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Emotional influences on time perception

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Abstract

In studies on prospective time perception, a prolonging effect of arousal on time estimates is commonly reported for durations under 2s while the effect vanishes for longer intervals. In this study, we investigated how arousal and pleasure induced by aural stimuli varying in volume and valence influenced reproductions in the range from 1.1s to 5s. As expected, higher arousal was associated with higher estimates for 1.1s durations. However, this effect was also found for 3.8s durations. An additional analysis with linear mixed models revealed an interaction between volume manipulation and subjective ratings regarding arousal and pleasure. Based on these results we propose that subjective experience of the emotional quality of stimuli might be interesting for further research on prospective time perception. Moreover, the results showed that not only within subject variation should be statistically controlled when analyzing such data. Instead, statistical models should also include parameters controlling for stimulus material.

Keywords: prospective time perception; reproduction; emotion; arousal; valence; linear mixed models

Introduction

The prolonging effect of emotions on prospective temporal duration judgments has been subject to a great number of research projects and publications in the last decade. Research on this phenomenon differs regarding methodology and the considered duration. Examples for the variety of methods to induce an emotional state are emotional pictures (Gil & Droit-Volet, 2012), music (Droit-Volet, Ramos, Bueno & Bigand, 2013), emotional faces (Gil & Droit-Volet, 2011), emotional sounds (Mella, Conty & Pouthas, 2011) and bodily expressions (Droit-Volet & Gil, 2015). Another variation in methodology relates to differing timing tasks, such as the bisection task (Droit-Volet, Brunot & Niedenthal, 2004), verbal estimates (Gil & Droit-Volet, 2012), and production (Gil & Droit-Volet, 2011) as well as reproduction tasks (Angrilli, Cherubini, Pavese & Manfredini, 1997). With respect to duration ranges, most of these studies focused on intervals between 400ms and 1600ms, while only a few experiments investigated longer durations up to 6000ms.

Gil and Droit-Volet (2012) asked participants to verbally estimate for how long different emotional pictures had been presented. The durations ranged between 50ms and 1600ms. The presented pictures systematically varied with respect to the arousal level they caused (high vs. low) as well as with respect to the discrete emotion they evoked (disgust, fear, sadness, or none for neutral pictures). Results showed higher estimates for emotional pictures compared to neutral ones and indicated that this effect gained in magnitude with increasing arousal (Gil & Droit-Volet, 2012). The same effect was found in all other studies reported above for durations smaller than two seconds.

These results accord with the clock speed hypothesis (c.f. attentional-gate-model, Block & Zakay, 1996) which assumes that prospective timing relies on accumulated pulses generated by an internal clock. The clock accelerates when arousal increases. This leads to a higher count of pulses compared to unchanged or decreased arousal. More pulses cause a prolonged time perception and consequently lead to higher estimates. Thus, the finding that a raising of arousal leads to *longer* estimates can be explained by an increased number of pulses due to an accelerated clock.

However, this effect seems to change for longer intervals. Noulhiane, Mella, Samson, Ragot and Pouthas (2007) studied the impact of different arousal levels (low vs. high) on time estimates for 2s-durations and found that stimuli evoking high arousal led to *shorter* estimates than those evoking low arousal. This finding was consistent over emotionally negative and positive stimuli and was found for verbal timing tasks as well as for reproductions. It clearly contradicts the clock speed hypothesis and deviates from all other studies reported above.

Noulhiane et al.'s surprising result (2007) raises the question why the arousal effect turns into the opposite direction. One explanation could be that subjects start to cognitively process emotions when confronted with an emotion induction long enough, as for two seconds (Noulhiane et al., 2007). Such a processing would bind attentional resources by reducing the attention on the timing task. Less attention on the timing task means that more pulses of the clock are missed, leading to a lower count of pulses and a shorter estimate. This explanation is in line with literature on the shortening effect of distraction on prospective timing (Brown, 2008). Another explanation could be that the reversed effect is modality specific. Noulhiane et al. (2007) used aural stimuli in their experiment. Angrilli et al. (1997) induced emotions via visual stimuli and report results consistent with the clock speed hypothesis. More precisely, they report longer estimates for high arousing stimuli than for low arousing stimuli at two seconds durations.

To sum up, evidence for the prolonging effect of arousal on time estimates of durations smaller than two seconds is very strong and supports the clock speed hypothesis. Looking at durations lasting for two seconds, however, the influence of arousal is unclear. Starting from this summary, it is obvious that the arousal effect on time perception during intervals greater than or equal to two seconds requires further inspection. Both, Angrilli et al. (1997) as well as Noulhiane et al. (2007), reported no such an effect for four seconds and six seconds durations. In their experiments, time estimates did not significantly differ between arousal levels for these intervals. Nather, Bueno, Bigand and Droit-Volet (2011) induced arousal via pictures of body postures. Even though they found the prolonging arousal effect at durations ranging from 400ms to 1600ms, they did not detect such an effect at durations ranging from two to eight seconds. These studies give support to the assumption that the lengthening effect of arousal vanishes at durations longer than two seconds.

Up to this point, only the effect of arousal on time estimates has been discussed. Another important dimension of emotions is valence and many of the studies described above did not only vary arousal but valence as well. Noulhiane et al. (2007), for example, compared low-arousing emotional with low-arousing neutral sounds and reported longer estimates for emotional compared to neutral stimuli for the 2s-duration. Likewise, Gil and Droit-Volet (2012) compared emotional stimuli to neutral ones and found the same pattern. Similar results were reported by Droit-Volet et al. (2004) as well as by Gil and Droit-Volet (2011).

Summing up the results, it is obvious that a comprehensive investigation of emotional influences on time perception ought to address both, arousal as well as valence for a larger area of durations. This leads to the following research question: How do arousal and valence affect time perception of durations ranging from under to over two seconds? To answer this question, we conducted an experiment in which valence and arousal were varied for durations between 1.1s and 5.0s. This range includes durations for which an arousal effect is commonly found, for which results are ambiguous and for which the arousal effect is expected to vanish. With respect to stimuli, we decided to focus on the same modality as Noulhiane et al. (2007). The use of aural stimuli allows a comparison with their rather uncommon findings and might help to decide between the two explanations discussed earlier.

Methodological notion on Linear Mixed Models

Another reason for the ambiguous state of affairs concerning the relationship between emotions and time perception may be methodological in nature. In this field of research, mostly ANOVAs are used to analyze data. To this account, most studies cited above used stimuli that were rated for arousal and valence beforehand and averaged the dependent variable over trials for certain groups of stimuli. However, even though all stimuli from one group are similar to each other on the predefined dimension, slight differences can cause systematic variation in the data. If systematic by-item variation is not statistically accounted for, error variance increases and thus makes type II errors more likely.

Linear mixed models (LMM) offer a solution to this problem. They are called ‘mixed models’ because they can include fixed effects, like factors or covariates, as well as random effects for subjects and items (Winter, 2013). Random effects account for variance between subjects and between items in three ways: by including random intercepts for both subjects and items, by including random slopes considering variance between subjects respectively items for all main effects and interactions and by considering correlations between intercepts and slopes (Bates, Kliegl, Vasishth & Baayen, 2015). All this can be done in one statistical model which gives an advantage over a single within ANOVA because the ANOVA only allows to consider either variance of subjects or of items. Thus, LMMs can help to reduce error variance (Winter, 2013) and therefore increase statistical power (Kliegl, Wei, Dambacher, Yan & Zhou, 2011). Moreover, LMMs make it possible to analyze the complete data set, instead of averaging over certain dimensions. This helps to improve the understanding of complex structures within the data as for example by identifying important covariates (Kliegl et al., 2011). Furthermore, they allow the inclusion of covariates or predictors that vary within subjects thus offering another advantage over an ANOVA.

This advantage is especially important when looking at time perception because its analysis may be strongly influenced by inter-individual differences. For example, time perception changes with age (Block, Zakay & Hancock, 1999) and studies suggest that it differs between gender (Block, Hancock & Zakay, 2000). Therefore, including statistical parameters for variation between participants may improve the understanding of important participant characteristics (Kliegl et al., 2011) and help to detect effects that were otherwise overlooked.

Method

Participants

A study was conducted with *N*=20 participants (11 male, 9 female). All participants were young adults (M_{age}= 25.1, SD_{age}=3.3) comparable to the studies cited above.

Design, material and procedure

The study was based on a 2x3x4 within-subjects design consisting of the factors valence (negative, neutral), volume (low, medium, loud) and duration (1.1s, 2.4s, 3.8s, 5.0s). To implement the factor valence, twelve stimuli were taken from the International Affective Digital Sounds System (Lang, Bradley & Cuthbert, 2008). Six of them were categorized as neutral and six as emotionally negative according to the norm by Lang et al. (2008). All sounds showed a continuous pattern of noise. For the factor volume, the levels were low, medium and loud. The difference between these levels was established by amplifying the original sound from the IADS by the factors 0.04, 0.4 and 4 respectively. The mean volumes were the following: M_{low}=41dBA (SD=2.9), M_{medium}=61dBA (SD=2.5), M_{loud}=70dBA (SD=2.3). Arousal induction via volume was chosen because noise is known to stimulate the central nervous system and to increase arousal level (Hockey, 1972). Moreover, this variation allows the use of the same sounds to elicit different levels of arousal. Under each combination of valence, volume and duration, six sounds were presented, resulting in 144 stimuli. In addition to these, 36 trials with random durations between 0.9s and 5.3s were introduced to increase the variability of the durations. Altogether, this adds up to a total of 180 trials.

The experiment consisted of two successive phases, a rating and a test phase. In the rating phase, participants heard each stimulus for 6s and filled in the self-assessment manikin SAM (Bradley & Lang, 1994) to judge its emotional effect in terms of pleasure and arousal. At the beginning of the test phase, the forthcoming trials and the reproduction procedure were explained. Participants were instructed not to count while perceiving or reproducing the durations. After the instruction, they completed three practice trials with a neutral sound that was not used otherwise in the experiment. Each trial was started by the participants themselves by pressing the space key. After a 2s delay, the aural stimulus was presented, followed by a request to reproduce the duration. The reproduction was accomplished by a continuous key press without any sound. This response type was chosen because continuous key presses show less variability than responses that indicate only the end or both start and end of an interval (Mioni, Stablum, McClintock, & Grondin, 2014). After each trial, participants were asked to report whether they had counted (by pressing key 1) or not (key 3). They started the next trial by pressing space.

The presentation of stimuli and instructions as well as the recording of data was implemented in Matlab 2014b and the Psychophysics Toolbox extensions version 3 (Brainard, 1997; Pelli, 1997). All visual information (e.g. instructions, requests) were given on a 22-inch desktop display. Sounds were presented over headphones, while a fixations cross was shown on the display. Pupil dilation was measured but its data is not reported in this paper due to limited space.

Data analysis

Prior to the analysis, all trials with random duration as well as all trials in which participants had counted were eliminated from the data set. For the remaining 2839 trials, perceived time ratios (PRTs) were computed by dividing the duration of the reproduction by the duration of the presented interval (Block, Hancock & Zakay, 2010). PTRs were preferred over the original data of the reproductions because they represent a measure for goodness of estimation. A PTR of one represents a perfect estimation independently from the presented duration, while a PTR smaller respectively bigger than one indicates underestimation respectively overestimation. PTRs allow for comparing duration estimates regarding the strength of their over- or underestimation which can vary between different arousal levels or even different durations.

The data was analyzed with a repeated measurements ANOVA and with a Linear Mixed Model (LMM). We choose to use both methods to find out if the LMM provides more insights than the ANOVA. Data analysis was conducted with R (R Core Team, 2015) using the ez (Lawrence, 2013), lme4 (Bates, Maechler, Bolker & Walker, 2015) and ggplot (Wickham, 2009) packages. In accordance with common practice for ANOVAs, all data was averaged over sounds with negative valence and over sounds with neutral valence for each duration and volume level resulting in 24 values per subject. Additionally, a manipulation check for the segmentation of the 12 sounds into neutral and negative valence groups was conducted. To this account, t-tests were conducted with the subjective ratings from the rating phase regarding pleasure and arousal averaged over the neutral and over the negative sounds. As expected, the negative group of sounds was rated as inducing less pleasure than the neutral sounds, *t*(19)=-10.8, *p*<.001, *r*=.93. Regarding arousal, the negative group of sounds was rated as inducing more arousal than the neutral sounds, *t*(19)=4.7, *p*<.001, *r*=.73. Hence, both pleasure and arousal were different for the two valence conditions. Moreover, mean correlation coefficients computed via z transformation showed high correlations between arousal and valence for negative sounds, *r*= -.67, and medium correlation for neutral sounds, *r*= -.35.

Results

Using the averaged data, an ANOVA Type III was conducted with the factors duration, volume and valence (4x3x2). The ANOVA revealed significant main effects for volume, *F*(1, 38)=20.8, *p*<.001, *ges*=.025, duration, *F*(1.16, 21.99)=54.2, *p*<.001, *ges*=.286, and valence, *F*(1, 19)=15.3, *p*<.001, *ges*=.008.

Regarding the main effect of volume, low volume sounds had lower PTRs (M_{low}=0.83) compared to sounds with medium volume (M_{medium}=0.88), t^1(19)=-4.1, *p*<.01, *r*=.68. Moreover, PTRs of the latter were lower compared to those of loud sounds (M_{loud}=0.90), *t*(19)=-2.2, *p*<.05, *r*=.44. A closer inspection of the main effect of duration revealed that sounds played for 1.1s showed higher PTRs values ($M_{1.1s}$=1.04) compared to sounds played for 2.4s ($M_{2.4s}$=0.92), *t*(19)=5.3, *p*<.001, *r*=.77. Moreover, PTRs of the latter were higher than PTRs of sounds that lasted 3.8s ($M_{3.8s}$=0.80), *t*(19)=7.5, *p*<.001, *r*=.83. PTRs for the duration of 3.8s compared to those with a duration of 5.0s were also significantly higher ($M_{5.0s}$=0.73), *t*(19)=7.3, *p*<.001, *r*=.86. As the PTRs show, all durations were underestimated. Increasing duration led to stronger

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[1] p-values for all post-hoc t-tests were adjusted using Bonferroni-Holm correction

underestimations, while increasing volume led to weaker underestimations. Negative sounds ($M_{negative}$=0.89) led to weaker underestimations compared to neutral sounds ($M_{neutral}$=0.86).

The ANOVA also showed a significant interaction between volume and interval, *F*(2.64, 50.21)=4.9, *p*<.01, *ges*=.012, which is visualized in Figure 1. Post-hoc t-test revealed significant differences between low and medium sounds for 3.8s, *t*(19)=-4.0, *p*<.01, *r*=.68 but not for other durations, *ts*(19)>-2.4, *n.s.*. Furthermore, they showed significant differences between low and loud sounds at 1.1s, *t*(19)=-5.9, *p*<.001, *r*=.80 and at 3.8s, *t*(19)=-5.0, *p*<.001, *r*=.75. For none of the durations, a significant difference between medium and loud sounds was found, *ts*(19)>-2.6, *n.s.*. No other interaction effect of the ANOVA proved to be significant, *F*s<1, *ps*>.05.

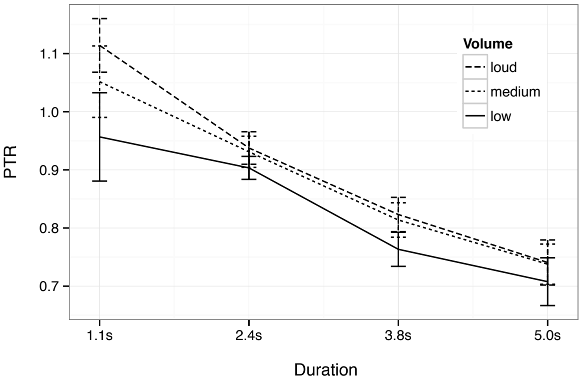

Figure 1: Interaction of the factors volume and duration. Error bars represent confidence interval computed according to Cousineau (2005).

In addition to the ANOVA, a LMM with the fixed effects duration and volume (4x3, centered variables) was fitted by restricted maximum likelihood (REML). The factor valence was replaced by two continuous predictors. These were the subjective ratings on arousal and pleasure for each sound given by each participant during the rating phase. All possible interaction terms between the four fixed effects were included. As random effect, both random intercepts for subjects and sounds as well as all random slopes for the two factors over subjects and sounds were comprised. The analysis started with the following model:

(1) PTR ~ (Duration+Volume+Pleasure+Arousal)^4 + (1+Duration+Volume+Duration:Volume|Subjects) + (1+Duration+Volume+Duration:Volume|Sounds)

To avoid over-parameterization unnecessary random effects were eliminated following the procedure suggested by Bates et al. (2015). Random effects in the final model are presented in formula (2). Random effects by subjects revealed that subjects not only differed regarding intercepts, but also with respect to the effect that duration had on PTR values. In other words, the strength of the duration effect differed between subjects. The random intercept of sound showed that the intercept changed between the 12 sounds. Furthermore, the effect of duration and volume changed in magnitude between the different sounds.

(2) (1+Duration|ID) + (1+Volume+Duration|Sound)

Regarding fixed effects, a stepwise backwards selection was conducted. During each step, a new model was fitted, in which one of the model terms was eliminated. Each new model was tested against the former model by a likelihood ratio test with an alpha criterion of .05. The remaining fixed effects and their output statistics are listed in Table 1. P-values were calculated using the lmerTest package (Kuznetsova, Brockhoff & Christensen, 2015).

Table 1: Fixed effects of model (2).

Fixed Effects	estimate	*SD*	*t*	*p*
Intercept	0.880	0.051	17.27	<.001
Duration	-0.081	0.020	-4.03	<.001
Volume	0.003	0.036	0.07	n.s.
Pleasure	0.001	0.005	0.13	n.s.
Arousal	-0.002	0.005	-0.48	n.s.
Duration:Vol.	-0.018	0.004	-4.10	<.001
Duration:Ple.	-0.005	0.002	-2.34	<.05
Volume:Ple.	0.006	0.005	1.16	n.s.
Volume:Aro.	0.008	0.005	0.16	n.s.
Pleasure:Aro.	-0.000	0.001	-0.01	n.s.
Vol.:Ple.:Aro.	-0.002	0.001	-2.01	<.05

Compared to the ANOVA the LMM showed the previously described effects of duration and of the volume-duration interaction. However, the LMM indicated that the effect of the arousal induction via volume on PTRs was dependent on the emotional qualities of the stimuli, namely arousal and pleasure. Moreover, the duration x pleasure interaction indicated that PTRs were higher for low pleasure stimuli compared to high pleasure stimuli, while this effect was stronger for longer intervals.

Discussion

In this study, we investigated the effect of arousal and valence on time perception regarding durations ranging from 1.1s to 5.0s. For this purpose, 12 sounds classified as either unpleasant or neutral were played at different volume levels and participants reproduced the duration of the presented sound. Data analysis was carried out on standardized estimates (PTRs) using both an ANOVA and a linear mixed model (LMM). Results revealed that underestimations grew stronger with increasing durations. While the ANOVA showed both an effect of volume as well as of valence, the LMM indicated that the relation between emotions and duration estimations are more complicated than a simple main effect of arousal or of valence.

The effect of volume as shown in the ANOVA and the interaction between volume and duration in both analyses can be regarded as further support for the prolonging effect of arousal on time perception. Here, estimates increased with the volume of the presented sound. Literature on noise and its effect on arousal level indicates that high volume noise increases arousal (e.g. Hockey, 1972). These findings support our interpretation that the louder sounds elicited higher arousal which in turn caused an increase of time estimates. This arousal effect lends further support to the clock speed hypothesis as predicted by the attentional-gate-model (Block & Zakay, 1996).

However, the prolonging effect of volume differed within the duration range. At 1.1s low and loud volumes lead to significantly distinct estimates. This is not surprising because it is in line with the commonly found arousal effect for durations smaller than two seconds. In contrast to other studies (Angrilli et al., 1997; Noulhiane et al., 2007; Nather et al., 2011), however, the effect did not vanish for duration longer than two seconds. Even though the found prolonging effect did not prove as significant for 2.4s durations, a significant difference in estimates was found at 3.8s concerning the low and medium as well as the the low and loud volume. Before declaring this finding as further support for the clock speed hypothesis though, one point has to be made. The clock speed hypothesis not only predicts higher estimates when arousal is increased, it also predicts that this effect should gain in magnitude when durations grow longer. This prediction is based on the mode of action belonging to the clock. If durations are longer, the clock has more time to produce pulses. Hence, increased clock speed will not lead to an additive increase of pulses but to a multiplicative increase (Gil & Droit-Volet, 2012; Nather et al., 2011). However, when comparing effect sizes of the difference between low and loud sounds between 1.1s and 3.8s durations, the results of this study provide no evidence for an increased arousal effect. Thus, even though the arousal effect did not vanish as described by other authors, it does not show a multiplicative increase either.

Comparing our results to those by Noulhiane et al. (2007), we could not replicate the reversal of the arousal effect for two second durations. Moreover, our results do not support the assumption of a modality specific effect because they are consistent with results gained by applying visual instead of aural stimuli (Angrilli et al., 1997). Instead, the arousal effect reported in this study as well as the vanishing arousal effect described by other authors for durations longer than two seconds, might be connected to a change in cognitive processing for durations exceeding two seconds. More precisely, attentional processes might come into play for durations greater than 2 seconds. Thus, the interplay of arousal and attention as described in the attentional-gate-model (Block & Zakay, 1996) might become particularly important for longer intervals.

Regarding the effect of valence shown in the ANOVA, estimates for negative stimuli were higher than those for neutral stimuli. Even though it was only a small effect, it is in line with earlier findings (Droit-Volet et al., 2004; Gil & Droit-Volet, 2011; Gil & Droit-Volet, 2012; Noulhiane et al., 2007). Nonetheless, as shown in the manipulation check for the segmentation of stimuli into negative and neutral, both groups did not only differ regarding pleasure but also regarding arousal. Thus, the difference in PTRs between groups cannot be distinctly associated with either either dimension. In the analysis using LMM, the factor valence was therefore replaced by arousal and pleasure ratings given by each subject for each sound. The analysis revealed that PTRs were affected by an interaction of the subjective ratings. Furthermore, the interaction effect was dependent on volume, and thus on the level of arousal induction. This three-way interaction cannot be easily interpreted for two reason: First, the two rating dimensions covary and second, both ratings were measured on a nine-point scale making post-hoc comparisons of means or slopes unusable.

However, we derive two hypotheses from the three-way interaction that should be tested further in future studies. First, people differ in their subjective experience of the emotional quality of stimuli and their experience has a distinct impact on time perception. Whether this experience can be measured by ratings as done here, or if other measures (e.g. physiological data) are needed, remains open. Second, there is a close connection between arousal and pleasure and their impact on time perception. Previous studies have already looked beyond the scope of the clock speed hypothesis by including valence as an impact factor on time perception. However, we want to emphasize the importance to look at the effect of subjectively experienced emotional reactions to the stimuli rather than at the effect of predefined categories of arousal levels and valence. Such an approach seems more appropriate for the interplay of arousal and valence. An alternative operationalization might be a measure for emotional intensity, a concept that has been discussed by Reisenzein (1994) and Scherer (2005).

Summing up, the reported results of the ANOVA are in line with a prolonging arousal effect on time. Moreover, the arousal induction method by volume changes seems to be comparable to other induction methods. However, the arousal effect did not vanish for durations longer than 2s, but it did not gain in magnitude as predicted by the clock speed hypothesis either. Thus, in line with other studies (e.g. Noulhiane et al., 2007), our results suggest a change in cognitive processing for durations exceeding two seconds. When including subjective predictors with help of a LMM it becomes clear that the effect of arousal and the effect of valence on time perception are interconnected. Focusing research on the effect of their interplay might enhance the understanding of the cognitive processes involved in time perception. However, such research should include also positive stimuli and not only neutral and negative ones as done here. Reflecting the data analysis strategy, LMMs are a handy tool to include continuous predictors with within-subject variation in the statistical model. Moreover, the random effect structure of the LMM showed that it is reasonable to not only consider by-subject variations as it is done in the ANOVA, but also to consider by-item variations.

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