

Brief communication

Dynamic calibration of our sense of time

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ABSTRACT

An accurate sense of time contributes to functions ranging from the perception and anticipation of sensory events to the production of coordinated movements. However, accumulating evidence demonstrates that time perception is subject to strong illusory distortion. In two experiments, we investigated whether the subjective speed of temporal perception is dependent on our visual environment. By presenting human observers with speed-altered movies of a crowded street scene, we modulated performance on subsequent production of “20 s” elapsed intervals. Our results indicate that one’s visual environment significantly contributes to calibrating our sense of time, independently of any modulation of arousal. This plasticity generates an assay for the integrity of our sense of time and its rehabilitation in clinical pathologies.

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1. Introduction

Cognitive functions ranging from language to decision-making rely on precise temporal processing (Gallistel, 1990; Tallal, Merzenich, Miller, & Jenkins, 1998). However, constitutive aspects of our sense of time, the perception of duration and succession between sensory events, are prone to striking distortions (Eagleman, 2008), suggestive of a degree of malleability dependent on both subjects’ state and objects’ features.

Stimulus features and the context in which they are presented have been shown to modulate their perceived duration. Droit-Volet and Wearden (2002) asked children to compare the duration of 200–1600 ms visual stimuli with the duration of either a constant or flickering (7 Hz) target stimulus. They showed that as compared with a constant referent stimulus, the durations of flickering target stimuli were overestimated. In line with these results, Ortega and Lopez (2008) further demonstrated that modifications of the learned correspondance between internal clock speed and actual duration also modulate perceived duration. If the flickering stimulus is presented during the learning phase, the duration of subsequently presented constant stimuli are underestimated. Consistently, Kanai, Paffen, Hogendoorn, and Verstraten (2006)

demonstrated that absolute duration judgment of visual or auditory stimuli, consisting in trains of tones or flash presented with a frequency of up to 8 Hz, increased as a function of the flickering frequency following an exponential function.

These results were interpreted in terms of pace-maker/accumulator models (Treisman, Faulkner, Naish, & Brogan, 1990). According to these models, an internal pace-maker emits pulses at regular intervals, and the number of accumulated pulses over a given time interval determines perceived duration. The above-mentioned flickering stimulus would have accelerated the pulse rate of the internal pace-maker by increasing participants’ arousal. Consequently, flickering stimuli are perceived as lasting longer than their actual duration because the pulse rate was high during their presentation. This hypothesis is consistent with studies showing that pharmacological intervention impacting arousal level also modulates perceived durations (Maricq, Roberts, & Church, 1981; Meck, 1983).

While illusory distortions of stimulus perceived durations have been extensively studied, there is no evidence for corresponding effects on the subjective speed of the passage of time, i.e. our perception of the flow of time independently of any stimulation. We addressed this issue by asking human observers to complete a duration production after exposure to speed-altered films. We tested whether the speed of the visual environment modulates the subjective speed of the passage of time and, consequently, whether speed-altered films impact subsequent performance in duration production. A second experiment was designed to determine the interaction between exposure to speed-altered movies and arousal modulation.

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2. Methods

2.1. Subjects

Eleven male subjects participated in Experiment 1 (mean age \pm SD: 29.72 ± 5.83 years) and five (mean age \pm SD: 29.8 ± 2.95 years) in Experiment 2. Three were left-handed in Experiment 1 and one in Experiment 2 (Oldfield, 1971). None of the subjects had a history of neurological or psychiatric illness, and they all reported normal hearing. They all provided written consent to participate in the experiments. All procedures were approved by the Ethics Committee of the Faculty of Biology and Medicine at the University of Lausanne and were conducted in accordance with the Declaration of Helsinki.

2.2. Experimental paradigm

Movies presented in Experiments 1 and 2 were sequences of a crowded street filmed with a Panasonic NV-GS75 Digital camera from a height of 1.75 m. Three different sequences were then extracted from the original movie, muted, and down-sampled to a resolution of 720×576 pixels. These sequences were presented on a 20" screen covering a visual angle of $\sim 40^\circ$. The two speed-altered conditions were obtained by slowing down and speeding up the control (normal speed) condition by 50% in either direction and then cropping the film to be two minutes in duration (using the Pinnacle Studio software). The frame rate was maintained constant across conditions (25 fps). This procedure resulted in a total of 9 sequences (3 speed conditions \times 3 sequences).

Experiment 1 investigated whether exposure to speeded or slowed natural visual scenes affects the subsequent rate of subjective passage of time. Following the exposure to the accelerated (150% of normal speed), normal (100%) or decelerated (50%) two minute-long muted movies, participants were asked to produce a "20 s" empty duration in a dark and silent environment and without counting nor generating motor rhythms.

In Experiment 2, Galvanic skin response (GSR) and heart beat rate (beats per minute, BPM) were recorded during the presentation of the speed-altered movies in order to assess whether exposure to speed-altered movies influences participants' level of arousal.

The task during Experiment 1 was divided into three blocks of nine trials ($3 \times 50\%$; $3 \times 100\%$; $3 \times 150\%$ conditions). Within each block, the 9 trials were randomly

presented so that the order of sequence presentation was counterbalanced within and across participants. Each trial consisted in the presentation of an accelerated (150% of normal speed), normal (100%) or decelerated (50%) movie.

In Experiment 1, at the end of the movies, subjects were presented with a black screen and asked to press a response button when they estimated that 20 s has passed from the end of the movie. After the subject's response, an inter-trial interval of 750 ms was introduced and the next trial started.

In Experiment 2, subjects were exposed to the speed altered films and ECG and GSR were recorded. The experiment entailed 1 block of 9 trials ($3 \times 50\%$; $3 \times 100\%$; $3 \times 150\%$ conditions). The 9 trials were randomly presented so that the order of sequence presentation was counterbalanced within and across participants. Each trial consisted in the presentation of an accelerated (150% of normal speed), normal (100%) or decelerated (50%) movie followed by a break of 60 s, then the next trial was presented. GSR sensors were placed on fingerprint region of the forefinger and middle finger of the left hand. ECG sensors were placed on the left radial artery on inner part of the left wrist. Mean skin conductance and mean beats per minute (BPM) were recorded using a Biosemi ActiveTwo amplifier. BPM and GSR were measured during the 2 min period of movie presentation and then averaged across subjects and conditions.

All procedures were conducted in a dark, acoustically attenuated booth. Participants sat in a comfortable chair in front of the computer monitor. Stimulus delivery and response recording were controlled by E-Prime 2.0 (Psychology Software Tools).

3. Results

Experiment 1 investigated whether exposure to speeded or slowed natural visual scenes affects the subsequent rate of subjective passage of time. Short exposure to speed-altered natural visual scenes modulated the subsequent rate of subjective passage of time (Fig. 1d and e shows gains in produced duration normalized according to the 100% normal speed condition). The mean produced durations in the decelerated (50%), normal (100%) and accelerated (150%) movie condition were 29.14 ± 4.5 s (mean \pm SEM), 27.24 ± 4.2 s and 25.84 ± 3.8 s, respectively (Fig. 1b and c). A

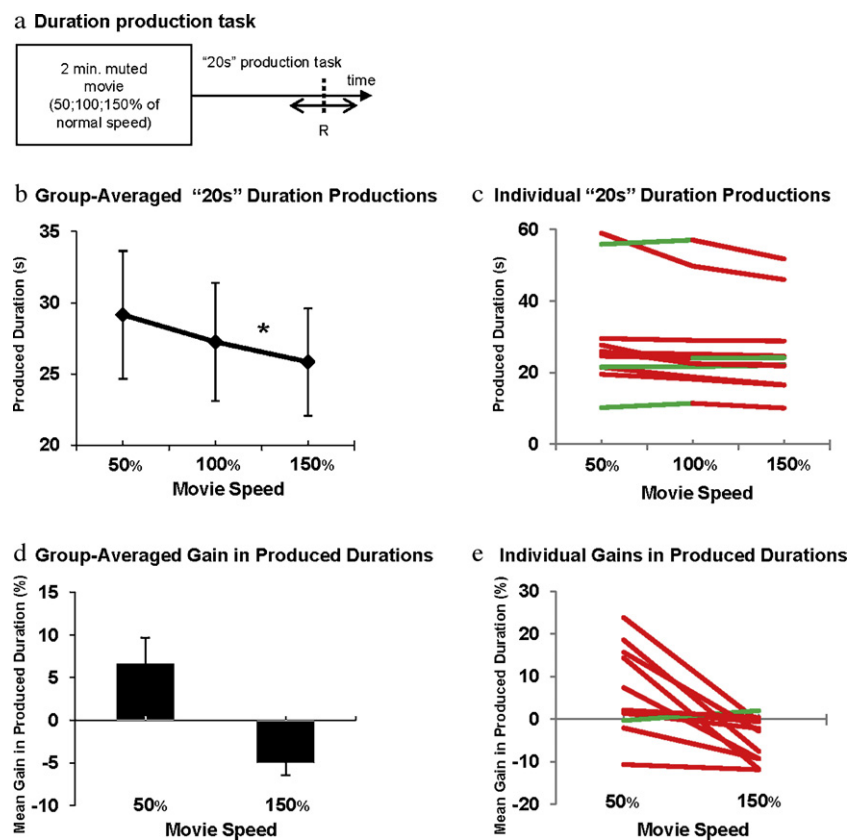


Fig. 1. (a) Experimental design. (b) Group-averaged and (c) individual 20 s duration productions as a function of the preceding movie's speed. (d) Group-averaged and (e) individual gains in produced durations as compared to the control 100% condition. Mean gains in duration production reveal an increase and a decrease of produced durations following the exposure to slowed and speeded movies, respectively. Positive slopes are represented in green and negative slopes in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

repeated measures ANOVA with film speed as the within subject factor revealed that exposure to speed-modulated movies significantly influenced produced durations ($F(2,20)=6.53$; $p=0.018$; $\eta p^2=0.395$). This effect was driven by significantly shortened duration estimates following the viewing of accelerated films (100% vs. 150%: $t(10)=2.609$; $p=0.03$; 50% vs. 150%: $t(10)=3.254$; $p=0.02$; two-tailed paired t -tests). There was a non-significant trend for duration estimates to be slowed by viewing decelerated films (50% vs. 100%: $t(10)=2.01$; $p=0.07$). In order to emphasize the modulations in duration production induced by speed-altered movies, we computed an index of performance gain relative to the 100% control condition using the following formula: produced duration in the 50% or 150% condition divided by the performance in the 100% condition, minus 1 and multiplied by 100. Normalized results indicate that as compared with the control (100%) condition, exposure to accelerated and decelerated movies shortened by $4.9 \pm 1.6\%$ and lengthened down by $6.5 \pm 3.1\%$, respectively, produced durations (Fig. 1d and e). While we cannot exclude that this pattern of results reflects a response bias driven by participant's eventual awareness of the expected result rather than an actual alteration of subjective time, we consider the latter hypothesis more likely. The direction of our effect would have been difficult to predict by naïve subjects and was only reliable here following accelerated films (whereas a response bias would have led to symmetric effects for decelerated films).

Experiment 2 investigated whether the exposure to speed-altered movies modulated the level of arousal viz. BPM and GSR measures. Exposure to speed-altered movies had no effect on BPM (the mean \pm SEM BPM was 72.5 ± 2.6 for the 50% condition, 73.3 ± 2.1 for the 100% and 72 ± 2.2 for the 150%). A one-way ANOVA with condition (50; 100; 150%) as within subject factor failed to exhibit a significant difference across conditions ($F(2,3)=2.791$; $p>0.2$; $\eta p^2=0.650$). Consistently, mean GSR responses over the 2 min of exposure to speed-altered movies showed no significant modulations as a function of speed condition (mean \pm SEM GSR ($k\Omega$): 44.1 ± 6.3 for the 50% condition, 42.9 ± 6.9 for the 100% and 42.6 ± 8.4 for the 150%; $F(2,3)=0.221$; $p>0.8$; $\eta p^2=0.128$).

4. Discussion

We provide evidence that temporal processing accuracy is subject to context-dependent plasticity. Specifically, the rate of subjective passage of time is calibrated based on the speed of scenes within the visual environment. This effect persists for at least 30 s after the end of the exposure to speed-altered scenes and does not appear to be a direct consequence of changes in arousal.

Illusory distortions of time representation have been examined for short time-scale and using duration perception or reproduction tasks only (Droit-Volet & Wearden, 2002; Ortega & Lopez, 2008). Here, we show that the subjective speed of the passage of time is calibrated based on naturalistic cues from the visual environment and that this effect manifests on subsequent duration productions performed in an impoverished environment. This finding is in line with recent evidence that internal timing mechanisms adapt to the temporal statistics of the environment (Jazayeri & Shadlen, 2010). Modulation in arousal has been advanced as a potential cause of distortion in perceived durations (Maricq et al., 1981) and could explain that our effects were of higher magnitude following accelerated than slowed movies. Though negative results must be interpreted with caution, our results from Experiment 2 suggest that participants' arousal was not modulated by the speed of the visual scene and by extension, that the effects of speed-altered movies are not directly mediated by participant's arousal.

The recalibration of the subjective passage of time induced by exposure to speed-altered movies persists for at least 30 s after the end of the movie, that is, during the time interval when participants performed the duration production. However, our study cannot disentangle the dynamics of the movie-induced after-effect amplitude as we averaged behavioral measures performed right after the end of the movie with measures performed later during the task. Additional studies including several production times, or duration production phase starting at various delay following the end of the movies are required to determine the exact dynamics of our effect on duration production.

The observation of stronger context-induced plasticity in time representations following accelerated versus decelerated films can be considered in terms of providing an adaptive value to an organism. That is, faster processing, even if erroneous according to the tasks we required of our participants, would nonetheless be advantageous for avoiding fast-occurring and/or approaching stimuli that often have a higher propensity for being threatening or signaling danger (Rosenblum, Wuestefeld, & Saldaña, 1993). The costs of potentially over-reacting to a fast-changing environment (i.e. inefficient expenditure of energy) might be less than that of not reacting at all (e.g. death or injury). This may in turn aide in learning adaptive behaviors; something that will be the focus of future experimentation. Conversely, there is minimal (if any) advantage or cost of modifying behavior in a slowly changing environment, particularly if that environment also includes (occasional) rapidly changing events. This hypothesis is consistent with evidence that approaching stimuli are misperceived as lasting longer than receding or stationary stimuli (Tse, Intriligator, Rivest, & Cavanagh, 2004; van Wassenhove, Buonomano, Shimojo, & Shams, 2008). That is, their duration is over-estimated. However, this ethological hypothesis should be taken with caution as we assessed the effect of speed altered movies using highly cognitive tasks. Moreover, further manipulations are required to assess whether fast- and slow-occurring events, presented at their normal speeds (e.g. a running crowd versus a walking crowd), would induce similar effects as with the artificially accelerated stimuli used in the present study.

We showed that the immediately preceding temporal context impacts the subjective experience of elapsed time. This evidence demonstrates the possibility for using the rate of subjective time as an independent variable, thereby opening a new avenue for the study of normal and impaired temporal processing as well as for the rehabilitation of time-related neuro-pathologies.

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