sensitivity to the passage of time. The analyses on the Weber ratio indicated that time sensitivity was reduced under conditions of high compared to low control, in particular for high-arousing stimuli and also when images were negative. This is consistent with the analysis on dl where experimental control increased the variability when judging high-arousing images.

The implications of these findings with regard to the literature on time perception will be discussed in section 5. General Discussion.

4. Impact of Experimental Control and Control in Daily Life on Time Perception

To investigate whether self-reported measures of control in daily life modulated the effects of experimentally induced control on time perception of emotional events, we first used a model selection-based approach to evaluate what combination of factors best accounts for the variability observed in the data. This approach has been shown to be a stronger method to select variables than null hypothesis significance testing (e.g., Mazerolle, 2006) and it will allow us to identify whether incorporating individual difference measures of control in daily life improves our understanding of the basic effect (the three-way interaction between Control, Arousal, and Valence) reported in Buetti and Lleras (2012). Compared to Buetti and Lleras (2012), the present study includes a substantially larger sample size in order to perform this analysis.

Given the roles arousal and valence play on time perception of emotional events (Lake, 2016; Lake et al., 2016) and recent findings showing that experimental control can also influence time perception (Buetti & Lleras, 2012; Mereu & Lleras, 2013), we explored models that included combinations of these factors (Arousal, Valence, Control), in addition to factors associated to control in daily life. We compared a total of sixteen models (Table 3) that included various combinations of the following key variables: experimental control (high and low) over emotional images in the Time Bisection task, arousal level of the images (high and low), valence of the images (positive and negative), and control scores obtained via self-reported measures of control in daily life. To our knowledge, this is the first study on this topic using this model selection approach. Thus, it was difficult to predict a priori which of the competing models would be the most parsimonious and whether it would include any of the manipulated variables (experimental control, arousal, valence), any of the self-reported measures of control, or how many total variables the most parsimonious model would contain.

4.1. Analyses

Missing items at the Desire for Control and Locus of Control questionnaires were interpolated for the different questionnaires or subscales of questionnaires. Raw scores from questionnaires were transformed into *Z*-scores.

Table 3.
Maximum-likelihood-based comparison of multiple models tested. Fixed and random-effect factors in the equation, degrees of freedom (df), Akaike's information criterion (AIC), Akaike weight (W_{AIC}) and normalized probabilities (Np) are reported in the table. Models are sorted by AIC. The most parsimonious model among the set of models considered is highlighted in bold. DC = Desire for Control; LC_I = Locus of Control Internality; LC_C = Locus of Control Chance; LC_P = Locus of Control Powerful Other; Ss = participants. Control refers to the experimental manipulation of control (high- vs low-control conditions).

#	Model equation (random effect in parenthesis)	df	AIC	w_{iAIC}	Np (%)
12	**Control × Arousal × Valence × DC × LC_I+(1|Ssnb)**	**34**	**9986.3**	**0.8747**	
8	Control × Arousal × Valence × DC+(1|Ssnb)	18	9990.2	0.1244	88
11	Control × Arousal × Valence × LC_I+(1|Ssnb)	18	10001	0.0005	100
7	Control × Arousal × Valence+(1|Ssnb)	10	10004	0.0001	100
15	Control × Arousal × Valence × DC × LC_I × LC_P+(1|Ssnb)	66	10004	0.0001	100
13	Control × Arousal × Valence × DC × LC_P+(1|Ssnb)	34	10005	0.0001	100
14	Control × Arousal × Valence × DC × LC_C+(1|Ssnb)	34	10007	0.0000	100
9	Control × Arousal × Valence × LC_C+(1|Ssnb)	18	10011	0.0000	100
10	Control × Arousal × Valence × LC_P+(1|	18	10013	0.0000	100
6	Arousal × Valence + (1|Ssnb)	6	10021	0.0000	100
4	Control × Arousal + (1|Ssnb)	6	10027	0.0000	100
2	Arousal + (1|Ssnb)	4	10036	0.0000	100
5	Control × Valence+(1|Ssnb)	6	10046	0.0000	100
3	Valence + (1|Ssnb)	4	10047	0.0000	100
1	Control + (1|Ssnb)	4	10050	0.0000	100
16	Control × Arousal × Valence × DC × LC_I × LC_P × LC_C + (1|Ssnb)	130	10058	0.0000	100

We used a maximum-likelihood-based model selection approach to find the most relevant variables that predict performance in the time perception task. Table 3 shows the 16 models that were compared. Maximum-likelihood-based model selection was performed to retain the models that minimized Akaike's information criterion (AIC). To compare the relative support for each model, Akaike weights were computed from the raw AIC value ($W_{i(\mathrm{AIC})}$; Burnham & Anderson, 2002; Wagenmakers & Farrell, 2004). Akaike weights were then used to compute normalized probabilities, which were computed as follows: $W_{1(\mathrm{AIC})}/(W_{1(\mathrm{AIC})} + W_{n(\mathrm{AIC})})$, where $W_{1(\mathrm{AIC})}$ is the Akaike weight for the most parsimonious model and $W_{n(\mathrm{AIC})}$ the Akaike weight for any other model. Akaike weights and normalized probabilities provide a measure of evidence in favor of a given model being the best fit to the data, given the population of models being considered. Finally, we also estimated marginal and conditional R^2. R^2 quantifies the proportion of variance explained by a model. Marginal R^2 estimates the variance accounted for by the fixed effects only, while conditional R^2 estimates the variance accounted for by both the fixed effects and the random effects. Analyses were conducted in R (version 3.5.2).

4.2. Results

4.2.1. Post-Experimental Questions and Questionnaires

As a manipulation check, we confirmed that in the high-control condition participants felt more in control over the experimental events than in the low-control condition (50% vs 33%), as reported in the post-experimental questions, $t(95) = -4.76$, $p < 0.0001$, Cohen's dz = 0.49 (mean difference = −17.02, 95% confidence interval [−24.11; −9.93]). In addition, participants reported more positive images in the high-control condition than in the low-control condition (71% vs 68%), $t(95) = -2$, $p = 0.048$, Cohen's dz = 0.20 (mean difference = −2.92, 95% confidence interval [−5.81; −0.03]). Mean scores from the Desire for Control and Locus of Control questionnaires and mean scores at the post-experimental questions are reported in Table 4. Figure 2 shows the sample's histograms at the Desire for Control and Locus of Control scales.

4.2.2. Model Selection

Maximum-likelihood-based selection among all tested models indicated strong support for Model 12, Control × Arousal × Valence × Desire for Control × Locus of Control Internality (Table 3). The Akaike weight for Model 12 indicates a 0.87 probability that this is the most parsimonious model among the population of models being considered. The marginal R^2 for Model 12 was 0.217 and the conditional R^2 was 1. The second, third, and fourth most likely models were, respectively: Model 8 (Control × Arousal × Valence × Desire for control; Akaike weight: 12%), Model 11 (Control × Arousal × Valence × Locus of Control Internality; Akaike weight: 0.5%), and Model 7 (Control × Arousal × Valence; Akaike

Table 4.
Mean scores (standard errors in parenthesis) from the questionnaires and post-experimental questions.

(A) Questionnaires regarding control in daily life:

Desire for control	*Locus of control Internality*	*Locus of control Powerful Other*	*Locus of control Chance*
94.03 (1.29)	29.0 (0.6)	16.4 (0.8)	17.0 (0.7)

(B) Post-experimental question:

Low-control condition *Participant felt in control*	*% Positive images*	*Computer was in control*
32.9% (2.8)	68.0% (1.5)	57.3% (2.6)

High-control condition *Participant felt in control*	*% Positive images*
50.5% (2.8)	70.6% (1.3)

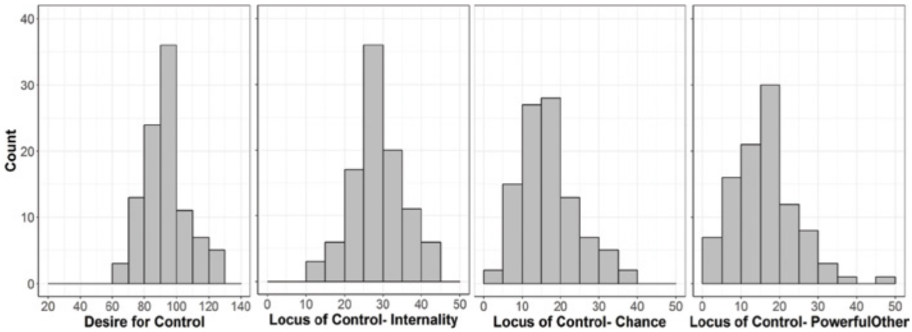

Figure 2. Histograms illustrating participants' scores at the different questionnaires. The Desirability for Control score ranges from 20 to 140. Each subscale at the Locus of Control ranges from 0 to 48.

weight: 0.1%). We computed a 95% confidence set for the best models by ranking the models and summing the Akaike weights until a sum of 0.95 was reached. Models 12 and 8 by themselves added up to 99.9%. Normalized probabilities indicate that Model 12 is 88% more likely than Model 8. Finally, chi-square tests confirmed that Model 12 is a better model than Model 8, $\chi^2(16) = 35.86$, $p = 0.003$, and that both Models 8 and 11 are better than Model 7, $\chi^2(8) = 29.68$, $p = 0.0002$ and $\chi^2(8) = 18.50$, $p = 0.018$.

4.3. Discussion

Analyses on PSEs indicated that, considering all the models evaluated, the most parsimonious model (Model 12) included the interaction between experimental control, arousal, valence, desire for control, and locus of control internality. The second-best model (Model 8), included the interaction between experimental control, arousal, valence, and desire for control. Given the observed Akaike weights of these models (87.5% and 12.4%, respectively), we feel confident that these two models (both of which include factors relating to individual differences in questionnaire-derived measures of control) are much more likely than the other models in explaining the variability in the data, including all the models that did not incorporate any individual differences (models 1–7) . Indeed, the combined likelihood of all other considered models was less than 0.9%.

The finding that the most parsimonious model includes both experimental control, desire for control, and locus of control internality suggests that these different conceptualizations of control might all modulate time perception of emotional events. Below we will provide a follow-up analysis describing the effects in the winning model.

4.3.1. Description of the Most Parsimonious Model

Below, we will only report the statistical effects on the PSE that contain an interaction between experimental factors (control, arousal, valence) and self-reported measures of control in daily life (i.e., Desire of Control scores, Locus of Control Internality). We were not interested in the main effects of self-reported control scores (DC, LC_Internality, LC_chance, or LC_powerfulother) or the interactions between these control scores on time perception itself, but all statistical terms are reported in Table 5.

We also applied an error control procedure. Given the large number of factors and potential interactions, it was important to implement an error control procedure to minimize the false discovery rate. To improve error control, we used a Bonferroni approach to correct the significance p-value threshold by dividing the alpha level ($p = 0.05$) by the number of effects considered. For the analyses on PSE, 21 effects were considered, thus the corrected p-value significance threshold was $p = 0.00234$. After adjusting the p-value significance thresholds, only three of the 21 statistical terms considered were significant: the triple interaction between valence, desire for control, and locus of control internality, the triple interaction between control, desire for control, and locus of control internality, and the four-way interaction between control, valence, desire for control, and locus of control internality.

First, the interaction between experimental control, desire for control, and locus of control internality was significant. As can be seen in Fig. 3C, this three-way interaction is best summarized by the observation that a heightened feeling of control has the effect of speeding up the passage of time in individuals with a high desire for control and a high internalization of that sense of control, compared to individuals who score low in one or both of these scales. To support this conclusion, we tested the slopes of the two functions against zero (High_LCI slope

Table 5.
Summary of Model 12. (A) Statistical terms of interest, containing an interaction between experimental factors (control, arousal, valence) and self-reported measures of control in daily life (i.e., desire of control scores, locus of control internality). (B) Other effects (not discussed here).

A. Interactions of interest

PSE	Estimate	SE	*t*-value	*p*-value
Valence × DC × LC_I	**−46.2691**	**9.5347**	**−4.853**	**<0.0001**
Control × DC × LC_I	**−40.9193**	**10.6866**	**−3.829**	**0.001**
Control × Valence × DC × LC_I	**42.4545**	**12.8674**	**3.299**	**0.001**
Valence × DC	−32.4354	10.8269	−2.996	0.003
Control × Arousal × Valence × DC	43.8938	19.1813	2.288	0.022
Control × DC	−25.2987	11.1047	−2.278	0.023
Control × Valence × LC_I	23.1266	13.8578	1.669	0.095
Control × LC_I	−14.1566	10.6598	−1.328	0.184
Control × Valence × DC	20.1832	15.2517	1.323	0.186
Control × Arousal × DC	−15.9586	14.5064	−1.1	0.271
Valence × LC_I	−10.4876	10.4515	−1.003	0.316
Arousal × DC × LC_I	−9.7263	10.159	−0.957	0.338
Arousal × Valence × DC	−12.4208	13.5766	−0.915	0.360
Arousal × LC_I	−9.3916	10.344	−0.908	0.364
Control × Arousal × Valence × LC_I	−15.0998	17.4931	−0.863	0.388
Arousal × Valence × DC × LC_I	8.4619	12.4483	0.68	0.497
Arousal × Valence × LC_I	7.555	13.1643	0.574	0.566
Control × Arousal × Valence × DC × LC_I	5.6824	16.5855	0.343	0.732
Control × Arousal × LC_I	2.0346	13.5115	0.151	0.880
Control × Arousal × DC × LC_I	−0.6403	13.597	−0.047	0.962
Arousal × DC	−0.1538	10.545	−0.015	0.988

B. Other effects

(Intercept)	893.3688	16.7419	53.361	<0.0001
Control × Arousal	91.5841	13.1475	6.966	<0.0001
Control × Arousal × Valence	−96.5613	17.3863	−5.554	<0.0001
DC × LC_I	29.1151	18.0171	1.616	0.106
Arousal	15.6275	9.8318	1.589	0.112
Valence	13.2308	10.9067	1.213	0.225
DC	12.9436	16.6816	0.776	0.438
Control × Valence	9.5069	14.225	0.668	0.504
Arousal × Valence	−7.7977	14.2828	−0.546	0.585
LC_I	−6.7495	18.7092	−0.361	0.718
Control	−2.3096	10.5852	−0.218	0.827

and Low_LCI slope in Fig. 3C). Only the High_LCI slope was significantly different from zero ($t = 2.97$, $p = 0.003$) but not the Low_LCI slope ($t = -1.07$, $p = 0.285$). Beyond the specific patterns observed linking time perception to individual differences (panels A and B), the results indicated that there is an interplay between

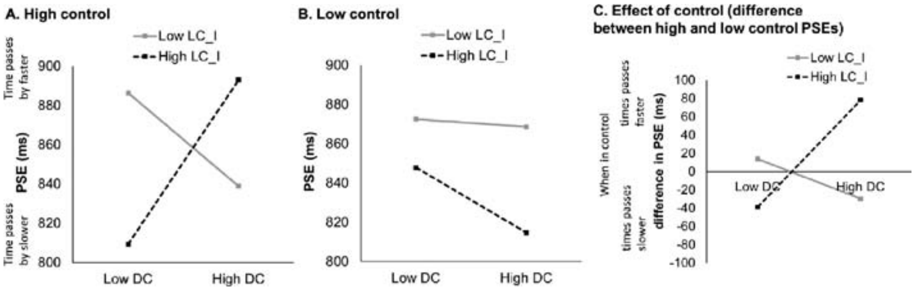

Figure 3. Interaction plots illustrating the interaction between control, desire for control (DC), and internality (LC_I) on Points of Subjective Equality (PSEs), shown separately for the high-control (A) and low-control conditions (B). The effects of LC_I and DC on PSEs are illustrated by estimating the model at one standard deviation above (High LC_I, dashed line; High DC) and at one standard deviation below (Low LC_I, solid line; Low DC) the population means. Higher values on the *y*-axis indicate that time is perceived as lasting shorter amounts of time while lower values indicates that time is perceived as lasting longer amounts of time. (C) The 'effect of experimental control', computed as the difference in PSE when subtracting the PSEs of the low-control condition from the PSEs of the high-control condition. A positive value indicated that control causes participants to perceive time as ticking faster.

the degree of perceived control induced by the experiment and individual differences in desire for control and locus of control in daily life, such that the effects of experimental control on time perception are greatest in individuals who score high on both scales. In other words, the effect of experimental control was greatest in those participants who had a high desire for control in their daily life (high DC) and also *experienced* a high level of control in their every-day life (high LCI).

Second, the results indicated an interaction between valence, desire for control, and locus of control internality. As illustrated in Fig. 4C, this interaction can be best described by the fact that individuals who score low on locus of control internality judge positive and negative images as lasting similar amounts of time irrespective of the level of desire for control (Low LC_I slope test against zero: $t = 0.65$; $p = 0.514$, see Fig. 4C). In contrast, individuals who score high on locus of control internality respond differently to positive and negative images as a function of desire for control (High LC_I slope test against zero: $t = -3.77$; $p = .0002$). Specifically, individuals who score high at both scales tend to perceive positive images as lasting longer than negative ones (Fig. 4C).

Finally, the two three-way interactions were qualified by a four-way interaction between control, valence, desire for control, and locus of control internality. The interaction is visualized in Fig. 5A. Given the complexity of interpreting a four-way interaction, we did not conduct additional analyses. That said, panels B and C illustrate the fact that the three-way interactions discussed above were driven by one cell in panel A: the high control, negative images condition. In other words,

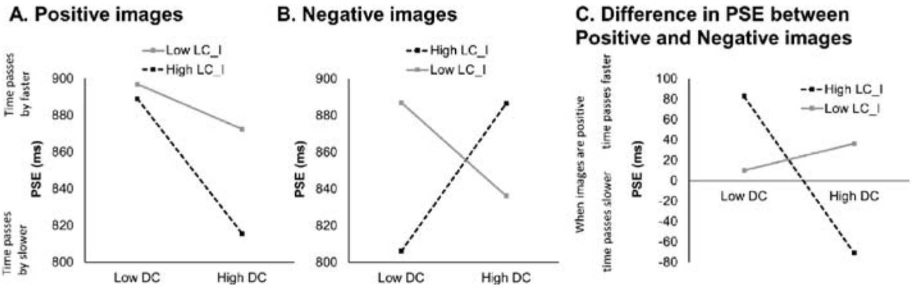

Figure 4. Interaction plots illustrating the interaction between valence, desire for control (DC), and internality (LC_I) on Points of Subjective Equality (PSEs), shown separately for the positive images (A) and negative images (B). The effects of LC_I and DC on PSEs are illustrated by estimating the model at one standard deviation above (High LC_I, dashed line; High DC) and at one standard deviation below (Low LC_I, solid line; Low DC) the population means. Higher values on the *y*-axis indicate that time is perceived as lasting shorter amounts of time while lower values indicate that time is perceived as lasting longer amounts of time. (C) The difference in PSE when subtracting the PSEs for negative images from the PSEs for positive images. A positive value means that positive images were perceived as passing by faster than negative images; a negative value means that positive images were perceived as lasting longer than negative images.

the pattern observed in the three-way interaction between control, desire for control, and locus of control internality (Fig. 3) was most evident in negative images (Fig. 5B, bottom). Similarly, the three-way interaction between valence, desire for control, and locus of control internality (Fig. 4) was most evident in the high control condition (Fig. 5C, right).

5. General Discussion

Previous research found that the time distortions that are typically observed in a time bisection task when observers experience low control over the experimental events are eliminated when (illusory) experimental control was given to the participants (Buetti & Lleras, 2012). In that study, perceived control was manipulated between subjects. Here, the same result was confirmed within subjects when experimental control was manipulated across different sessions. When participants experienced low levels of control over the experimental events, image characteristics influenced temporal judgements. Specifically, there was a significant crossover interaction between arousal and valence. The level of arousal determined the direction of the temporal distortion: when arousal was high, negative images were perceived to last longer than positive ones, whereas when arousal was low, the opposite was true. These emotion-driven distortions were eliminated when participants were given control over the exact same events. Below, we will first present the implications of these findings with regard to the literature on time perception.

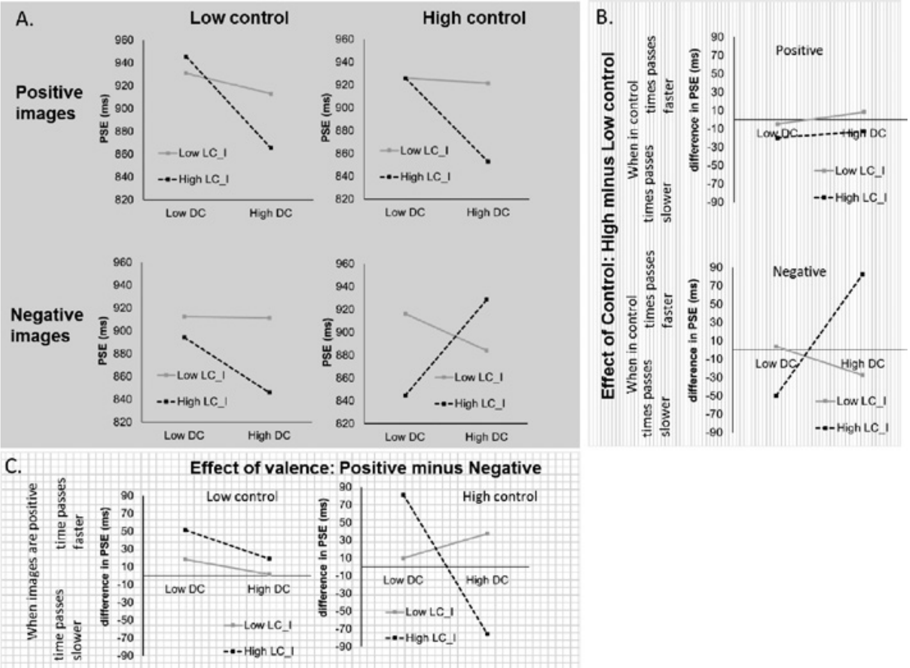

Figure 5. Interaction plots illustrating the interaction between control, valence, desire for control (DC), and internality (LC_I) on Points of Subjective Equality (PSEs). The effects of LC_I and DC on PSEs are illustrated by estimating the model at one standard deviation above (High LC_I, dashed line; High DC) and at one standard deviation below (Low LC_I, solid line; Low DC) the population means. (A) The PSEs as a function of experimental control (low control vs high control) and Image valence (positive vs negative) as a function of DC and LC_I. (B) The effect of experimental control obtained by subtracting the PSEs in the low-control condition from the PSEs in the high-control condition, separately for positive and negative images. Higher values on the *y*-axis indicate that time is perceived as lasting shorter amounts of time while lower values indicates that time is perceived as lasting longer amounts of time. A positive value indicates that control causes participants to perceive time as ticking faster. (C) The effect of Image valence obtained by subtracting the PSEs in the negative condition from the PSEs in the positive condition, separately for low control and high control. A positive value on the *y*-axis means that positive images were perceived as passing by faster than negative images; a negative value means that positive images were perceived as lasting longer than negative images.

We will then discuss the combined effects of self-reported measures of control and experimental manipulations control on time perception.

5.1. Effects of Experimentally Induced Control on Time Perception

With regard to the current results, under conditions of low-experimental control, the results indicated that the duration of high-arousing stimuli was overestimated compared to the duration of low-arousing stimuli. This is consistent with the idea that there is an acceleration of the ticking rate of the pacemaker with increased arousal. The crossover interaction between arousal and valence on time perception observed in the low-experimental control conditions is also consistent with previous findings and theories in the literature (e.g., Angrilli et al., 1997; Buetti & Lleras, 2012; Droit-Volet et al., 2004; Droit-Volet & Gil, 2009; Droit-Volet, Ramos, Bueno & Bigand, 2013; Gil et al., 2007; Mereu & Lleras, 2013; Noulhiane, Mella, Samson, Ragot & Pouthas, 2007; Smith et al., 2011). This interaction can be accounted for by differences in attentional orienting and avoidance to the different categories of images. High-arousing images in general produced more ticks, but when images were negative, observers spent more time attending to tracking the passage of time, compared to positive images where observers spent more time attending to the images themselves. Devoting cognitive resources to counting time may have allowed individuals to avoid (and disengage from) the unpleasant material. Overall, these differences in how participants attend to events lead to the temporal overestimation of negative images compared to positive images. In contrast, for low-arousing images, observers were more focused on attending to the passage of time when viewing positive than negative images. This suggests a relative increase in difficulty disengaging from negative images, perhaps due to greater interest value, which delays the start of tracking the time (Lake et al., 2016). As a result, positive images seem to last longer than negative ones.

In contrast, when the same participants experienced the same experimental events under conditions of *high-perceived control*, all the temporal distortions were eliminated. First, arousal no longer had an effect on time perception, which indicates that perceived control *equated the pacemaker's ticking rate across all conditions*. Second, the valence by arousal interaction was no longer present. PSEs for the different emotional categories converged toward the PSEs observed for positive images. This indicates that control *equated people's ability to focus on the counting task across image categories*. Thus, an experimentally induced feeling of control appears to have a direct influence on both the physiological (arousal) and cognitive (controlled attention) mechanisms underlying time judgements.

Finally, experimental control also influenced other parameters of the psychometric function (dl and Weber ratio). Specifically, a high level of perceived control decreased the temporal sensitivity in participants. In the high-control condition, participants had to balance cognitive demands across two tasks: the temporal judgement task and the appraisal of success or failure in terms of their control over the images. As a result, one would expect the sharing of cognitive resources across the two tasks to be accompanied by a reduction in sensitivity to either of those tasks, compared to when they perform those tasks in isolation (Ettwig & Bronkhorst, 2015; Pashler, 1994). Thus, it is possible that the dual task aspect of the high-control condition may have reduced the temporal sensitivity in this condition. And thus, it is possible to argue that perhaps the reason why the high-control condition is effective at decreasing the impact of the emotionality of the images on time perception is simply because it distracts participants away from the timing task. That said, we think this is unlikely given the patterns in the data we observed. Indeed, if the dual-task nature of the high-control condition completely distracted participants away from the time perception task, and equated all arousal and valence conditions, one would expect that participants would be much worse at the temporal judgment task in the high control condition. That is not what we found. Although there was a difference in overall PSEs across the high (888 ms) and low (893 ms) control conditions, the effect was rather small in magnitude (a difference of 5 ms). We doubt this difference is indicative of a dual-task cost that would be sufficiently large to completely disrupt the temporal judgment task and eliminate the substantially large emotion-driven effects on PSEs. Indeed, the magnitudes of the emotion-driven effects in the low-control condition were an order of magnitude larger: the effect of arousal had a 50 ms difference in PSEs; the effect of valence had a 26 ms difference in PSEs, and the arousal by valence interaction also produced larger differences in PSEs: a 76 ms difference between low arousing positive and negative images and a 23 ms difference between high arousing positive and negative images. Rather, we believe the heightened levels of perceive control provide participants with a buffering effect: it helps placate or downregulate the typical response to emotional events in emotion-processing areas of the brain (see Buetti & Lleras, 2012 and Leotti et al., 2010 for a review).

5.2. Effects of Experimentally Induced Control and Control in Daily Life on Time Perception

The statistical analyses on PSEs for the likeliest model (Model 12) indicated that the degree to which experimental control has an effect on time perception depended on individual differences in desire for control and locus of control internality. Individuals who scored high on both scales benefited the most from the control manipulation in the sense that they reported time as going by relatively faster under high levels of experimental control. The control manipulation had a lesser impact on the other participants' perception of time.

We can envision two possible alternatives to account for the effect of experimental control observed in participants scoring high on both scales. Previous research suggests that individuals who report a more enjoyable experience in a task are the ones who also report time as going by faster (Sackett et al., 2010). Perhaps the fact of being in control over the emotional events decreased the ticking rate of the pacemaker, as if physiological arousal had been lowered for these individuals. Thus, it is possible that participants who desire control and are used to feeling in control in their daily life (i.e., those who score high on both questionnaires) find the experiment more enjoyable when they feel they have some measure of control over the events in the experiment. Because feeling control is important to them, this feeling might have the effect of lowering physiological arousal. Another possibility is that under conditions of high control, participants were less sensitive to factors that would have impacted their orienting response (e.g., disengagement from negative images), allowing them to attend to the images more so than under conditions of low control. Unfortunately, behavioral data alone cannot discriminate between these separate accounts because we are lacking a direct measure of physiological arousal.

In addition, the results indicated that the effects of valence on time perception also depended on individual differences in both locus of control internality and desire for control. Individuals who scored low in locus of control internality irrespective of desire for control judged positive and negative events as lasting similar amounts of time. On the other hand, time judgements for individuals who scored high in locus of control internality were a function of the level of desire for control, such that positive images were perceived as lasting longer than negative ones for participants who also score high on their desire for control. According to models of time perception, this finding might indicate that individuals who scored high on both scales found it easier to track the passage of time when judging positive images. When judging negative images, these individuals seemed to spend longer times inspecting the negative images themselves, therefore delaying the tracking of the passage of time. This explanation suggests that the attentional orienting component of the model proposed by Lake et al. (2016) is impacted by individual differences among the aspects of control measured here. Alternatively, the fact that positive images were perceived as lasting longer than negative ones is also reminiscent of the pattern observed for low arousing events under low-control conditions. This might indicate that individuals who scored high on both scales presented a decreased level of physiological arousal, which would also be consistent with the findings in Fig. 2C. In sum, both interpretations suggest that a high desire for control when paired with a high locus of control internality may foster conditions that improve overall well-being via an enhanced experience of positive events, highlighting the importance of control on emotional well-being (e.g., Amoura et al., 2014; Burger, 2017; Thompson, 2002).

Finally, it is worth noting that the two three-way interactions were modulated by a four-way interaction, as illustrated in Fig. 5. Fortunately, the interpretation of the four-way interaction is made easy by the observation that this interaction is driven by one cell in Fig. 5A: the High Control/Negative Images cell. Inspection of the remaining three cells shows that the patterns are relatively similar across them. However, the High Control/Negative Images cell shows a strong cross-over interaction that ultimately determines the direction of the two, simpler, three-way interactions. We can now more precisely argue that the impact of control on time perception arises from how participants who want control and experience it in daily life react to negative images, when they are feeling in control in the experiment: the combination of wanting control and feeling it in the task results in their perception of negative events as lasting shorter amounts of time. This finding suggests that this optimal state of wanting control and feeling in control alleviates the negative experience of seeing negative images. Similarly, looking at the effect of valence on time perception, these same participants are the ones who experience positive images as lasting longer than negative images. This is also consistent with the idea that desiring control and feeling in control in daily life is associated with the positive outcome of perceiving positive events as lasting longer.

Experiencing a heightened level of control in daily life has been shown to be associated with positive psychological outcomes (e.g., reduced depression and anxiety, and improved adaptive functioning and stress coping, e.g., Amoura et al., 2014; Burger & Arkin, 1980; DeNeve & Copper, 1998; Moulding & Kyrios, 2007; Thompson, 2002). The present study suggests that in the context of a time judgment task, there is a relationship between self-reported measures of control in daily life and experimentally-induced control. Specifically, self-reported measures of control in daily life interact with experimental control in a manner that seems to favor a positive psychological outcome and that renders the emotional task more enjoyable.

Finally, one might ask the question: why is time perception so deeply impacted by both emotions and perceived control? Why does perceived control have such an impact on time perception tasks? As proposed by Leotti et al. (2010) and Leotti and Delgado (2011), the opportunity to exert control over events that have a direct impact on participants (such as stressful events or the emotional images used in this study) provides a downregulating effect that reduces the stress response and the magnitude of the emotion-related responses in the brain (see also Buetti & Lleras, 2012). Thus, one answer might be that perceived control has a strong impact on the perceived duration of emotional images because control downregulates the emotional response to the events, and therefore minimizes the impact of the emotionality of the images on the time perception task. A look at the underlying structures responsible for the perceptions of time and control also supports the idea that these two forms of perception are tightly interlinked and might therefore interact with one another. Probably the most famous neurally-plausible model of time perception is the Striatal Beat Frequency model (Allman & Meck, 2012; Dallal et al., 2015; Meck, 1996, 2006a, b, c). It proposes that time perception arises through connections between three brain areas: the (dorsal) striatum, the cortex and the thalamus. There are oscillating neurons in the striatum that become synchronized upon the release of dopamine in this region. Ensembles of these neurons oscillate at varying intrinsic frequencies and they fall out of sync at different times after the dopamine release. These oscillating neurons converge on individual medium spiny neurons in the striatum that integrate these oscillatory patterns, which in turn form the basis for learning specific temporal intervals (different temporal intervals result in different ensembles of oscillatory patterns). The striatal output is sent to the thalamus, which projects back to the cortex. The key in this model is that at the center of temporal perception is, then, activity in the dorsal striatum and that activity in this area is also connected to activity in prefrontal cortex (Coull et al., 2010; Lewis, 2002; Lewis & Miall, 2006; Macar et al., 2002; Wiener et al., 2010). The striatum also happens to be the region of the brain that responds to things like rewards, emotions and more crucially, manipulations of control over events (Bjork & Hommer, 2007; Coricelli et al., 2005; Delgado et al., 2004; Leotti & Delgado, 2011; O'Doherty et al., 2004; Tricomi et al., 2004). Thus, the tight interconnection between prefrontal cortex and striatum seems to be critical for both the perception of control and the perception of time. Furthermore, the prefrontal cortex is known to play an important role in the top-down regulation of emotional responses (Delgado et al., 2008; Kober et al., 2008; Ochsner & Gross, 2005). And the prefrontal cortex mediates the relationship between the controllability of a stressor (here, this would be controllability over the emotional images) and stress responses, with lowered stress responses under more controllable conditions (Amat et al., 2005, 2006; Maier et al., 2006). Thus, it may very well be that the same cortico-striatal network is responsible for both perception of time and perception of control, which would explain the strong interactions between these two forms of perception observed in this study. Future neuroimaging studies could test this hypothesis.

5.3. Limitations

A potential limitation of the current study is that the population was not chosen randomly (see Appendix 1 for full details). We wanted to ensure that the sample would include a certain amount of participants who scored high in depression and mania questionnaires. That said, we also included a number of participants who scored low on both questionnaires, which resulted in an overall well-balanced sample. Most relevant to the current paper, the sample's score on the Desire for Control and Locus of Control scales compares favorably to published norms. For example, the Desire for Control scale usually has a mean of about 100 with a standard deviation of 10 in college students (Burger & Cooper, 1979). Our sample had a mean of 94 with a standard deviation of 13. For the Locus of Control scale, the means along the three scales reported in a large sample validation study ($n = 3668$, Kourmousi et al., 2015) were 27.9 (SD = 4.88), 14.5 (SD = 6.8) and 13.4 (SD = 6.8) for the Internality, Powerful Other and Chance subscales, respectively. In comparison, the scores in the current sample where 29 (SD = 6.3), 16.4 (SD = 8.4) and 17 (SD = 7.3), with the most critical factor being the internality score (29), which closely matched the large sample's mean (28). Future work could validate the current conclusions with a truly random sample of the population. It is important to remember, however, that most samples in psychology studies only recruit undergraduate students, which may not be the most representative sample of the population at large (Henrich et al., 2010). In fact, Kourmousi et al. (2015) recruited Greek educators (not undergraduate students) in their reliability study. The relatively small difference in mean LC_Internality scores across the two studies in spite of the difference in populations sampled gives us some reassurance that the recruitment procedure produced a representative sample of participants in the LC scale.

6. Conclusions

The present study used a within-subject design to manipulate perceived control over emotional events. The results replicated the finding that the temporal distortions by emotional events observed under low perceived control were eliminated under high perceived control.

When individual differences with regard to control in daily life were considered, the model-selection-based approach suggested that the data were best accounted for by a model that included these individual difference measures. The statistical effects of the most parsimonious model indicated that individual differences in Desire for control and Locus of control modulate the impact of emotion on time perception. Overall, individuals with a high desire for control and a high degree of internality seemed to have an enhanced experience of positive events. These same individuals also benefited more from the experimental control manipulation, speeding the passage of time and perhaps making the task more enjoyable, particularly when faced with negative events.

Author Contributions

SB developed the theoretical framework and designed the experiment. WH contributed to the theoretical framework. JH and GJPN took care of recruitment. FX conducted the GLMM analyses and QL double-checked the statistics and conducted the Bayesian analysis. SB wrote the paper. WH, JH, and FX, edited the paper. This work was supported by a NARSAD Young Investigator Grant from the Brain & Behavior Research Foundation awarded to SB (award number 22539).

Note

1. The Spearman–Kärber (SK) method was applied to extract different measures from the Time Bisection task data (Miller & Ulrich, 2001). As noted above our dependent variables were not normally distributed. Thus, we preferred to use this method as it makes no assumptions about the underlying distribution. We compared PSEs obtained from logistic regressions (as previously done in Buetti & Lleras, 2012) to PSEs obtained from the SK method on a small number of participants. Correlations were computed separately for each experimental control condition (high and low control) and for each arousal level (high and low). We subtracted PSEs of negatively

valenced images from PSEs of positively valenced images. The results indicated that PSEs obtained via logistic regression and PSEs obtained via the SK method are highly correlated (high-control condition: high arousing, $r(43) = 0.965$, $p < 0.001$; low arousing, $r(43) = 0.952$, $p < 0.001$; low-control condition: high arousing, $r(39) = 0.956$, $p < 0.001$; low arousing, $r(39) = 0.957$, $p < 0.001$).

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Appendix 1: Participants' Characteristics and Recruitment

As already mentioned in Section 1. Introduction, participant selection in this research was not entirely random. This study was part of a larger project that looks at the effects of experimental control on time perception of emotional events in individuals who vary in their emotional profile with regard to depressive and hypomanic symptoms. Depression and hypomania are of our particular interest due to their likely impact on perceived sense of control. For example, depression is known to be closely related to *learned helplessness*, which is an actively acquired expectation that one's behavior or responses are independent of the outcome of significant life events, i.e., that one lacks control over the outcome (Alloy et al., 1984; Seligman, 1975). Learned helplessness is a key factor in risk and maintenance of depression. On the contrary, hypomania is associated with a cognitive distortion opposite to that of depression, that is, an overly optimistic expectation concerning future success (Beck, 1967). To that end, we sampled our undergraduate population to identify potential participants who would be representative of scores at different points on the mood spectrum. Figure A1 shows the distribution of scores of the participants on the different questionnaires, where it can be seen that the resulting sample included a range of scores and was not composed of at-risk individuals only. The results regarding the relationship between participants' emotional profiles and their susceptibility to experimental manipulations of control is the topic of a separate paper, currently under preparation.

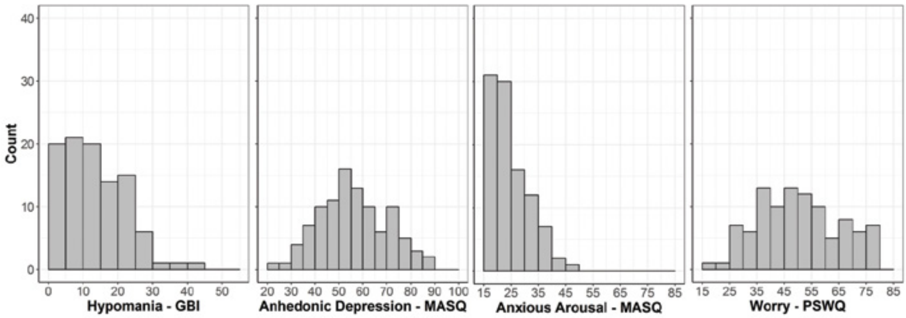

Figure A1. Histograms illustrating participants' scores on the different questionnaires. The hypomania score of the General Behavior Inventory (GBI) ranges from 0 to 57. The Anhedonic Depression score of the Mood and Anxiety Symptom Questionnaire (MASQ) ranges from 21 to 105 (note that item 38 "Thoughts about death or suicide" was not administered). The Anxious Arousal score of the MASQ ranges from 17 to 85. The score at the Pensilvania Worry Questionnaire ranges from 16 to 80.

Out of the 109 participants, because of experimenter errors, one participant did not complete the questionnaires in the first experimental session and one participant completed the high-control condition both in sessions 1 and 2 (performance at session 2 was not analyzed). Regarding missing data points, 13 participants only completed session 1, seven in the low-control condition and six in the high-control condition.

A.1. Recruitment Process

Participants were selected on the basis of their scores on several trait questionnaires. The recruitment process was a two-step process. First, a large number of undergraduates enrolled in psychology courses were prescreened by filling out the following questionnaires: Mood and Anxiety Symptom Questionnaire (MASQ. 39-items version although item 38 "Thoughts about death or suicide" was not administered; Dunn et al., 2009; Watson et al., 1995a, b) and the General Behavior Inventory (GBI, only the 19 hypomania items of the scale were administered; Depue et al., 1989). The Anhedonic depression scale of the MASQ was used to assess anhedonic depression. The hypomania scale of GBI was used to assess hypomanic symptoms. The hypomania subscale was scored in a Likert fashion, where the four-point rating scale was weighted 0, 1, 2, and 3, respectively, and all items were then summed. A score of 0 indicates no affective disturbance or dysregulation (Depue & Iacono, 1989; Depue et al., 1989). Second, participants were invited to continue to participate in the study if their scores on the MASQ and GBI met one of the following criteria: (i) a score in the 50th percentile or below on the MASQ and GBI (to recruit individuals who were not at risk for depression or hypomania); (ii) a score at the 80th percentile or above on the MASQ and at the 50th percentile or below on the GBI (to recruit individuals at risk for depression); (iii) a score at the 80th percentile or above on the GBI and at the 50th percentile or below on the MASQ (to recruit individuals at risk for hypomania). This method of thresholding for higher scores has been used repeatedly in previous research by co-author Heller and colleagues and has been shown to predict clinically-significant outcomes (e.g., Bredemeier et al., 2010; Nitschke et al., 2001).

Appendix 2: Complete List of Tasks and Questionnaires Used in the Procedure

In addition to the first two theoretical questions stated in Section 1. Introduction there were two separate theoretical questions that will be reported separately. These two questions focus on evaluating how participants' mood impact time perception in general and whether the manipulation of experimental control has similar beneficial effects as observed in 'normal' participants. To evaluate the effects of mood on time perception, we will conduct analyses that will include (i) the scores in Depression and Anxiety as predictors, along with the experimental variables (Experimental Control and image characteristics: Arousal and Valence) and (ii) the scores in Hypomania along with the experimental variables. Finally, all the tasks and measures used in this project are reported in the methods as well as below.

During sessions 1 and 2, after answering the post-experimental questions, participants completed the Positive and Negative Affect Schedule (PANAS) state scale (20-items version to evaluate positive and negative affect; Williams, 1988). Then, they watched a short video aimed at inducing a positive mood (one person dancing in difference cities in the world) and completed a five-minute task that evaluated the impact of perceived experimental control on monetary gain. In this task they were asked to press one of two keys and the keypress was followed by a message on the screen ("You won $0.25" or "You lost $0.25"). Finally, participants completed again the PANAS state questionnaire.

During session 1 only, in addition to the desire for control and locus of control scales, participants also completed other trait questionnaires to evaluate symptoms of depression and anxious arousal [Mood and Anxiety Symptom Questionnaire (MASQ), 38 items], anxious apprehension (16-items version of the Penn State Worry Questionnaire; Meyer et al., 1990), hypomania [19-items version of the General Behavior Inventory (GBI)]. Anxious arousal and anxious apprehension measure different dimensions of anxiety (Nitschke et al., 2001). Anxious arousal indicates the level of somatic anxiety (Clark & Watson, 1991; Watson et al., 1995a) while anxious apprehension is a measure of trait worry, which is a dominant feature of generalized anxiety disorders (Fresco et al., 2003).

During session 3, participants completed another version of the Time Bisection task (35 min), where 25% of the images were positive and 75% were negative. Only the data collected during Sessions 1 and 2 were reported and analyzed in the current study.

Appendix 3: Images used in the Experiment

The same images as in Buetti and Lleras (2012) were used in the present experiment.

High-arousing positive: 4656, 4607, 4651, 4668, 4647, 4649, 4652, 4670, 4631, 8080, 8033, 8186, 8179, 8180, 7405, 4664, 8490, 4608, 4611, 5629, 8370, 8185, 5621, 8492. Average arousal: 6.5; average valence: 6.9.

Low-arousing positive: 1600, 1441, 1450, 5210, 5030, 5040, 5725, 2057, 2304, 2302, 1602, 2040, 2306, 2060, 2388, 2153, 5764, 2358, 1620, 5831, 1333, 7325, 1419, 5001. Average arousal: 3.8; average valence: 7.0.
High-arousing negative: 3150, 3010, 3000, 3001, 3168, 3062, 3030, 3061. Average arousal: 6.3; average valence: 1.9.

Low-arousing negative: 2399, 2722, 9001, 2590, 2491, 7078, 9110, 2039. Average arousal: 3.8; average valence: 3.4.