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Brief Communication

The Effect of the Symbolic Meaning of Speed on Implicit Timing

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Abstract

It has been demonstrated that the stimulus's features, including size, brightness, numerosity, and loudness, can affect the perception of subjective and explicit time. But, in a daily life situation, actual events presumably involve an implicit processing of time rather than an explicit processing, with some studies suggesting that the presentation of emotional stimuli before the target stimulus influences implicit timing. The present study aims to test the implicit component of temporal processing that the symbolic meaning of speed might influence. We used a time foreperiod task in which participants were first presented with a warning signal recalling the meaning of fast or slow speed, followed by the target. Our study shows significant main effects of the presented image cue and foreperiod effect. We observed faster reaction time when the target was preceded by a faster image compared to a slow image and in dependence of the factor of weight. Based on this, we conclude the symbolic meaning of speed can affect implicit timing by altering how the brain interprets temporal data.

Keywords

foreperiod effect, time perception, emotion, symbolic meaning of speed

1. Introduction

Despite people being accurate in estimating and processing time, our perception of the passage of time is relative and can be affected by different factors. It has been shown that subjective perception of time can be modulated by stimulus properties such as its size (Ono & Kawahara, 2007; Xuan et al., 2007), brightness (Matthews et al., 2011; Stévens & Hall, 1966), numerosity (Vicario, 2011), or loudness (Grassi & Mioni, 2020; Stévens & Hall, 1966). Moreover, the effects of emotional stimuli on time have long been studied, indicating that time passes faster during a highly emotional event compared to a neutral one (Droit-Volet, 2016; Droit-Volet & Meck, 2007; Yamada & Kawabe, 2011). Most of the above-mentioned studies asked participants to attend to the stimulus's duration, which was the explicit goal of the task. Participants knew in advance that they had to estimate time (explicit timing).

However, time is not always explicitly processed; probably in most real-life situations, time is implicitly processed. Imagine that you are driving your car and that you arrive at the intersection with a red traffic light. Although you do not know how long the traffic light has been red, the longer you wait, the faster you will push the accelerator when the green light finally comes. In the laboratory setting, the above example can be mimicked by presenting a warning signal (i.e., the red traffic light) followed by a target (i.e., the green traffic light) and by manipulating the time interval (or foreperiod) between the warning signal and the target. Participants are generally instructed to press a key as fast as possible when the target appears on the screen; in addition, they are not informed of the variable time (or variable foreperiod) between the warning and the target stimuli. The results typically show that the participants' reaction times (RTs) are faster for the longest foreperiod trials, an effect known as the 'foreperiod effect' (Capizzi et al., 2013; Niemi & Näätänen, 1981; Visalli et al., 2021). The foreperiod effect is explained by the increasing conditional probability that the target stimulus is going to appear, given that it has not already occurred (Nobre et al., 2007; Vangkilde et al., 2013). Since no explicit information about time is given to participants, the foreperiod effect is taken as evidence for an implicit processing of time (Coull & Nobre, 2008; Capizzi et al., 2023).

Similar to the observed over- or underestimation biases produced by emotional stimuli on explicit timing (Droit-Volet, 2013; Droit-Volet & Meck, 2007; Yamada & Kawabe, 2011), the presentation of emotional stimuli before the target stimulus also affects implicit timing. Emotional stimuli have been shown to yield a faster or slower RT to a subsequent target depending on the emotional congruency between the prime and target stimuli (Hermans et al., 2001; Murphy & Zajonc, 1993).

Droit-Volet (2016) used a variation of the time generalisation task to test for the effect of angry and neutral emotional facial expressions on implicit timing.

Facial emotional stimuli (angry, sad and neutral facial expressions) were displayed between two auditory stimuli (variable duration); participants were instructed to press the designed key as fast as possible after the second sound. Results showed a main effect of emotion, indicating shorter RT with the emotional stimulus of anger/sadness than with the emotional stimulus of neutrality. However, the interaction between the emotional stimuli and the foreperiod duration was not significant, a result consistent with an automatic acceleration of motor executive functioning in response to aggressive stimuli, regardless of the foreperiod duration. The author reasoned that the lack of a clear effect of emotional stimuli on implicit timing could have been caused by the type of stimuli used; indeed, the effect of emotional stimuli on subjective time depends on the stimuli used and their meaning for individuals. Droit-Volet and Berthon (2017) replicated the same procedure in a between-participants design with images from the International Affective Pictures System (IAPS; Bradley & Lang, 2007). Participants were assigned to highly or moderately arousing conditions. The results replicated the findings of Droit-Volet (2016) indicating faster RT for highly arousing stimuli. Moreover, they also extended previous results demonstrating that the effects of emotion on RT varied as a function of the foreperiod durations and showing that emotional stimuli directly affected implicit time processing.

Taken together, previous studies confirmed that highly arousing negative stimuli may impact RT showing shorter RTs after highly arousing stimuli, but it is still unclear whether this effect is caused by a general automatic acceleration of motor responses or a variation at the level of the internal clock.

In a series of previous studies, we investigated the effect of the symbolic meaning of speed on explicit timing (Mioni et al., 2015, 2018) and time-to-contact (Battaglini & Mioni, 2019), reporting that the presentation of images that recalled the meaning of fast speed influenced subjective perception of time by reducing the reproduced time (Mioni et al., 2018), shifting the psychometric function to the right (temporal underestimation; Mioni et al., 2015), and shortening time-to-contact estimated with stimuli recalling the meaning of high compared to low speed with long occlusion duration (Battaglini & Mioni, 2019). Also, previous studies indicated that the faster the vehicle/object, the shorter the estimated duration, consistent with the assumption that the retrieval of speed and duration information types are both subject to a reconstructive process (see also Harris, 1973; Loftus & Palmer, 1974). In particular, previous results were interpreted in accordance with an inferential/reconstructive process occurring in memory and acting on temporal judgements: Knowing the relationship between action speed and event duration influences temporal processing (Loeffler et al., 2018).

The present study aims to test the implicit component of temporal processing that might be influenced by the symbolic meaning of speed. We used a variable foreperiod task in which participants were first presented with a warning signal consisting of an image recalling the meaning of fast or slow speed (Battaglini

et al., 2021), followed by the target; participants were instructed to press a designed key as soon as the target appeared after the variable foreperiod. We hypothesise that RT should be faster when the target is preceded by an image (warning signal) that recalls the meaning of fast speed. Based on the literature and former research (Battaglini & Mioni, 2019; Droit-Volet & Berthon, 2017), we expect that warning signals with faster meaning, such as a Formula-1 car, can cause changes in the implicit perception of time evident as a modification of the foreperiod effect (i.e., change in the slope).

2. Study 1

2.1. *Participants and Procedure*

Twenty-eight university students participated in the study [11 male; mean age = 22.06 years (0.97); range = 20–24 years]. In this and the following experiments, all the participants were recruited and tested at the Department of General Psychology, University of Padova. Moreover, all of them were naive with respect to the purpose of the experiment and gave informed consent according to the Declaration of Helsinki prior to their inclusion. They all had normal or corrected-to-normal visual acuity.

2.2. *Foreperiod Task*

In this paradigm, each trial started with the presentation of one of two images (warning signals) representing a vehicle recalling the meaning of slow (bicycle) or fast (motorbike) speed (Fig. 1). The two pictures were embedded in an invisible rectangle of 5.5×4.125 degrees and presented at the centre of the computer screen, the same as used by Battaglini and Mioni (2019). The length of the bicycle and the motorbike was the same, 5.5 degrees. The images remained on the screen for 2000 ms followed by a blank screen (variable foreperiod) of 500, 1000, or 1500 ms. The target was a black capital 'X' that appeared for 100 ms once the foreperiod duration elapsed. The participants were instructed to respond by pressing the spacebar as quickly as possible. Following the response to the target, or after 1900 ms in case of a missed response, we presented a variable Inter Trial Interval (ITI) (between 500 and 1500 ms) and the next trial began. The foreperiod task comprised three blocks of variable foreperiod in which all durations were randomly presented. Participants performed three blocks that included 96 trials (a total of 288 trials). An initial training phase with six trials was used to ensure that participants correctly understood the task.

2.3. *Statistical Analyses*

Trials with RT less than 100 ms or longer than 1000 ms and trials without responses were rejected from the analysis (this approach was used in all subsequent studies,

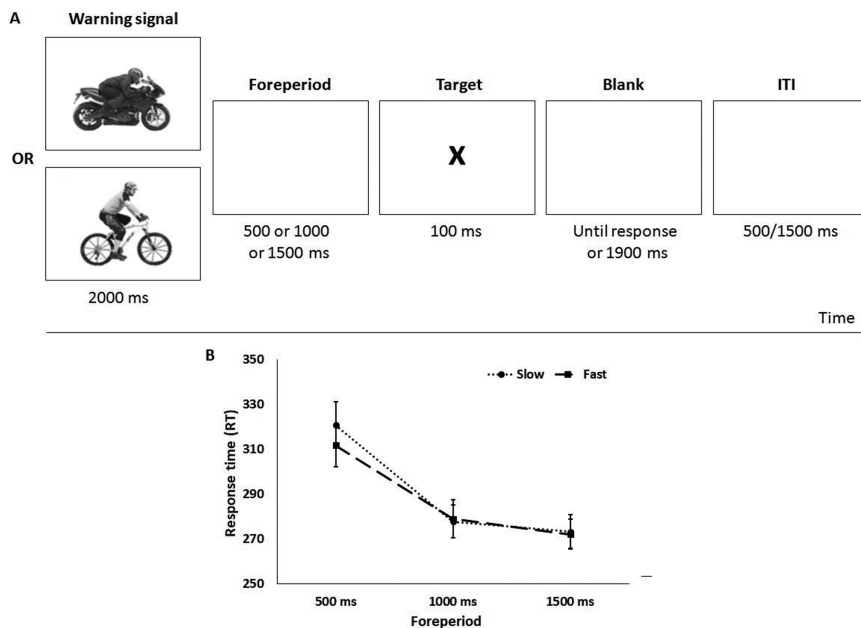


Figure 1. (A) The foreperiod paradigm with images of a person driving a motorbike or a bicycle as warning signals. After a variable foreperiod, participants were instructed to press a key when the target appeared on the screen. (B) Mean reaction times as a function of vehicle and foreperiod; a significant difference is observed between slow and fast vehicles at 500 ms ($p = 0.019$). The bars indicate standard errors.

such that we report it only here to avoid redundancy); analyses were performed on 96% of the trials. For this and the subsequent analyses, mean RTs for each participant and condition were analysed through a repeated-measures ANOVA with *Vehicle* (slow, fast) and *Foreperiod* (500, 1000 and 1500 ms) as within-participant factors. All analyses were conducted using *Jamovi* 2.3.16 (The Jamovi Project, 2021) and the level of significance was set at $p < 0.05$. Data normality was checked with the Kolmogorov–Smirnov test. We carried out post-hoc *t*-tests applying Bonferroni’s correction (for all studies).

2.4. Results and Discussion

Significant main effects of *Vehicle* ($F_{1,27} = 5.54, p = 0.026, \eta^2_p = 0.17$) and *Foreperiod* ($F_{2,54} = 111.65, p < 0.001, \eta^2_p = 0.80$) were found as well as significant interaction between the two variables ($F_{2,54} = 3.39, p = 0.041, \eta^2_p = 0.11$) (Fig. 1B). Post-hoc analyses indicated that faster responses were observed as the duration of the foreperiod decreased for both slow (bicycle; all $p < 0.001$, all $d \geq 0.91$) and fast (motorbike; all $p < 0.001$, all $d \geq 0.68$) vehicles; moreover, participants gave faster responses when the stimulus was the motorbike compared to the bicycle for the 500-ms foreperiod ($p = 0.019, d = 0.17$); no differences between vehicles

were observed at 1000 ($p > 0.05$, $d = 0.02$) and 1500 ms ($p > 0.05$, $d = 0.03$) foreperiod intervals.

Consistent with our prediction, we observed faster RT when the target was preceded by a fast vehicle compared to a slow vehicle and this effect was evident at 500 ms. It is possible that in a longer foreperiod participants reached the fastest performance, limiting the effect of the image on motor preparation. At shorter foreperiods (500 ms), it is possible that the presentation of a fast vehicle acted on motor response facilitating motor preparation. Previous studies have also shown that the implicit knowledge of weight influences time perception (Vicovaro et al., 2019) and time-to-contact performance (Battaglini & Mioni, 2019; Vicovaro et al., 2019). Study 2 was conducted to further investigate the effect of the symbolic meaning of speed on implicit timing by controlling for the implicit knowledge of weight (Vicovaro et al., 2019); in particular, an image of a tank (high weight but slow speed) and an image of a Formula-1 car (low weight but fast speed) were used.

3. Study 2

3.1. *Participants and Procedure*

Twenty-eight university students participated in the study [13 male; mean age = 21.36 years (1.40); range = 19–24 years]. As in the previous study, in the foreperiod paradigm, each trial started with the presentation of one of two images representing a vehicle recalling the meaning of slow (tank) or fast (Formula-1 car) speed (Fig. 2A). The two pictures were of the same size as in Study 1. An initial training phase with six trials was used to ensure that participants correctly understood task instructions.

3.2. *Results and Discussion*

After trial rejection, the analyses were performed on 93% of the total number of trials. Significant main effects of *Vehicle* ($F_{1,27} = 6.16$, $p = 0.020$, $\eta^2_p = 0.19$) and *Foreperiod* ($F_{2,54} = 65.14$, $p < 0.001$, $\eta^2_p = 0.71$) were found, indicating that participants were faster when the target was preceded by the fast vehicle (Formula-1 car) than when it was preceded by the slow vehicle (tank); also, participants were generally faster as the temporal interval increased (foreperiod effect; 500 ms vs 100 ms, $p < 0.001$; 500 ms vs 1500 ms, $p < 0.001$; 1000 ms vs 1500 ms, $p = 0.002$). No interaction between variables was found ($F_{2,54} = 0.45$, $p = 0.640$, $\eta^2_p = 0.02$). Unlike in Study 1, here we observed a main effect of the fast vehicle indicating that when the image of the Formula-1 car preceded the target, participants tended to give faster responses compared to when the image of the tank was presented. The results confirmed the effect of speed on motor preparation independently of the physical characteristics of the image. As mentioned, Study 2 was

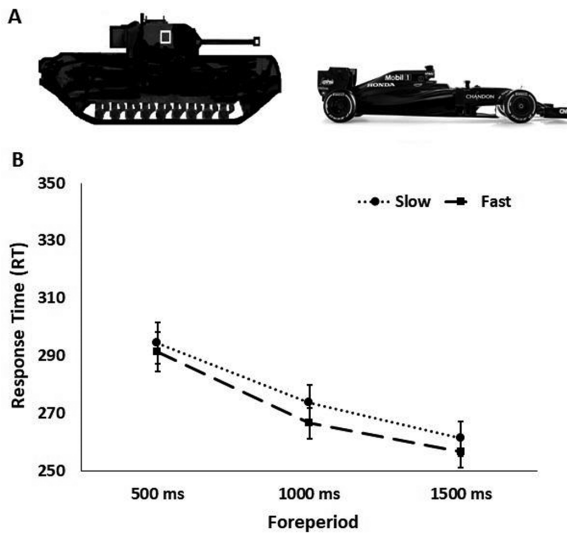


Figure 2. (A) Images of a tank (slow vehicle) and a Formula-1 car (fast vehicle) used as warning stimuli. (B) Mean reaction times as a function of vehicle and foreperiod. The bars indicate standard errors.

conducted to control for the effect of implicit knowledge of weight on implicit timing. We acknowledge that a tank (in real life) is not only heavier compared to the Formula-1 car, but it is also bigger in size. A number of studies have demonstrated that large stimuli are perceived to last longer (explicit timing) than smaller ones presented for the same duration (Rammsayer & Verner, 2015; Xuan et al., 2007). Although the images used in the study were controlled for size (embedded in an invisible rectangle of 5.5×4.125 degrees), we cannot rule out the possibility that recalling the representation of the physical size of the vehicles might have affected our results; one could indeed argue that slower RTs were observed after tank presentation not only because it recalls the idea of a slow object but also because of its bigger size.

For this reason, we conducted two new studies in which we investigated the effect of the symbolic meaning of speed on implicit timing as well as the physical size of the objects. For study 3, we employed two animals of similar size and weight: a turtle (slow speed) and a hare (fast speed); while for study 4 we used two new animals: a turtle (slow speed — small size) and a horse (fast speed — big size).

4. Study 3

Twenty-eight university students participated in the study [16 male; mean age = 22.01 years (1.08); range = 21–23 years]. As for the previous studies, in the foreperiod paradigm, each trial started with the presentation of one of two images,

for this study representing an animal recalling the meaning of slow (turtle) or fast (hare) speed (Fig. 3A). The two pictures had the same length and were embedded in an invisible rectangle of 5.5×4.125 degrees. An initial training phase with six trials was used to ensure that participants correctly understood task instructions.

4.1. Results and Discussion

Considering trial rejection, the analyses were conducted on 97% of the total number of trials. Significant main effects of *Animal* ($F_{1,27} = 8.38, p = 0.007, \eta^2_p = 0.24$) and *Foreperiod* ($F_{2,54} = 43.20, p < 0.001, \eta^2_p = 0.61$) were found (Fig. 4B). Faster responses were observed as the duration of the foreperiod increased (500 ms vs 100 ms, $p < 0.001$; 500 ms vs 1500 ms, $p < 0.001$; 1000 ms vs 1500 ms, $p = 0.080$), moreover, participants gave faster responses when the stimulus was the hare compared to the turtle. No interaction between variables was found ($F_{2,54} = 1.56, p = 0.219, \eta^2_p = 0.05$).

Results of Study 3 confirmed a significant main effect of the symbolic meaning of speed on implicit timing; in particular, in this study we controlled for the physical and perceptual size of the stimuli presented. The animals selected are approximately the same size and weight in everyday life. These two animals are often associated with the meaning of slow and fast animals. Indeed, children learn “the hare and the tortoise race” in which a slow but more intelligent (the tortoise)

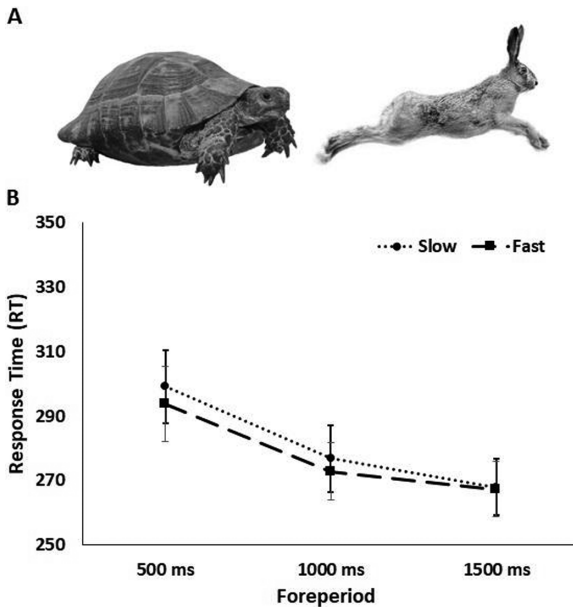


Figure 3. (A) Images of a turtle (slow animal) and a hare (fast animal) used as warning stimuli. (B) Mean reaction times as a function of animal and foreperiod. The bars indicate standard errors.

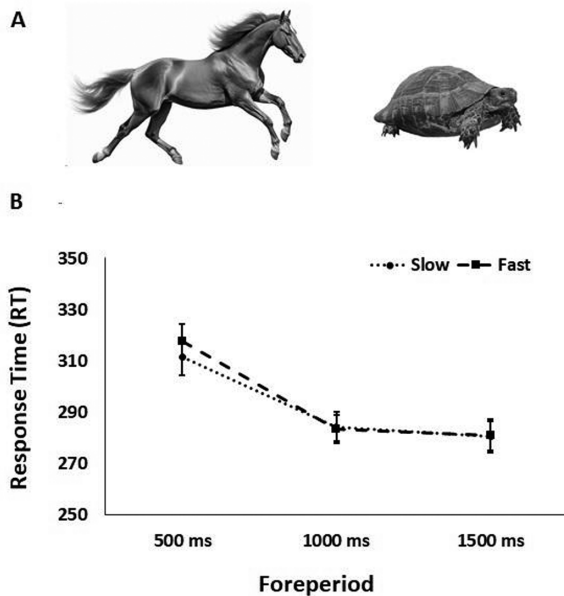


Figure 4. (A) images of a horse (fast animal) and a turtle (slow animal) used as warning stimuli. (B) Mean reaction times as a function of *Vehicle* and *Foreperiod*. The bars indicate standard errors.

wins the race, beating the faster hare. The association of these two animals is often used, at least in Western culture, to teach the prototypical characteristics of animals; this might have influenced the motor preparation of our participants. The fourth study was conducted to control for the physical and perceptual size of the objects used as warning signals. As mentioned before, the results of Study 2 did not rule out the possibility that the slower RTs observed when the tank preceded the cue were caused not only by the symbolic meaning of speed (tank slower than an F1 car) but also by the representation of the physical size of the vehicles (big objects perceived as slower). To overcome this limitation, we used two new animals with different sizes in everyday life and opposite characteristics compared to the two vehicles selected for Study 2. The horse was selected because it is bigger and heavier than a turtle, but it recalls the meaning of a fast animal compared to a turtle.

5. Study 4

Twenty-eight university students participated in the study [14 male; mean age = 24.14 years (3.22) range = 20–33 years]. As for the previous study, in the foreperiod paradigm, each trial started with the presentation of one of two images, for this study representing an animal recalling the meaning of slow (turtle) or fast (horse)

speed (Fig. 3A). The length of the horse was 11×7 cm and turtle was 7×4 cm. An initial training phase with six trials was used to ensure that participants correctly understood task instructions.

5.1. Results and Discussion

Considering trial rejection, the analyses were conducted on 98% of the total number of trials. A significant main effect of the *Foreperiod* ($F_{2,54} = 45.44, p < 0.001, \eta^2_p = 0.63$) was observed, indicating faster RT as the duration of the foreperiod increased (500 ms vs 100 ms, $p < 0.001$; 500 ms vs 1500 ms, $p < 0.001$; 1000 ms vs 1500 ms, $p > 0.05$). No main effect of *Animal* ($F_{1,27} = 0.308, p = 0.583, \eta^2_p = 0.01$) nor interaction between variables was found ($F_{2,54} = 1.88, p = 0.162, \eta^2_p = 0.06$). In this fourth study, we thus failed to observe the effect of the symbolic meaning of speed on implicit timing, as there was only a significant main effect of foreperiod (foreperiod effect).

As a control analysis, we combined data from all the studies (112 participants) and analysed them through a repeated-measures ANOVA with *Symbolic meaning of speed* (slow, fast) and *Foreperiod* (500, 1000 and 1500 ms) as within-participant factors. Significant main effects of the *Symbolic meaning of speed* ($F_{1,111} = 5.19, p = 0.025, \eta^2_p = 0.04$) and *Foreperiod* ($F_{2,222} = 231.86, p < 0.001, \eta^2_p = 0.68$) were found, showing that participants were faster when the target was preceded by an image recalling the meaning of fast speed compared to slow speed. Moreover, participants were overall faster as the temporal interval increased (foreperiod effect). No interaction between variables was found ($F_{2,222} = 0.30, p = 0.743, \eta^2_p = 0.01$) (Fig. 5).

6. General Discussion

Implicit processing of time is considered an automatic process that allows individuals to anticipate the arrival of the next target and to be prepared to respond as quickly as possible when it appears (Coull & Nobre, 2008). Previous studies showed that emotional factors during the temporal preparation for action can modulate the effect of the foreperiod (Droit-Volet & Berthon, 2017).

Consistent with our hypothesis, the results of the current studies demonstrated an effect of the symbolic meaning of speed on RTs in an implicit timing task using a variable foreperiod manipulation. Specifically, we observed faster RTs when the target was preceded by an image depicting a fast vehicle compared to a slow vehicle.

As expected, we also observed the classic foreperiod effect whereby RTs were faster for targets appearing after long foreperiods compared to short foreperiods (Niemi & Näätänen, 1981). This effect is thought to reflect participants' increased temporal readiness at long foreperiods due to the conditional probability of target onset increasing over time after the warning signal (Elithorn & Lawrence, 1955).

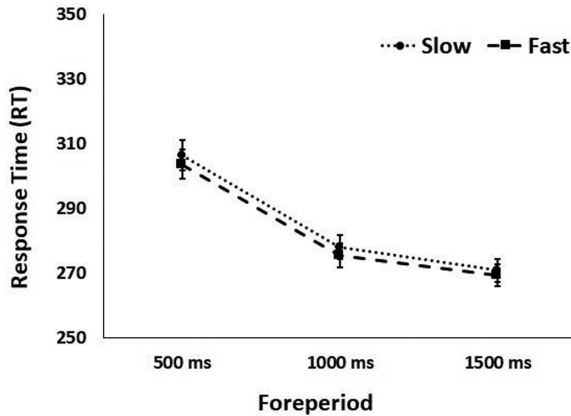


Figure 5. Mean reaction times as a function of symbolic meaning of *Speed* and *Foreperiod*. Slow and Fast refer to all the stimuli used as warning signals across the four studies referring to slow or fast vehicles and animals. The bars indicate standard errors.

Our results confirm previous findings showing the robustness of the foreperiod effect across different experimental designs.

The present work suggests that the effect of the symbolic meaning of speed on implicit timing is more evident as a generalised effect on readiness to respond rather than a clear effect on the foreperiod effect. In Experiment 1, we observed a significant interaction between the symbolic meaning of speed and foreperiod duration, but this interaction was not confirmed in Experiments 2 and 3 nor when we combined data from all the studies. What becomes evident from our studies is a prominent arousal effect, especially noteworthy in the first experiment, where the short foreperiod duration appears to amplify this phenomenon. In the second and third experiments, this general arousal effect persists, contributing to an overall pattern of results. However, Study 4 only showed a main foreperiod effect and no effect of the symbolic meaning of speed on implicit timing; the study was conducted to control for the possible confounding effect of physical size and weight on the effect of the symbolic meaning of speed on implicit timing. Previous studies have demonstrated that big stimuli are perceived to last longer compared to small stimuli (Rammsayer & Verner, 2015; Xuan et al., 2007). A horse and a turtle were selected because they represent a big and fast animal compared to a small and slow animal (turtle). It is possible that in this study, the meaning of fast animal and its perceptual size have acted on implicit timing, obscuring the effect we have observed. It is very challenging to control for imagined speed independently of the physical characteristics of the image. We acknowledge this is a limitation of the present study and future studies should further investigate this issue. Importantly, when all studies were pulled together we observed the main effect of the symbolic meaning of speed on implicit timing.

The effect of the symbolic meaning of speed on RTs is consistent with previous studies showing emotional stimuli can modulate implicit timing (Droit-Volet, 2016; Droit-Volet & Berthon, 2017). For example, Droit-Volet (2016) used emotional facial expressions as cues in an implicit timing task and found faster RTs for angry compared to sad faces, though no difference between angry and neutral faces was observed. Droit-Volet and Berthon (2017) extended this by demonstrating arousal level of emotional pictures affected peak time of the U-shaped RT curve in an implicit timing task. However, the effect of emotion was not consistently observed across studies, possibly due to differences in stimuli and methodology.

Our findings align with previous work showing the symbolic meaning of speed can influence explicit time perception (Mioni et al., 2015, 2018) and time-to-contact judgements (Battaglini & Mioni, 2019). It has been proposed that temporal judgements are subject to reconstructive processes that can be biased by semantic information about speed stored in memory. The present results suggest a similar inferential process may operate during implicit timing.

These results can be explained within the framework of embodied cognition. Embodiment refers to the physical experiences that emerge from interacting with the world and engaging in introspection. These bodily experiences are seen to have a significant impact on cognition and specifically subjective perception of time. For example, it has been observed that the presentation of images of older and younger adults to younger participants affected their perception of time; youngsters tended to underestimate time when the temporal interval was marked by an image of older adults compared to an image of younger participants when the participants had the same gender as the stimulus faces (Chambon et al. 2008). Moreover, Nather et al. (2011) investigated the effect of images of different body postures on time perception. The results showed that the duration was judged longer for the posture requiring more movement than for the posture requiring less movement.

Overall, our study indicates the symbolic meaning of speed affects not just explicit timing but also implicit timing measured through RTs in a foreperiod paradigm. This lends further support to embodied cognition models proposing dynamic interactions between perceptual processing and semantic knowledge. Further research is warranted to clarify the mechanisms by which symbolic meaning alters temporal information processing across different contexts and tasks.

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