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RESEARCH ARTICLE

# How visual stimulus effects the time perception? The evidence from time perception of emotional videos

Cansın Özgör[1,2] · Seray Şenyer Özgör[1] · Adil Deniz Duru[2] · Ümmühan Işoğlu-Alkaç[1]

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**Abstract**
Time perception is defined as a subjective judgment on the elapsed time of an event. It can change according to both external and internal factors. There are two main paradigms of time perception; retrospective time perception (RTP) and prospective time perception (PTP). Two paradigms differ from each other according to whether the subject has knowledge on the importance of passage of time in the given task. Since RTP paradigm studies are harder to conduct, studies on RTP paradigm is far fewer than studies on PTP. Thus in the current study, both RTP and PTP paradigms are investigated. Also, time perception is discussed in relation to internal clock model and cognitive load. Emotional motion videos are used to create cognitive load and manipulate internal clock. Results showed the effect of emotion on time perception. Another major finding is that shorter videos are perceived longer whereas longer videos are perceived shorter as in accordance with Vierordt's Law. However, there was no difference between RTP and PTP paradigms. These results indicate that emotional videos change our internal clock while a number of changes in a motion video create cognitive load causing disturbance of time perception.

**Keywords** Retrospective time perception · Prospective time perception · Emotion · Vierordt's law

## Introduction

Time perception is studied at two separate subdomains as prospective and retrospective time perception (see review, Block and Zakay 1997). Prospective time perception (PTP) is the situation that subject clearly has the information about that researcher is going to ask questions regarding the time of the stimuli in the future. Thus, subject knows the importance of attending on time mainly. On the contrary, retrospective time perception (RTP) refers to a situation that the subject does not know the necessity of attending on time which can be asked after the presentation of stimuli. In both PTP and RTP, there are several issues such as cognitive load and internal clock model which may be used to explain the idea of time perception. In our study, we mainly focus on cognitive load paradigm that refers to information processing and mental efforts on a given task in a particular time (Block et al. 2010). We also address the internal clock model which explains the idea of how living creatures perceive the time (see Treisman 1963).

Internal clock model explains the time perception with an internal counting system in a linear line (Treisman 1963). According to the most popular and accepted sub-model (scalar expectancy theory) of internal clock model, time is counted by pulses through a pacemaker to an accumulator. On the other hand, the flow of pulses is controlled by a key which is opened or closed by attention (Gibbon 1977). Thus, the amount of pulses gathered in the accumulator changes according to attention and level of cognitive load which uses attentional resources. The most

✉ Adil Deniz Duru
deniz.duru@marmara.edu.tr

Cansın Özgör
cozgor@gmail.com

Seray Şenyer Özgör
seraysenyer@yandex.com

Ümmühan Işoğlu-Alkaç
alkac@istanbul.edu.tr

[1] Department of Physiology, Istanbul Faculty of Medicine, İstanbul University, Çapa, 34353 Istanbul, Turkey

[2] Neuroscience in Sports Laboratory, Faculty of Sport Science, Marmara University, Anadolu Hisarı Campus, 34820 Beykoz/Istanbul, Turkey

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evident effect of cognitive load on time perception is seen on the PTP and RTP paradigms because of their relationship with short-term memory and attention. Due to lack of information about the necessity of attending on time, the subject switches his attention to non-temporal information on the RTP paradigm, and pulses lost during the flow. In PTP paradigm, however, the subject focuses his attention on temporal information with causing more pulses to gather in the accumulator. Furthermore, the capacity of short-term memory determines the amount of temporal and non-temporal information is stored. Especially, some studies show that hippocampus plays an important role for the sequential encoding (see Wagatsuma and Yamaguchi 2007). Thus, time perception is disrupted when the subject attends on and tries to remember more than one stimuli or information at the same time (Ornstein 1969; Block 2003).

Cognitive load is generated by the researchers in the laboratory settings via complex stimulus exposure to the subject, hardly compliable tasks or time itself with long durations (see Hintzman 2001; Friedman and Wilkins 1985). Also, emotional stimuli are used to increase cognitive load level of subjects in time perception tasks due to its effect on attention and perception (see Droit-Volet and Meck 2007). Studies on emotion and time perception present multi-faceted results. According to internal clock model, pulses flow faster when arousal level of emotional stimuli increases and cause time to be perceived longer (Buhusi and Meck 2006). Contrarily, if arousal level of the emotional stimuli is too high, then pulses lost because of salience of emotional information during the task and cause time to be perceived shorter (Meck 1996). Furthermore, duration of emotional stimuli affects the perception of time. Noulhiane et al. (2007) found that emotional auditory stimuli with duration of 3–4 s accelerate the speed of pulses independently from arousal level. The speed of pulses returns to normal after 4 s. This is explained by habituation. Moreover, they reported that negative stimulus is perceived longer than positive ones under 4 s.

By considering studies about effects of emotion on time perception, it is seen that simple stimuli are used by separating auditory and visual components and by using static and emotion-based images (see Droit-Volet and Meck 2007; Yamada and Kawabe 2011; Mereu and Lleras 2013; Tamm et al. 2014). On the other hand, complexity, amount of stimulus (Ornstein 1969), and its concepts may affect the PTP and RTP due to the rise of cognitive load (Block 1989). Thus in the current study, we have decided to use more complex stimulus which is more adaptable to the real-life situations. This is unlike to the most recent studies that used fundamental techniques. Furthermore, there are only a few studies using RTP paradigm because of the difficulty of asking the time of stimulus without informing the subject about the importance of temporal information. Also, the subject gains the idea on further questions about the time of stimulus when it is once asked. However, we designed two experiments by conducting same procedure with using similar stimuli set and recruited same participants in order to assess both RTP and PTP paradigms.

## Materials and methods

### Participants

Twenty subjects (9 male, 11 female) voluntarily accepted to participate in the experiments. University students and graduated volunteers with a history of the neurological or psychiatric disease and color blinded people are not recruited for the experiments. Subjects are informed about the general attention points, rules and major materials that going to use during experiments.

### Materials

Experiments are conducted in a room possibly isolated from sound and bright light. Stimuli are presented from the 21" LCD computer screen (fixed resolution: 1024 × 768). Experiments are presented by homemade stimulus presentation software using C# and MATLAB programs and all responses are gathered with left mouse button. Gathered data is analyzed with MATLAB and SPSS 18v.

### Stimuli

#### Time perception paradigm experiments

During main experiments of the current study, visual and auditory-based stimuli are used as short video clips. The videos are gathered from the movies that are listed on Internet Movie Database (IMDB). Totally, 180 emotional videos and 180 screenshots which are picked from each video presented during the experiments. All emotional videos are selected by a pilot study.

#### Pilot study

360 movies are chosen from the IMDB movie list (www.imdb.com) by researchers according to their content (120 positive, 120 negative, 120 neutral). 360 movie videos are selected (120 positive, 120 negative, 120 neutral) from the movies with one alternative of it. After all videos are selected, three educated professionals who graduated from both psychology and film and television departments eliminated the one video from the alternative. Thus, 360 unique videos remained (120 positive = 60 four seconds + 60 eight seconds, 120 negative = 60 four

**Table 1** Distribution of stimulus in RTP and PTP

| | RTP | | | PTP | | |
|---|---|---|---|---|---|---|
| | Positive | Negative | Neutral | Positive | Negative | Neutral |
| 4 s | 15 | 15 | 15 | 15 | 15 | 15 |
| 8 s | 15 | 15 | 15 | 15 | 15 | 15 |

seconds + 60 eight seconds, 120 neutral = 60 four seconds + 60 eight seconds). These videos were again categorized by 100 volunteer subjects as positive, negative or neutral. After the categorization process, videos having the lowest points according to their valence level are eliminated by researchers. As a result, 180 videos (90 four seconds, 90 eight seconds; divided equally under positive, negative and neutral conditions) remained. These groups were used for RTP and PTP paradigms separately and equally (see Table 1).

## Procedure

Retrospective and prospective time perception paradigm presented with different data set. Although, the only difference between two sets is that different videos and screenshots were used for each paradigm during the procedure. The Number of videos in each set and category is presented previously in Table 1. In addition, each subcategory sets are divided to two different time duration as four (45) and eight (45) seconds. The sets are presented in two different stages. In the first stage, videos and screenshots were presented to the subjects. Subjects were asked to categorize the videos in this stage in a 7-likert type scale (− 3, − 2, − 1, 0, 1, 2, 3; from negative to positive respectively with 0 refers to neutral content response). During the second stage, screenshots of each video were presented again and the subjects were asked to give time estimation judgments for each video. Subjects indicated their judgments about the duration of each video on a 9-point time scale in seconds (2, 3, 4, 5, 6, 7, 8, 9, 10). The maximum and minimum choices on the scale are optimized as 2–10 to give two extra response range for 4 and 8 s stimuli. Time estimations are calculated through error rates in the analysis. The error rate is defined as the absolute difference of obtained time and predicted time. How videos are perceived (longer or shorter) by subjects is analyzed based on their error rates. Also in every stage of two experiments, confidence rates of subjects about their answers are taken in a 6-likert type scale (1, 2, 3, 4, 5, 6; from "definitely not confident" to "definitely confident" respectively).

RTP paradigm works as a memory task and PTP paradigm works as an attention task. To control the attention and memory performance of subjects, standardized and computerized Go/No-go (see an example) and N-back (see an example) tasks were conducted. Subjects who are underperformed in control tasks are excluded from the study. Additionally, before the main analyses of this data, outlier analyses were conducted. No outlier has been detected. Furthermore, if any score of the subjects exceeded the three standard deviations of the mean, it is also excluded from the analyses.

## Experiments

Subjects were asked about to not using alcohol 3 days before the experiments and also they were informed about having a good sleep and a breakfast before experiments. Each subject was instructed about the general procedure of experiments. All experiments are conducted according to the ethics committee approval, and all subjects signed informed consent form.

### RTP experiment 1

The first experiment is RTP paradigm. Each subject must get the RTP paradigm at first because in PTP paradigm subject learns the importance of time for the experiment which consequently violates the RTP procedure. Thus, subjects were told before the experiments that they will only rate the several videos during the study. There were two different stages in the first experiment. At the beginning of these two stages, subjects were instructed separately. In the first stage, subjects received 90 videos and after each video showed up individually, a screenshot of that video appeared on the screen. Subject evaluated all videos from the Likert type scale ranged − 3 to 3. After the evaluation of a video, the next video shows up. Between the videos, a shadow screen was used to give the subjects a very short resting state. This procedure continued till to the end of the 90 videos. Figure 1 shows the details of the first stage of experiment 1.

At the end of the first stage of the experiment 1, instruction of the second stage was given by researcher and after that second stage has started. In this stage, the scale for prediction of time of the videos at the first stage ranged from 2 to 10 (the scale starts from the 2 and it goes until 10, each number reflects a duration in seconds) (Fig. 2).

After the subjects finished the experiment 1, they get a small (1 min) break before the start of the experiment 2.

### Experiment 2

All steps of the experiment 2 were similar with an only difference of videos. There are 90 new videos which are categorized in the same way with the experiment 1. In the experiment 2, subjects know that they will be asked about


**Fig. 1** Emotional category evaluation stage


**Fig. 2** Time estimation stage

the times of videos at the second stage of experiment two. Therefore, they were instructed similarly with experiment 1, but this time they were also instructed before the start of the first stage as "you should attend the time of videos, it will be asked at the next stage" (see Appendix for detailed instructions).

After the end of the experiment 2, again the subjects get a short break at about 1–2 min. After the break, they are instructed for standardized Go/No-go task (see Schröger 1993) as an attention task. All subjects get the Go/No-go task first and then N-Back task. After Go/No-go task, subjects took a short break (1 min) and get the standardized N-back task (see Owen et al. 2005) with 2-back condition as a memory task. With the use of these additional tasks, researchers have the advantage of controlling the attention and memory performance of subjects which are very crucial for the RTP and PTP paradigms.

## Results

20 subjects were accepted to experiments. However, two subjects did not finish the experiments properly. Confidence rates, Go-Nogo and N-back scores of all included subjects were calculated. Results of the confidence rates showed that there were no outliers in terms of confidence for giving responses. Go-Nogo and N-back scores showed that all subjects except one have no attention (Go-Nogo $M = 99.2$; $SD = 0.7$) or memory (N-back Success $M = 94.4$; $SD = 2.8$) problem which is necessary during time perception paradigm experiments. One subject was eliminated because of her low attention score according to results of Go-Nogo task (success rate = 30%). Thus, eight women and nine men (Mean age = 24.6, ranged between 18 and 28) involved for further analyses.

Subjects watched the videos in the first stage of the two experiments. To understand whether videos categorically differ from each other as expected, category rates of subjects were analyzed with analyses of variances (one-way ANOVA) at first. The results showed that there is a significant difference at least one of the three groups of videos called positive, negative and neutral, ($F(2,48) = 150.92$; $p < 0.001$). The relation of answers and the categories of videos were measured with eta square ($\eta 2$) and the result of the analysis ($\eta 2 = 0.86$) indicated a strong relation. Further Tukey HSD analyses showed statistical significance between subgroups ($p < 0.001$). As a result, there are significant differences between three kinds of videos; positive ($M = 1.79$, $SD = 1.21$), negative ($M = -1.99$, $SD = 1.31$) and neutral ($M = 0.41$, $SD = 1.01$) (Fig. 3).

After categories of videos were assessed, error rates of subjects' time estimation were analysed to find if there is any effect of emotion, duration and paradigm. A three-way ANOVA was used to measure main effect of paradigm (RTP, PTP), emotion category (positive, negative, neutral), duration (4, 8 s) and to measure their interaction effect. A significant effect for emotion category and duration were found at $p < 0.001$, whereas there was no significant effect of paradigm. There was a significant main effect of emotion category on error rates, $F(2, 32) = 19$, $p < 0.001$. Further post hoc comparisons using Bonferroni correction showed significant differences between error rates of subjects' time estimation for positive videos ($M = 1.9$, $SE = 0.1$) and for neutral videos ($M = 2.13$, $SE = 0.1$),

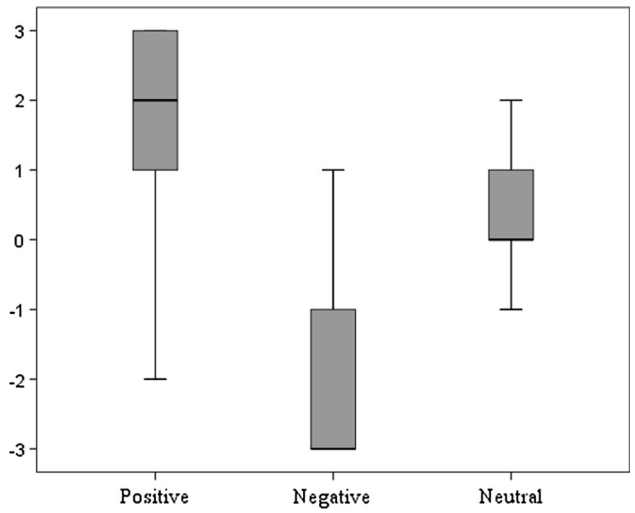


**Fig. 3** Categorical evaluation of videos

$p = 0.002$. There was also a significant difference in error rates for negative videos (M = 1.8, SE = 0.1) and for neutral videos (M = 2.13, SE = 0.1), $p < 0.001$ (Fig. 4). These results indicate that error rates for positive and negative videos were significantly lower than error rates for neutral videos. To understand the direction of the error rates, mean values were recalculated for obtained time responses of subjects for positive, negative and neutral videos, apart from error rates. It is found that time of positive (M = 4.9, SD = 1.51) and negative (M = 5.1, SD = 1.6) videos estimated longer compared to neutral videos (M = 4.26, SD = 1.34).

The significant main effect of duration on error rates was also found F(1, 16) = 49, $p < 0.001$, indicating that error rates of subject's time estimation for 8 s videos (M = 3, SE = 0.21) were significantly higher than 4 s videos (M = 0.94, SE = 0.1). After this significant result was found, mean values were recalculated for obtained time responses of subjects for 4 and 8 s videos, apart from error rates. When the obtained time estimations are considered, it is also seen that participants estimated 4 s videos longer than their actual duration (M = 4.3, SE = 0.71) whereas they estimated 8 s videos shorter than their actual duration (M = 5.18, SE = 1.1) (Fig. 5).

Furthermore, results revealed a significant interaction effect of emotion category and duration F(2, 32) = 20.12, $p < 0.001$. This result indicates that emotion category has different effects on error rates of subjects' time estimation depending on the duration of videos. Further Bonferroni corrected post hoc comparisons showed significant differences between error rates for 8 s positive videos (M = 2.84, SE = 0.24) and for 8 s neutral videos (M = 3.42 SE = 0.18). There was also a significant difference between error rates for 8 s negative videos (M = 2.61, SE = 0.23) and for 8 s neutral videos (M = 3.42, SE = 0.18). These results indicate that error rates of subjects' time estimation for positive and negative videos were significantly lower than neutral videos in 8 s duration.

A significant interaction effect between paradigm, emotion category and duration F(2, 32) = 4.64, $p = 0.017$ was also found. This significance indicates that paradigm has different effects on error rates of subjects' time estimation depending on emotion category and duration of the videos. Post hoc analysis using Bonferroni correction showed significant difference between error rates of subjects' time estimation for 8 s neutral videos in RTP paradigm (M = 3.68, SE = 0.18) and for 8 s neutral videos in PTP paradigm (M = 3.15, SE = 0.22). This result indicates that error rates of subjects' time estimation for 8 s neutral videos in RTP paradigm was higher than error rates for 8 s neutral videos in PTP paradigm.

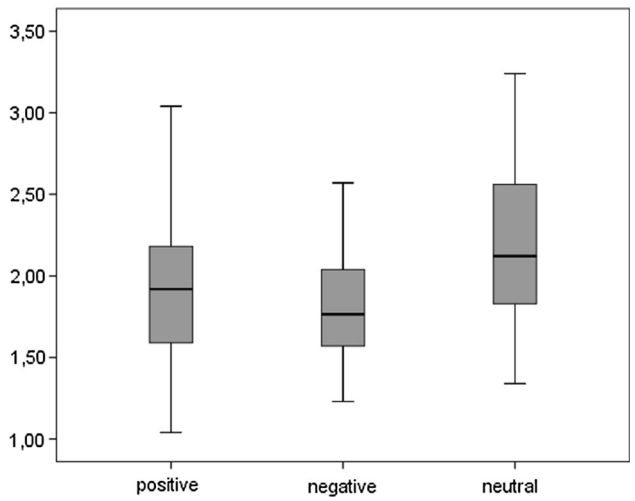


**Fig. 4** Error rates of time estimation for emotional videos

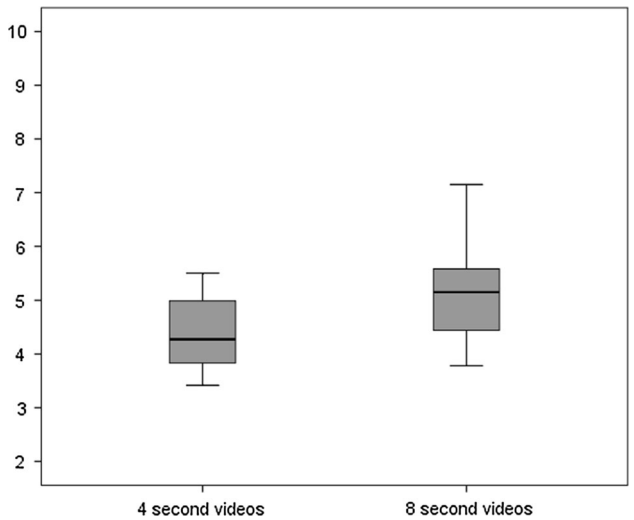


**Fig. 5** Time estimation of 4 and 8 s videos

Repeated measure ANOVA results showed no significant interaction between paradigm and emotion category, $F(2, 32) = 1.77$, $p = 0.19$. However, post hoc analysis using Bonferroni correction yielded a significant difference between error rates of subjects' time estimation for positive videos ($M = 1.9$, $SD = 0.12$) and for neutral videos ($M = 2.22$, $SD = 0.09$) in RTP paradigm, $p = 0.001$. There was also a significant difference between error rates of subjects' time estimation for negative videos ($M = 1.84$, $SD = 0.11$) and for neutral videos ($M = 2.22$, $SD = 0.09$) in RTP paradigm, $p = 0.001$. Furthermore, a significant difference between error rates of subjects' time estimation for positive videos ($M = 1.91$, $SD = 0.09$) and for negative videos ($M = 1.8$ $SD = 0.07$) in PTP paradigm was found, $p = 0.026$. Additionally, there was a significant difference between error rates of subjects' time estimation for negative videos ($M = 1.8$ $SD = 0.07$) and for neutral videos ($M = 2.1$, $SD = 0.11$) in PTP paradigm, $p = 0.005$.

There was also no significant interaction between paradigm and duration, $F(1, 16) = 3.04$, $p = 0.1$, However, post hoc analysis with Bonferroni correction again revealed a significant difference between error rates of subjects' time estimation for 4 s videos ($M = 0.9$, $SD = 0.1$) and for 8 s videos ($M = 3.11$, $SD = 0.23$) in RTP paradigm, $p < 0.001$. There was also a significant difference between error rates of subjects' time estimation for 4 s videos ($M = 1.01$, $SD = 0.13$) and for 8 s videos ($M = 2.81$, $SD = 0.23$) in PTP paradigm, $p < 0.001$.

## Discussion

The current study aimed to investigate effect of emotion and duration on time perception in different paradigms. The results showed that emotion and the duration of stimuli affect the perception of time regardless of the paradigm. For the effect of duration, it is revealed in the present study that time perception of 4 and 8 s videos differs in a way that 4 s videos are perceived longer than their actual duration whereas 8 s videos are perceived shorter than their actual duration in both RTP and PTP paradigms. This finding is found to be compatible with Vierordt's Law which is one of the basic phenomena in time perception literature. According to this phenomenon, longer stimuli are perceived shorter while shorter stimuli perceived longer, respectively (Lejeune and Wearden 2009).

For the effect of emotion, it is observed that time estimation of subjects for positive and negative videos were more accurate and longer than for neutral videos in both RTP and PTP paradigms. The literature on emotion and time perception meets at a common point that emotion changes our perception of time (e.g. Angrili et al. 1997; Noulhiane et al. 2007; Yamada and Kawabe 2011). Furthermore, most of the literature indicate that negative stimuli are perceived longer compared to positive and neutral stimuli because of its evolutionary perspective (e.g. Loftus et al. 1987; Sutherland and Mather 2012). Researchers state that negative emotions provoke stimulation of attention because of their vital importance for living creatures and cause more detail of the stimuli to be remembered (e.g. Arstila 2012). This creates a cognitive load which further leads to overestimation of duration of the stimuli (Block 1989). However, in our study there was no difference in terms of positive and negative stimuli. Both of the positive and negative videos found to be perceived longer and more accurate than neutral videos. This finding is assumed to be resulting from the cognitive load and level of difficulty of the task based on a recent study of Wearden (2015). He pointed that that the difficulty level of the task in experimental conditions can also changes the perception of time. He stated that people remember duration of a stimuli longer when the task is too easy or too hard to accomplish. On the other hand, it is remembered shorter when the task has an intermediate level of difficulty. This situation is explained by the level of attention as people give more attention to the stimuli as its difficulty increases at some degree which lead them to remember the duration shorter. However, if the task is too difficult, then it causes too much cognitive load which further leads duration to be remembered longer. In the current study, motion videos were used as emotional stimuli which both increasing the level of difficulty of the task and cognitive load. From this point of view, it can be assumed that increased difficulty level of the task causes positive and negative stimuli to be separated from each other in terms of their effect on time perception while they still differentiated from the neutral ones.

In the current study it is also found that time estimations for positive and negative videos are differed from the neutral ones only for 8 s videos when the interaction of emotion and duration are considered. This result is thought to be resulted from the complexity of the stimuli because it consists of motion videos rather than static images. Although all negative, positive and neutral videos are significantly separated from each other in terms of their categories, 4 s duration is assumed to be a relatively short duration to stimulate the emotional effect for videos compared to 8 s duration.

One of the other and most important result of the study showed that paradigm changes the time perception of subjects in relation with the emotion and duration of the stimuli. Duration of the 8 s neutral videos are found to be estimated more accurately in prospective time estimations than duration of 8 s neutral videos in the retrospective time estimations. This result supports the idea that attention has a crucial role on time perception. Directing attention

toward time's itself makes time to be perceived more accurately because it decreases loss of pulses during the flow according to the view of internal clock model (Gibbon 1977). Also, it helps people to focus on one stimuli which is time itself and eliminate the distractor effect of other stimuli according to the cognitive load theory (Ornstein 1969; Block 2003). On the other hand, this effect could not be seen for positive and negative videos but only for neutral videos. Again, this result is consistent with the internal clock model and the cognitive load theory since positive and negative videos cause increased attention to the stimuli itself due to their emotional content. Thus, they cause attention to split more than one stimuli, and cause increased cognitive load and change in the flow of pulses. Furthermore, this effect is found to be seen only 8 s videos rather than 4 s videos. This result is assumed to be resulted from increased duration of the stimuli and limited short term memory capacity. As durations of the stimuli increases, some of the temporal and non-temporal information about is lost due to limited short term capacity. Thus, error rate increases as the duration of the stimuli increases. Furthermore, in the current study both 4 and 8 s videos presented together in a randomized order. However, participants were not informed about the different durations of the stimuli. Thus, when limited short term memory is also considered, it is assumed that participants tend to misjudge durations of longer stimuli as more close to the shorter ones. To understand this relationship between duration of the stimuli and error rates of time judgements thoroughly, future studies are necessary with using different stimuli durations in wider ranges together.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

## References

Angrili A, Cherubini P, Pavese A, Manferidni S (1997) The influence of affective factors on time perception. Percept Psychophys 59:972–982

Arstila V (2012) Time slows down during accidents. Front Psychol 3:1–9

Block RA (1989) Experiencing and remembering time: affordances, context, and cognition. In: Levin I, Zakay D (eds) Time and human cognition: a life span perspective. Elsevier Science Publishers, Nort-Holland, pp 333–363

Block RA (2003) Psychological timing without a timer: the roles of attention and memory. In: Helfrich H (ed) Time and mind II: information processing perspectives. Hogrefe & Huber, Göttingen, pp 41–59

Block RA, Zakay D (1997) Prospective and retrospective duration judgments: a meta-analytic review. Psychonomic Bull Rev 4:184–197

Block RA, Hancock PA, Zakay D (2010) How cognitive load affects duration judgments: a meta analytic review. Acta Physiol (Oxf) 134:330–343

Buhusi CV, Meck WH (2006) Interval timing with gaps and distracters: evaluation of the ambiguity, switch, and time-sharing hypothesis. J Exp Psychol Anim Behav Process 32:329–338

Droit-Volet S, Meck WH (2007) How emotions colour our perception of time. Trends Cogn Sci 12:504–513

Friedman WJ, Wilkins AJ (1985) Scale effects in memory for the time events. Mem Cogn 13:168–175

Gibbon J (1977) Scalar expectancy theory and Weber's law in animal timing. Psychol Rev 3:279–325

Hintzman DL (2001) Judgements of frequency and recency: how they relate to reports of subjective awareness. J Exp Psychol Learn Mem Cogn 27:1347–1358

Lejeune H, Wearden JH (2009) Vierordt's the experimental study of the time sense (1868) and its legacy. Eur J Cogn Psychol 21(6):941–960

Loftus EF, Schooler JW, Boone SM, Kline D (1987) Time went by so slowly: overestimation of event duration by males and females. Appl Cognit Psychol 1:3–13

Meck WH (1996) Neuropharmacology of timing and time perception. Cogn Brain Res 3(3–4):227–242

Mereu S, Lleras A (2013) Feelings of control restore distorted time perception of emotionally charged events. Conscious Cogn 22(1):306–314

Noulhiane M, Mella N, Samson S, Ragot R, Pouthas V (2007) How emotional auditory stimuli modulate time perception. Emotion 7(4):697–704

Ornstein RE (1969) On the experience of time. Penguin, Harmandsworth

Owen AM, McMillan KM, Laird AR, Bullmore E (2005) N-back working memory paradigm: a meta-analysis of normative functional neuroimaging studies. Hum Brain Mapp 25:46–59

Schöger E (1993) Event-related potentials to auditory stimuli following transient shifts of spatial attention in a Go/Nogo task. Biol Psychol 36(3):183–207

Sutherland MR, Mather M (2012) Negative arousal amplifies the effects of saliency in short-term memory. Emotion 12(6):1367–1372

Tamm M, Uusberg A, Allik J, Kreegipuu K (2014) Emotional modulation of attention affects time perception: evidence from even-related potentials. Acta Physiol (Oxf) 149:148–156

Treisman M (1963) Temporal discrimination and the indifference interval: implications for a model of the "internal clock". Psychol Monogr Gen Appl 576:1–31

Wagatsuma H, Yamaguchi Y (2007) Neural dynamics of the cognitive map in the hippocampus. Cogn Neurodyn 1:119–141

Wearden JH (2015) Passage of time judgements. Conscious Cogn 38:165–171

Yamada Y, Kawabe T (2011) Emotion colours time perception unconsciously. Conscious Cogn 20(4):1835–1841