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Estimating the duration of visual stimuli in motion environments

Judit Mate*[1], Ana C. Pires[1], Guillermo Campoy[2] & Santiago Estaún[1]

[1]*Universitat Autònoma de Barcelona;* [2] *Universidad de Murcia*

The aim of this research is to determine the influence of visual motion on the temporal estimation of a static object. Previous research has shown that the magnitude of temporal distortion caused by movement depends on objects' speed, although those studies have not taken into account the possible interference of the environment in which objects are embedded. On the basis of the results obtained in a psychophysical task in which the constant-stimuli method was used, we suggest that high-speed conditions produce an overestimation of the duration of an static object whilst, in contrast, low-speed conditions do not show an appreciable effect. The implications of these results are discussed within the comparative framework of the main theoretical models of temporal estimation.

In everyday life, we encounter situations that involve the presence of moving stimuli such as crossing a street with traffic. In these situations, an efficient and adapted performance requires an accurate estimation of variables such as speed (Conchillo, Nunes, Ruiz, & Recarte, 1999) and acceleration (López-Moliner, Maiche, & Estaún, 2003) but it is also necessary to assess, predict and compare the temporal duration of different environmental stimuli (Aubry, Guillaume, Mogicato, Bergeret, & Celsis, 2008). The present study focuses on time estimation and how motion-related factors can distort or modulate the subjective duration of an event.

Regarding time estimation, it is possible to differentiate between a low-level processing, which is sensory-modality-dependent and that is associated with short intervals of time -from around 300 milliseconds until

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2 or 3 seconds (Fraisse 1967; Grothe, 2003; Pöppel, 1988)- and a high-level processing, sensory-modality-independent, which is involved in longer durations and has higher cognitive implications (Lewis & Miall, 2003; Mauk & Buonomano, 2004). Research on time estimation associated with short intervals of time has a long tradition in Psychology, and several studies have focused on the estimation or reproduction of the duration of an static or a moving stimulus (Brown, 1995; Fleury, Basset, Bard, & Teasdale, 1998; Fraisse, 1967, 1984; Kojima & Matsuda, 2000; Perbal, Droit-Volet, Isingrini, & Pouthas, 2002; Predebon, 2002; Zelking & Sprug, 1974). Most of these investigations use a prospective temporal estimation paradigm, in which participants are aware that a time judgment must be performed. On the contrary, in a retrospective temporal paradigm, participants must perform the task without being aware that time is a crucial dimension (Block & Zakay, 1997). Judgments under a prospective paradigm are directly related to the amount of attention drawn to the temporal information of an event (Block, Zakay, & Hancock, 1999) and are considered more accurate than their counterparts in a retrospective paradigm (Block, Zakay, & Hancock, 1998).

It should be noted that the estimation of a short time interval requires internal and external signals. The different perspectives underlying such behavior can be grouped on research based on the personal variables involved in time estimation (Delay & Mathey, 1985; Melges, 1982) and on research that analyzes the characteristics of the stimulus or other phenomena that can potentially affect time estimation (Brown, 1995; Plomp, Gepshtein, & van Leeuwen, 2006; Predebon, 2002; Tayama, Nakamura, & Aiba, 1987).

Within the latter perspective, several theoretical models have been proposed differing in the emphasis given to the factors or mechanisms involved in time estimation, although they may not be mutually exclusive in terms of their predictions. On the one hand, the *storage-size model* proposed by Ornstein (1969), suggests that perceived time depends on the amount of space required to encode and store events in memory. So, a greater complexity or a higher number of stimuli require more memory space and the subjective duration of the interval increases. On the other hand, authors as Fraisse (1967), Loftus, Schooler, Boone and Kline (1987) and Poynter (1989) have developed the *change-segmentation model*, in which the number of perceived changes is assumed to be responsible for an expansion in the remembered duration, assuming change as the index of psychological passage of time. That is, if an interval is divided into more distinct segmentations, more changes will be perceived resulting in an expanded temporal perception. According to Poynter (1989), a duration judgment is based on the ability to sequence the events that occur within an interval relative to the whole duration. Another model is the *attentional locus model*, which states that the lesser attention is given to time, the lesser the subjective duration (Block & Zakay, 1997; Hicks, Millaer, & Kinsbourne, 1976; Zakay, 1989, 1993). Futhermore, Zakay (1989, 1993) highlights the role of attention over the role of memory and states that the mechanism responsible for temporal estimation would involve an internal pulse accumulator whose quantity determines the perceived duration. When attention is withdrawn from the storage of pulses, subjective duration decreases.

Thus, it is assumed that the estimated duration of an event when no concurrent tasks are required, is not only defined by the amount of changes that occur during the interval (Brown, 1995; Fraisse, 1967, 1984; Ornstein, 1969; Poynter, 1989; Thomas and Brown, 1974) but also in terms of the complexity of the event (Avant, Lyman, & Antes, 1975; Thomas & Weaver, 1975).

Regarding motion, it has been studied in several investigations related to temporal issues as it is a factor that determines the estimated duration of a given event (Gibson, 1975; Poynter, 1989). Poynter (1989) highlights the idea that duration is determined by the perceived number of changes, and an important kind of change is the one that takes place on the spatial location (p. 326). Research that has focused on studying the relationship between motion and time estimation (Fraisse, 1967; Kanai, Paffen, Gerbino, & Verstraten, 2004; Kanai, Paffen, Hogendoorm, & Verstraten, 2006; Piaget, 1961; Prebedon, 2002), may be interpreted on the basis of both the storage and the change-segmentation models. The prediction of both models is that the expansion of the estimated time would be proportional to the speed or frequency of changes. In other words, a high speed or high frequency stimulation would produce a greater tendency to overestimate the time compared to a low speed, although in both cases it would cause an overestimation.

In this line, one of the most influential studies was conducted by Brown (1995), suggesting that: (a) moving stimuli expand perceived time, and (b) the subjectively estimated time is superior with both high and low speed, but in a greater degree when the speed is high. However, there is some controversy with regard to these assumptions. For example, Tayama et al. (1987), suggest that the motion of one or more stimuli does not necessarily imply an overestimation of subjective duration. Their results showed that while high speed actually produced a subjective overestimation, low speed produced an underestimation of a moving stimulus compared to a static one. Recently, other authors have questioned the results of Brown (1995) and have indicated that the speed of the stimuli *per se* does not influence time estimation consistently and that the determining factor would be the stimulation frequency (Kanai et al., 2006) or the changes in the direction of motion (Predebon, 2002).

In summary, the studies conducted so far show some contradictions regarding the magnitude of the temporal distortion caused by motion. Moreover, they all focus exclusively on the change that takes place in the stimulus to be judged (its movement, frequency or complexity) without taking into account the possible influence of the environment. Thus, these investigations assume that the system is able to select the visual stimulus that is relevant to the task without considering the fact that contextual information, although irrelevant, can produce a bias or distortion in the perception of several features of the target stimulus such as duration (Kim & Wilson, 1997; Oberfeld & Hecht, 2008). Therefore, it is necessary to study a factor that could be of great interest: The influence of the context motion on the estimated duration of a static stimulus, which becomes relevant when extrapolated to the dynamic reality of our world. For example, in situations such as driving, individuals engage in appropriate actions depending on how they interpret the relationship between their own vehicle and external circumstances (Sato & Akamatsu, 2007). So, perception of different stimuli (traffic signs, pedestrians or other vehicles) may be influenced by the speed at which the environmental elements move, among other factors.

In conclusion, it is of major significance to determine the distortion produced by a dynamic context (at different speeds) and the direction of this distortion (underestimation or overestimation). The aim of the present study is to analyse these issues by using the psychophysical method of constant stimuli. This method appears to be the most reliable as it provides a valuable reference before and after each time judgement (Plomp et al., 2006; Tse, Intriligator, Rivest, & Cavanagh, 2004; Vatakis & Spence, 2006).

EXPERIMENT 1

METHOD

Participants. Seven students, five females and two males (aged between 20 and 23) participated in the experiment. All reported having normal or corrected-to-normal visual acuity.

Apparatus and stimuli. The experiment was conducted on a computer with a Pentium III processor and a 21" monitor with a resolution of 800 x 600 pixels and a refresh rate of 85 Hz. A software developed *ad hoc* was used for stimulus presentation and response registration. Participants sat at approximately 50 cm from the screen so that the overall angle of vision was 31º vertical and 39º horizontal.

The standard stimulus was a red rectangle that appeared in the centre of the screen for 1.5 seconds, embedded in an environment consisting of 16 static blue circles presented on a white background (see Figure 1). The choice of a standard duration of 1.5 seconds is due to the fact that it falls into the temporal range considered as *subjective present*, that is, the temporal interval in which only short-term or working memory processes are involved (Fraisse, 1967; Michon, 1978; Tse et al., 2004). The comparison stimulus was a rectangle of the same size and colour that also appeared in the centre of the screen, surrounded by 16 blue circles. During the presentation of the comparison stimuli, the circles of the context moved up, down, left and right (four circles in each direction). The environment moved at two different speeds: In the slow condition circles moved at a speed of 10 cm /s, and at 33 cm/s in the fast condition. The duration of comparison stimuli on the screen was variable, with six possible durations: 0.9, 1.2, 1.4, 1.6, 1.8 or 2.1 seconds. This range allows us to adjust the corresponding psychometric function for each participant (Tse et al, 2004).

Procedure. The constant stimuli method with two-alternative forced-choice (Yes/No) was used. The type of environment, with two levels (high / low speed) was the independent variable, resulting in a within-subjects design.

The task consisted of comparing the duration of the standard stimulus with the duration of the comparison stimulus. Each trial began with a fixation point located at the centre of the screen, whose duration was determined at random in each trial between 0.5 and 1.5 seconds. Then, the standard stimulus appeared (for 1.5 seconds in a static environment) followed by a blank screen. One second after the disappearance of the standard stimulus, the comparison stimulus was presented for one of the six possible durations (0.9, 1.2, 1.4, 1.6, 1.8 or 2.1 seconds) and in one of two speed conditions of the environment (high, low). Finally, the question *Has the second rectangle been on the screen for longer than the first?* appeared and participants had to respond by pressing the S key (YES response) or the N key (NO response).

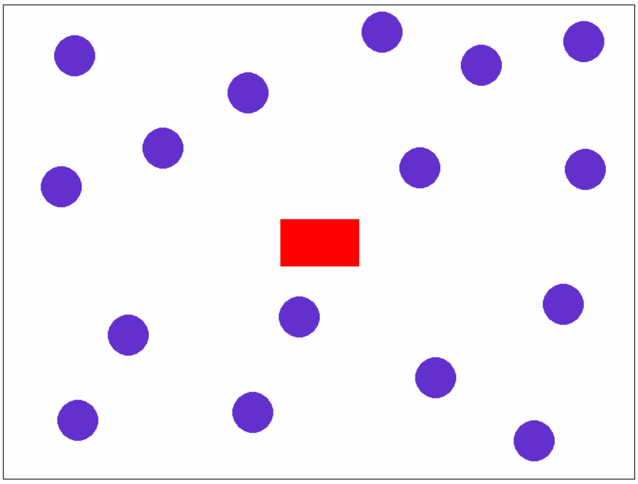

Figure 1: Example of the display during stimuli presentation

The experiment consisted of 192 trials divided into four blocks of 48 trials. Within a block, there were four trials of each of the 12 comparison stimuli resulting of the combination of the six possible durations with the two speeds of the environment. Trials appeared randomly. Participants were not warned in advance about the different types of stimuli, being instructed only to judge the duration of the red rectangles and to respond to the question presented on the screen at the end of each trial. The experiment was preceded by 9 practice trials and it ran for approximately 90 minutes. Participants were asked to rest for a few minutes between blocks.

RESULTS AND DISCUSSION

Two psychometric functions (for low and high speed) were adjusted for each subject. *Logit* transformation was applied on the proportions of affirmative answers *(p),* so that $logit(p) = ln[(p/1-p)] = \alpha+\beta X$, where X is the duration of the comparison stimulus. Finally, the point of subjective equality *(PSE)* defined by the value of the stimulus for a probability of .5 was estimated ($PSE= -\beta/\alpha$). The PSE value, therefore, represents the duration of the comparison stimulus that the participant perceives as equal to the duration of the standard stimulus. The adjustment of the estimated psychometric functions of each speed condition showed significant levels of goodness-of-fit. The squared correlation (R^2) was above 0.65 in all cases, with an average of 0.89.

The analysis showed that the PSE in the high-speed condition ($\overline{X}$ = 1.35; S_X = 0.15) was significantly lower than in the low-speed condition ($\overline{X}$ = 1.55; S_X = 0.12), [$t(6) = 5.39$, $p < .01$; two-tailed], and also significantly lower than the duration of the standard stimulus (1.5), [$t(6) = 2.63$, $p = .04$, two-tailed]. On the other hand, the PSE in the low-speed condition was above the duration of the standard stimulus, although the difference was not significant [$t(6) = 1.15$, $p = .29$, two-tailed]. Thus, results revealed that participants overestimated the duration of comparison stimuli presented in high-speed environments, while the duration of the comparison stimuli presented in low-speed environments was not overestimated or underestimated significantly. However, although the effect of fast environments seems to be clear, the absence of a control condition in which comparison stimuli were presented in static environments does not allow discarding alternative explanations, such as biases of the procedure used to obtain the PSE. For this reason, a second experiment was carried out which was essentially equivalent to Experiment 1, but including this necessary control condition.

EXPERIMENT 2

METHOD

Participants. Eighteen students, ten females and eight males (aged between 19 and 34 years), participated voluntarily. All reported having normal or corrected-to-normal visual acuity.

Apparatus, stimuli and procedure. Materials and procedure were the same as in Experiment 1 with the following exceptions. First, a new type of comparison stimulus presented in a static environment was introduced. Therefore, 18 different types of comparison stimuli were shown, which were the result of combining the six possible durations (0.9, 1.2, 1.4, 1.6, 1.8 or 2.1 seconds) with the three environmental conditions (static, low-speed, high-speed). In this case, the total number of trials was 216; 54 in each of the four blocks. Secondly, the order of presentation of comparison and standard stimuli was randomly determined in each trial. In half of the trials, the comparison stimulus appeared after the standard stimulus and in the other half it appeared before. This manipulation was intended to control any effect arising from the order of stimuli presentation. The blank screen presented between the standard and the comparison stimulus was replaced by a black screen, to avoid any effect of visual persistence (Coltheart, 1980).

RESULTS AND DISCUSSION

Again, three psychometric functions (for static, low-speed and high-speed) were adjusted for each participant. The same *logit* transformation on the proportions of affirmative answers *(p)* was used. The goodness-of-fit was high, with R^2 values above .50 in all cases with an average of .64.

A within-subjects ANOVA with repeated measures was conducted on the averages of the PSE values in the three environment conditions (static, low-speed, high-speed). This analysis revealed a significant effect of the type of environment, F (2, 34) = 8.80, p <.01, which was due to the PSE corresponding to fast environments ($\overline{X}$ = 1.42; S_X = 0.16) being significantly lower than the PSE of static environments ($\overline{X}$ = 1.59; S_X = 0.09) and the PSE of slow environments ($\overline{X}$ = 1.59; S_X = 0.10), respectively F (1, 17) = 11.56 and 9.35, p <.01. The PSE of slow and static environments did not differ (F <1). Comparisons showed that the PSE of the fast environment condition was significantly lower than the duration of the standard stimulus (1.5), [t (17) = 2.15, p <.05; two-tailed]. The fact that the PSE of fast environments was lower than the duration of the standard stimulus and also than the PSE obtained with static environments reveals, consistent with Experiment 1, that the duration of stimuli presented in fast environments was overestimated.

Moreover, the PSE obtained with slow and static environments did not differ (the mean was 1.59 in both cases) proving that the duration of stimuli presented in slow motion environments is not overestimated or underestimated. It should be noted, however, that the PSE of both slow and static environments were significantly above the standard duration of stimulation, [t (17) = 3.68 and 3.98, p <.01; two-tailed] respectively. This unexpected result could be due to the greater difficulty of the task when the duration of the comparison stimuli was above the duration of the standard stimulus, compared to the trials in which the duration of the comparison stimuli was less than 1.5 seconds. Initially, this difference in the difficulty was not expected due to the fact that the duration of the comparison stimuli above and below the duration of the standard stimulus were different from 1.5 in the same degree (see Appendix 1). Futhermore, it seems reasonable that the difficulty of the task was in fact determined by the relationship between the durations to compare, rather than by the difference between the durations considered in absolute terms. Thus, the difficulty of the task can be calculated by the formula *difficulty = short duration / long duration,* which yields values between zero and one (1 = maximum difficulty). As shown in Appendix 1, the difficulty of discrimination was higher with durations of comparison stimuli above 1.5. The result of such difference between stimuli above and below the standard duration implies a positive bias to the PSE values. To illustrate this, we calculated the PSE value that should be obtained by a hypothetic participant whose performance was different from perfect performance in a degree proportional to the value of difficulty of the task for each duration of the comparison stimulus. Therefore, for comparison stimuli with a duration less than 1.5 seconds (which would imply a perfect performance at $p = 0$) p values were calculated by the equation $p = 0 + (0.5 \times \text{difficulty})$. For comparison stimuli with a duration greater than 1.5 (which would imply a perfect performance at $p = 1$), we used the formula $p = 1 - (0.5 \times \text{difficulty})$. With these p values, the obtained PSE was 1.55, which is above the standard duration. Therefore, we conclude that the PSE of the comparison stimuli in static environments being above 1.5 was probably due to a greater difficulty of the task for the comparison stimuli with durations over 1.5 seconds. Hence, comparisons between the obtained PSE and the duration of the standard stimulus are not appropriate, since the characteristics of the procedure may bias PSE values positively. Fortunately, the inclusion of a control condition with comparison stimuli presented in static environments solves this problem by providing a suitable point of comparison for the PSE in the two other conditions of environment. Taking this control condition as a point of comparison, the results clearly show that fast environments produce an overestimation of the duration of a static stimulus, while slow environments do not have any influence on time estimation.

GENERAL DISCUSSION

The aim of this research was to investigate the influence of the speed of environmental stimuli on the duration estimation of a static object. This work provides additional information compared to previous investigations, which have focused on the distortions in the subjective duration of one or more moving stimuli without taking into account the role of the environment in which stimuli are embedded.

The two experiments showed consistently that participants overestimated the duration of stimuli presented in fast environments while the duration of stimuli presented in slow environments was not overestimated or underestimated. This was especially clear in Experiment 2, which included a control condition that allowed more appropriate comparisons. These results are consistent with previous research (Brown, 1995; Kanai et al., 2006), which found that the higher the speed, the greater the subjective duration, although in these studies motion was only present in the target and not in the environment.

A possible interpretation arises from the memory model proposed by Ornstein (1969). According to Ornstein, the greater complexity of the screen where the objects move at high speed produces the feeling that more events have taken place and therefore there is a higher memory demand and a consequent greater subjective duration. Another explanation based on the number of changes due to the fast movement of the surrounding stimuli is given by Poynter (1989). In the high-speed condition, the interval is divided into more significant parts with respect to the low-speed condition, so more changes are perceived and subjective duration increases. However, the attentional model would point to the opposite trend: Despite the fact that participants are not required to respond to the context in which the target appears, it seems reasonable that the presence of contextual motion stimuli captures their attention (Grondin & Macar, 1992; Macar, Grondin, & Casini, 1994; Predebon 1996). If attention is drawn to the environment, the accumulation of internal pulses should be lower and the result would be an underestimation of the duration of the target stimulus. Therefore, the results of this study can be accounted for by both the memory and the segmentation models, but seem to be inconsistent with attentional models.

An important issue that deserves special consideration is that the effect did not appear in slow motion environments. The models of memory and segmentation would predict an overestimation of duration in both contexts of movement, but probably of a lower magnitude in the case of low speed. This pattern has been found in most investigations that have studied the influence of the stimulus motion without manipulating the environment (Brown, 1995; Predebon, 2002; Tse et al., 2004), even in the cases in which the speed was less than the low speed used in our experiments (Kojima & Matsuda, 2000; Predebon, 2002). One possible explanation is that, in the present study, participants' attention was focused on the target stimulus, which remained static in all cases. Consequently, it is reasonable to think that the movement had a minor effect in comparison with experiments in which the target stimulus, and not the environment, moves. This outcome might explain why an overestimation of the duration was only observed in the high-speed condition, in which, presumably, the level of complexity was enough to produce the effect. Another possible explanation is that, in our study, the control condition includes itself an environment consisting of 16 stationary blue circles, which adds information to the episode. According to the memory model premises, a stimulus presented in an environment, though static, does include some extra visual information and hence it implies higher level of memory demands. This could lead to a greater difficulty to detect an additional effect produced by the slow movement of the surrounding stimuli.

In summary, the results of our research suggest that a significant distortion in the estimation of the subjective duration of a stationary visual stimulus takes places when the environmental speed adds a certain level of complexity to the event.

RESUMEN

Estimación de la duración de estímulos visuales en contextos en movimiento. En este trabajo se investiga la influencia del movimiento visual del entorno sobre la estimación temporal de un objeto estático. Las investigaciones previas muestran que la magnitud de la distorsión temporal provocada por el movimiento depende de la velocidad de los objetos, si bien dichos estudios no han tenido en cuenta la posible interferencia del contexto en el que éstos se encuentran. A partir de los resultados obtenidos en una tarea psicofísica en la que se empleó el método de los estímulos constantes, se sugiere que se produce una sobreestimación de la duración subjetiva del objeto cuando la velocidad de los estímulos circundantes es alta, mientras que a velocidades bajas el efecto no es apreciable. Las implicaciones de estos resultados se discuten en el marco comparativo de los principales modelos teóricos sobre estimación temporal.

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APPENDIX

Difference in absolute terms between the duration of the comparison and the standard stimuli and difficulty rate of the discrimination between durations

Duration of the comparison stimuli	Duration of the standard stimulus	Difference between durations in absolute terms	Discrimination difficulty between durations
0.9 s.	1.5 s.	0.6 s.	0.60
1.2 s.	1.5 s.	0.3 s.	0.80
1.4 s.	1.5 s.	0.1 s.	0.93
1.6 s.	1.5 s.	0.1 s.	0.94
1.8 s.	1.5 s.	0.3 s.	0.83
2.1 s.	1.5 s.	0.6 s.	0.71

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