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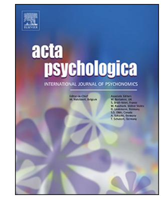

The effect of symbolic meaning of speed on time to contact

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A R T I C L E I N F O

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A B S T R A C T

The effects of moving task-irrelevant objects on time-to-contact (TTC) judgments are examined in six experiments. In particular, we investigated the effects of the symbolic meaning of speed on TTC by presenting images of objects recalling the symbolic meaning of high speed (motorbike, rocket, formula one, rabbit, cheetah and flying Superman) and low speed (bicycle, hot-air balloon, tank, turtle, elephant and static Superman). In all experiments, participants judged the TTC of these moving objects with a black line, indicating the end of the occlusion. Experiment 7 was conducted to disambiguate whether the effects on TTC, found in the previous experiments, were either a by-product of a speed illusion or they were rather elicited by the implicit timing task. In a two-interval forced choice task, participants were instructed to judge if "high-speed objects" moved actually faster than "slow-speed objects". The results revealed no consistent speed illusion.

Taken together the results showed shorter TTC estimated with stimuli recalling the meaning of high compared to low speed, but only with the long occlusion duration (3.14 s). At shorter occlusion durations, the pattern was reversed (participant tend to have shorter TTC with stimuli recalling the meaning of low speed). We suggest that the symbolic meaning of speed works mainly at low speed and long TTC, because the semantic elaboration of the stimulus needs a deeper cognitive elaboration. On the other hand, at higher speeds, a small erroneous perceptual judgment affects the TTC, perhaps due to a speed expectancy violation of the expected "slow object".

1. Introduction

In everyday life, we often have to estimate the reappearance of objects that disappeared from our view for a brief period. For example, in order to avoid an accident while driving, it is important to properly estimate the time of reappearance of a motorbike that passes behind a truck. In literature, the task used to study this phenomenon is called prediction-motion task (Tresilian, 1995). The task consists of pressing a button when a target (generally in translational motion), which disappears behind an occluder, reaches a visible cue. In other words, observers are required to estimate the time to contact (TTC) between the occluded target and the cue (Battaglini, Campana, & Casco, 2013). To efficiently achieve this goal, observers have to extrapolate the motion of the occluded target and predict its future position according to the speed of the moving object (Battaglini & Casco, 2016; Peterken, Brown, & Bowman, 1991).

Rosenbaum (1975) found that observers are very good in estimating the TTC when the target moved at a constant velocity. However, several studies suggest that the relationship between the physical arrival time (actual TTC) and TTC (estimated) is not linear (Sokolov & Pavlova, 2003) and may depend on different parameters, such as the target's speed and size, duration of occlusion, typical object speed (Makin, Stewart, & Poliakoff, 2009) and the implied mass of the object (Vicovaro, Noventa, & Battaglini, 2019). For example, Makin et al. (2009) showed that, after observers classified a red target as slow and a green target as fast, when performing a TTC task they responded as the green target was moving faster in those trials in which both red and green target moved at the same speed (20 deg/s). Moreover, also the presence of distractors (Bennett, Baurès, Hecht, & Benguigui, 2010; Lyon & Waag, 1995) influences the TTC estimation. Battaglini, Contemori, Maniglia, and Casco (2016) reported an overestimation of the TTC with a background moving in the opposite direction of the target and vice versa (Battaglini et al., 2016). Also, a random dynamic noise background (that looks like a detuned TV) can modulate motion extrapolation, resulting in an underestimation of the TTC (Battaglini et al., 2018). The effect of size on the TTC was studied by Sokolov and Pavlova (2003). They found that the TTC of a small target is perceived as shorter than the TTC of a bigger one. Battaglini et al. (2013) confirmed this finding using a big square or a thin rectangle as a target. Note, however, that results are different with objects in approaching motion: a larger object produces a shorter TTC estimates than a smaller object (DeLucia & Warren, 1994), suggesting that TTC estimates in

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rectilinear motion and approaching motion can differ.

The effects of size and speed are also observed in other temporal domains. For example, in timing tasks in which participants are required to estimate the duration of presented stimuli, the size of the stimulus and the movement might affect temporal estimations. Xuan, Zhang, He, and Chen (2007) have demonstrated that large stimuli are perceived to last longer than smaller stimuli and conclude that temporal and non-temporal dimensions (magnitude) are not independent. Brown (1995) showed how the duration of moving objects was systematically judged longer than the duration of stationary objects. Furthermore, this lengthening effect increased with increasing speed of motion, with the duration being judged longer when the shapes moved more quickly than when they moved more slowly.

Previous studies proposed different ways to estimate the TTC; TTC can be estimated directly, using the contraction of visual angle between the object and the target point (Hecht & Savelsbergh, 2004), or it can be measured using a clocking strategy (DeLucia & Liddell, 1998), using a visuo-spatial tracking (Makin & Poliakoff, 2011) or thanks to a common rate controller that updates the mental simulation (Makin, 2018). If the mechanism used to perform the TTC task involves the object speed estimates, it could be biased by top-down semantic information.

Every stimulus we perceive is subjected to a semantic analysis that produces its meaning across various dimensions (McKoon & Ratcliff, 1989). For example, to express the concept of weight it is possible to use a feather, to recall the idea of lightness, or to use a stone, to recall the idea of heaviness. Several works demonstrated that semantic-like analyses or implicit models of intuitive physics influence a variety of perceptual/cognitive tasks (Dils & Boroditsky, 2010; Hsu, Taylor, & Pratt, 2015; Meteyard, Bahrami, & Vigliocco, 2007; Ramachandran, Armel, Foster, & Stoddard, 1998). For instance, the prior semantic knowledge of the type of movement made by a frog (jump), biases the perception of element or group motion in a Ternus display (Hsu et al., 2015). Meteyard et al. (2007) conducted a study in which participants performed a motion detection task while listening to verbs that referred to motion. When the verbs were directionally incongruent with the motion signal, the perceptual sensitivity in the motion detection task significantly decreased. Face recognition can help participants to see a rotational face in three-dimensional motions instead of a random, incoherent, two-dimensional motion (Ramachandran et al., 1998).

Reed and Vinson (1996) showed a greater representational momentum (i.e.: error in visual perception in which instead of referring to the exact position of a moving object, people think that is a bit further along its trajectory) for an ambiguous stimulus labelled as a rocket, than for the very same stimulus labelled as a steeple. This bias was found even greater when using a picture of an actual rocket and of an actual church. Zago, McIntyre, Senot, and Lacquaniti (2008) suggested that an implicit, action-oriented model of the effect of gravity was used when intercepting a free-falling object. Vicovaro, Battaglini, and Noventa (2018) showed that participants used a heavy-fast, light-slow heuristic in judging the naturalness of a falling simulated wooden sphere and of a falling simulated polystyrene sphere, respectively.

Interestingly, the concept of implicit motion can influence perceptual judgments too. For example, the viewing of static pictures that conveyed a vivid sense of motion in a specific direction (implied motion) produced a motion after-effect in the opposite direction (Winawer, Huk, & Boroditsky, 2008) and also, the activation of visual motion areas (MT/MST) was higher when compared to the viewing of static pictures without implied motion (Kourtzi & Kanwisher, 2000).

Even though there are doubts that semantic-like analysis can actually affect perceptual sensitivity instead of producing a bias (Durgin, Klein, Spiegel, Strawser, & Williams, 2012; Firestone & Scholl, 2014, 2016), many findings indicate that the semantic stimulus elaboration (or implicit knowledge) affects significantly the performance in many perceptual tasks as well as it affects perceptual judgments.

A question that has been neglected is whether stimuli that embedded clear semantic meaning can alter the TTC. Does the semantic-like analysis also affect the TTC? Also, considering that TTC requires time estimation, extrapolation of motion, and invisible motion tracking (Battaglini & Casco, 2016), how would the semantic meaning of speed affect TTC?

Using a time bisection task Mioni, Zakay, and Grondin (2015) tested the effect of the symbolic meaning of speed on temporal processing. The stimuli proposed were a motorbike or a bicycle (static), presented for different durational ranges. Participants were instructed to estimate the duration of stimuli presentation on a computer screen and to judge if the duration was closer to two, previously learned, standard durations (standard short and standard long). Results showed that presenting images with different speed meanings affected time perception: an image representing a fast object, the motorbike, led to shorter perceived time than an image representing a slower object, the bicycle. The authors discussed these results within the framework of embodiment theories of cognition and in accordance with an inferential/reconstructive process, occurring in memory and acting on temporal judgments (Mioni et al., 2015; Mioni, Stablum, Grondin, Altoé, & Zakay, 2018).

In the current study, we tested the effect of the semantic meaning of speed on TTC. We reasoned that the semantic elaboration of stimuli is an embedded process that should bias not only temporal tasks, as the one used by Mioni et al. (2015, 2018), but also tasks that require implicit temporal estimation as with TTC (Coull & Nobre, 2008). Therefore, we expect shorter TTC with a target stimulus that expresses the concept of high speed, like a motorbike, compared to a target stimulus that expresses the concept of low speed, like a bicycle. A similar experiment (but with a different aim) was conducted by Horswill, Helman, Ardiles, and Wann (2005) using a motorbike and a van in approaching motion. They found that a motorbike (fast vehicle) was judged to arrive later than a van (slow vehicle). Their results were actually against our hypothesis. However, it is important to note that, with stimuli in approaching motion it could be very dangerous to underestimate the occlusion interval of a big vehicle. In line with this interpretation, Vagnoni, Lourenco, and Longo (2012) showed that the TTC of approaching (looming) threatening stimuli (spiders and snake) was underestimated compared to the TTC of approaching non-threatening stimuli (butterflies and rabbit). Other studies used ecological stimuli such as cars and trucks (Coull, Vidal, Goulon, Nazarian, & Craig, 2008; Oberfeld & Hecht, 2008); however, none of them investigated how the (pure) semantic meaning of a picture could influence the TTC in translational motion.

Therefore, in six different experiments, we used pictures that express the concept of low speed (a bicycle, a hot-air balloon, a tank, a turtle, an elephant and a static Superman) and pictures that express the concept of high speed (a motorbike, a rocket, a formula one, a rabbit, cheetah and a flying Superman). Using a prediction of motion task, in translational motion, we expect longer TTC when the expected slower objects are presented compared to the expected faster ones.

In the last experiment (Experiment 7), we investigated whether stimuli that express the concept of low or high speed can also affect the visible speed (before the occlusion), to check the possibility that speed misperception during the visible trajectory alters the following TTC estimation, such as in Battaglini et al. (2013).

2. Experiment 1

2.1. Method

2.1.1. Participants

Eighteen students from the University of Padova took part in the experiment. They were 10 males and 8 females aged between 19 and 33 (mean age 24 years old, $SD = 4$). For this and the following Experiments, all of the participants 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.

2.1.2. Apparatus and stimuli

The participants were seated in a dark room, 57 cm from the display screen. The viewing was binocular. Stimuli were generated with MATLAB and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997), and were displayed on a 19-in. CTX CRT Trinitron monitor with a refresh rate of 60 Hz. The screen resolution was 1600 × 1200 pixels. The maximum luminance was 120 cd/m^2, and the minimum luminance was 1 cd/m^2. The moving targets were two pictures (going rightward or leftward) displayed on a computer screen and representing a bicycle and a motorbike ridden by a person. The two pictures were embedded in an invisible rectangle of 5.5 × 4.125 deg, which moved in translational motion at a constant speed. The length of the bicycle and the motorbike was the same: 5.5 deg. After 9.5 deg the target disappears entirely behind an invisible occluder 11 deg long. A thin vertical black line (0.6 deg of thick) represents the end of the invisible occluder. The speed varied from trial to trial in four levels: 3.5, 7, 10.5, 14 deg/s with the corresponding occlusion duration (actual TTC) of 3.14, 1.57, 1.05, 0.79 s. The background was white (120 cd/m^2).

2.1.3. Procedure

The picture of a bicycle or motorbike appeared on the left or on the right 5.5 deg (tip of the front tyre) from the centre of the screen and moved for 9.5 deg before disappearing smoothly behind an invisible occluder. Participants were explicitly told that the bicycle or motorbike maintained constant speed after its disappearance and the task was to press a button when they thought that the leading edge of the target (tip of the tyre) reached the black line (TTC) (Fig. 1A). The target never reappeared. We used the psychophysical method of constant stimuli. Participants performed 4 blocks and each block consisted of 320 randomly presented trials: 2 *Pictures* (bicycle vs. motorbike) × 2 *Directions* × 4 *Occlusion Durations* × 20 Repetitions. The inter-trial interval was 1000 ms from key-press. No feedback was given. There was no fixation spot. Each experimental block was preceded by 20 practice trials with no feedback (the type of the pictures, the motion direction and the occlusion duration to present in the practice trials were chosen randomly).

2.2. Results

We analysed the mean TTC of the invisible trajectory estimates (TTC from the onset from the stimulus until button press minus the time to travel the visible trajectory) with a three-way repeated measures analysis of variance (ANOVA), with *Picture* (bicycle vs. motorbike), *Direction* (left vs. right) and *Occlusion Duration* (3.14, 1.57, 1.05, 0.79 s) as the factors. The Greenhouse-Giesser correction for the degree of freedom was used when the sphericity of the data was violated. The ANOVA showed a significant main effect of the *Occlusion Duration* ($F_{(1.144,19.44)} = 237.17$, $p < 0.001$, $\eta_p^2 = 0.93$) but not of *Picture* ($F_{(1,17)} = 3.24$, $p = 0.09$, $\eta_p^2 = 0.16$) and *Direction* ($F_{(1,17)} = 0.7$, $p = 0.41$, $\eta_p^2 = 0.04$). Most interesting the interaction *Picture* × *Occlusion Duration* resulted significant ($F_{(2.165,36.81)} = 6.4$, $p = 0.003$, $\eta_p^2 = 0.27$) (Fig. 1B and Table 1). Post hoc comparison (Bonferroni corrected *t*-test, this correction was applied to all the *t*-test reported in this manuscript) revealed that with long occlusion duration (actual TTC: 3.14 s) the TTC estimated with the bicycle was longer than the TTC estimated with a motorbike ($t_{(17)} = 2.88$; $p_{corr} = 0.01$; *Cohen's* $d = 0.14$), whereas when the actual occlusion duration was 1.57 s the result was the opposite but did not reach statistical significance at $\alpha = 0.05$: longer TTC was obtained with a motorbike ($t_{(17)} = 2.34$; $p_{corr} = 0.09$; *Cohen's* $d = 0.11$).

3. Experiment 2

According to our hypothesis, Experiment 1 showed that the symbolic meaning of the stimulus could affect the TTC. Indeed, the TTC estimated for the motorbike was shorter but only with long occlusion duration (slow speed). Probably, with shorter occlusion duration, there would not be enough time to process the semantic elaboration of the stimulus (Mioni et al., 2018). The aim of the second experiment is to replicate this effect with different stimuli and with a different motion path. Indeed, the effect of the symbolic meaning should be independent of the objects used and the direction of motion. In Experiment 2 we used a rocket to express the concept of high speed and a hot-air balloon to express the concept of slow speed.

A second reason why we used this kind of stimuli is the reverse effect obtained when the actual occlusion duration was 1.57 s (even though did not reach statistical significance, $p = 0.09$). Perhaps a different perceptual mechanism could explain the shorter TTC obtained with the bicycle (even though this effect seems to disappear when the occlusion duration was very short and the speed was at 10.5 and 14 deg/s, which is odd). This effect is called transposition principle (Brown, 1931; Epstein, 1978) and states that smaller objects are perceived as moving faster. It works even when the stimuli have the same length but one is thinner than the other (Battaglini et al., 2013). Indeed, in Experiment 1 the bicycle was thinner than the motorbike and could be perceived as moving faster. This illusory speed may be retained in memory and used during the TTC (Battaglini et al., 2013). If so, the rocket, being thinner, should be favoured by the transposition principle and the reverse effect obtained in Experiment 1, when the actual occlusion duration was 1.57 s, should disappear in this second experiment.

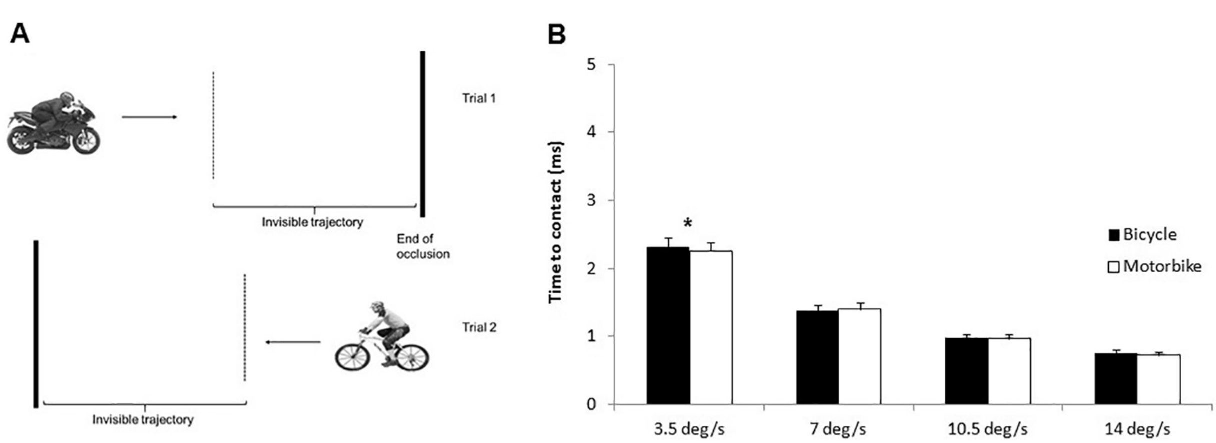

Fig. 1. A and B. (A) Examples of vehicles (bicycle, motorbike) used for the time to contact task. (B). Mean time to contact as a function of Occlusion duration (3.14, 1.57, 1.05 and 0.79 s) and Pictures (bicycle, motorbike).

Table 1
Mean and standard deviation in each experiment as a function of stimulus presented and occlusion duration.

	Stimuli	Occlusion duration 3.14 s	Occlusion duration 1.57 s	Occlusion duration 1.05 s	Occlusion duration 0.79 s
		Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
Experiment 1	Bicycle	2.32 (0.58)	1.37 (0.38)	0.97 (0.27)	0.75 (0.23)
	Motorbike	2.26 (0.56)	1.40 (0.39)	0.96 (0.28)	0.72 (0.22)
Experiment 2	Hot-air balloon	2.50 (0.75)	1.47 (0.49)	1.04 (0.39)	0.85 (0.39)
	Rocket	2.38 (0.70)	1.53 (0.52)	1.20 (0.42)	0.84 (0.34)
Experiment 3	Tank	2.12 (0.60)	1.26 (0.40)	0.93 (0.27)	0.67 (0.21)
	Formula one car	2.07 (0.58)	1.28 (0.40)	0.92 (0.29)	0.70 (0.19)
Experiment 4	Turtle	3.35 (0.66)	1.69 (0.57)	0.97 (0.35)	0.61 (0.26)
	Rabbit	3.21 (0.57)	1.72 (0.51)	1.04 (0.39)	0.63 (0.25)
Experiment 5	Elephant	3.75 (0.71)	2.01 (0.53)	1.31 (0.42)	0.88 (0.33)
	Cheetah	3.59 (0.62)	2.09 (0.44)	1.41 (0.44)	0.94 (0.32)
Experiment 6	Superman still	3.95 (0.67)	2.05 (0.51)	1.33 (0.34)	0.93 (0.31)
	Superman flying	3.81 (0.57)	2.10 (0.43)	1.41 (0.40)	0.99 (0.37)
Experiments collapsed	Slow speed	3.00 (0.66)	1.64 (0.48)	1.09 (0.34)	0.78 (0.29)
	High speed	2.89 (0.60)	1.69 (0.45)	1.14 (0.37)	0.80 (0.28)

3.1. Method

3.1.1. Participants

A different sample of eighteen students from the University of Padova took part in this experiment. They were 6 males and 12 females aged between 20 and 33 (mean age 25 years old; *SD* = 3).

3.1.2. Apparatus and stimuli

The apparatus was the same as Experiment 1. The stimuli used in this experiment were a hot-air balloon and a rocket (Fig. 2A). The motion was vertical and always upward. The figures were embedded in an invisible rectangle 4.125 × 7 deg, the length of the visible motion, the occlusion duration and of the occluder was the same as those used in Experiment 1. The upper edge of the screen represented the end of the invisible trajectory.

3.1.3. Procedure

The procedure was the same as Experiment 1 except that the picture of the hot-air balloon or the rocket appeared 2.5 deg above the bottom of the screen and the motion was vertical and upward. Participants were instructed to press the button response when the upper edge of the picture reached the end of the screen. Participants performed 4 blocks and each block consisted of 160 randomly presented trials: 2 *Pictures* (hot-air balloon vs. rocket) × 4 *Occlusion Durations* × 20 Repetitions. The inter-trial interval was 1000 ms from key-press. No feedback was given.

3.2. Results

We analysed the mean TTC of the invisible trajectory estimates with a two-way repeated measure analysis of variance (ANOVA), with *Picture* (hot-air balloon vs. rocket) and *Occlusion Duration* (3.14, 1.57, 1.05, 0.79 s) as the factors. The Greenhouse-Giesser correction for the degree of freedom was used when the sphericity of the data was violated. The ANOVA showed a significant main effect of the *Occlusion Duration* ($F_{(1.135,19.29)} = 181$, $p < 0.001$, $\eta_p^2 = 0.91$) but not of *Picture* ($F_{(1,17)} = 0.001$, $p = 0.98$, $\eta_p^2 < 0.001$). The interaction *Picture* × *Occlusion Duration* resulted significant ($F_{(3,51)} = 6.8$, $p < 0.001$, $\eta_p^2 = 0.28$) (Fig. 2B and Table 1). Post hoc *t*-test comparison revealed that with long occlusion duration (actual TTC: 3.14 s) the TTC estimated with the hot-air balloon was longer than the TTC estimated with a rocket motorbike ($t_{(17)} = 2.73$; $p_{corr} = 0.04$; *Cohen's d* = 0.23), whereas with short occlusion duration (actual TTC: 1.05 s) the result was the opposite: longer TTC was obtained with a rocket ($t_{(17)} = 2.9$; $p_{corr} = 0.03$; *Cohen's d* = 0.2).

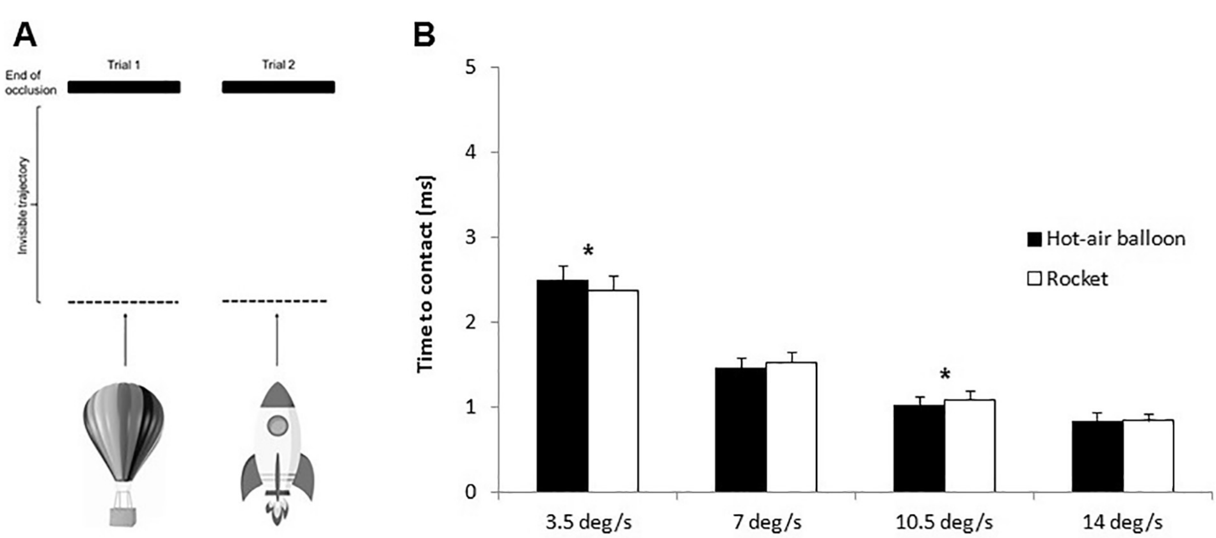

Fig. 2. A and B. (A) Examples of vehicles (hot-air balloon, rocket) used for the time to contact task. (B) Mean time to contact as a function of Occlusion duration (3.14, 1.57, 1.05 and 0.79 s) and Pictures (hot air balloon, rocket).

4. Experiment 3

In Experiment 2, we replicated the results obtained in Experiment 1 at slow speed. At high speed, instead, contrary to our hypothesis, the expected fast vehicle had longer TTC. The transposition principle failed to work with these stimuli. Therefore, it is very unlikely that it had a role in Experiment 1.

In Experiment 3, we tested the consistency of the effect of the symbolic meaning on the TTC at slow speed with a new pair of stimuli. A formula one car was used to express the concept of high speed whereas a tank was used to express the concept of slow speed.

Moreover, in this Experiment the expected fast object, i.e. formula one, was lighter than the tank in order to exclude any possible effect of the implicit knowledge of the weight on the TTC (which predicts longer TTC with the heavier object) that might explain the reverse effect obtained in Experiment 1 and 2 (even though it is not consistent among the speeds used). Indeed, in previous experiments the objects that express the concept of high speed were also heavier.

4.1. Method

4.1.1. Participants

A different sample of eighteen students from the University of Padova took part in this experiment. They were 5 males and 13 females aged between 21 and 30 (mean age 23 years old; *SD* = 2.5).

4.1.2. Apparatus and stimuli

The apparatus and the set up was the same as Experiment 1 with the only differences that the stimuli used were a tank and a formula one car (Fig. 3A). The two pictures had the same length and were embedded in an invisible rectangle of 5.5 × 4.125 deg as in Experiment 1.

4.1.3. Procedure

The procedure was the same as Experiment 1 except for the target objects. Participants were explicitly told that they have to press the response button when they thought that the leading edge of the picture reached the black line.

4.2. Results

We analysed the mean TTC of the invisible trajectory estimates with a three-way repeated measures analysis of variance (ANOVA), with *Picture* (tank vs. formula one), *Direction* (left vs. right) and *Occlusion Duration* (3.14, 1.57, 1.05, 0.79 s) as the factors. The Greenhouse-Giesser correction for the degree of freedom was used when the sphericity of the data was violated. The ANOVA showed a significant main effect of the *Occlusion Duration* ($F_{(1.084,18,433.)} = 174.6$, $p < 0.001$, $\eta_p^2 = 0.91$) but not of *Picture* ($F_{(1,17)} = 0.216$, $p = 0.65$, $\eta_p^2 = 0.013$) and *Direction* ($F_{(1,17)} = 3.41$, $p = 0.08$, $\eta_p^2 = 0.17$). Most interesting the interaction *Picture* × *Occlusion Duration* resulted significant ($F_{(3,51)} = 3.47$, $p = 0.023$, $\eta_p^2 = 0.17$) (Fig. 3B and Table 1). When the occlusion duration was long (actual TTC: 3.14 s), the TTC estimated with the tank was longer than the TTC estimated with a formula one but the *t*-test corrected did not reach significance at $\alpha = 0.05$ (tank: 2.12 s vs. formula one: 2.07 s, $t_{(17)} = 2.53$; $p_{corr} = 0.06$; *Cohen's d* = 0.12).

5. Experiments 4, 5 and 6

The differences in the TTC measured in previous Experiments could be influenced, not only by the semantic meaning of the objects, but some idiosyncrasies of the pictures can meddle the results. Therefore, we tested another sample of participants with different pictures to strengthen our findings. In Experiment 4, we used the picture of a turtle and of a rabbit in implied motion (for implied motion see Kourtzi & Kanwisher, 2000; Fig. 4A), in Experiment 5 we used a picture of a cheetah and an elephant without implied motion (Fig. 5A). These couples of stimuli were employed to explore also whether the implied motion embedded in a picture is (more) important to arise the idea of speed in a static picture of an animal. Experiment 6 was run to expand the findings obtained in Experiment 2 with the pictures moving in vertical motion. We decided to use two different pictures of Superman, one in which the superman is still in a pose and one in which superman is flying (Fig. 6A).

5.1. Method

5.1.1. Participants

A different sample of eighteen students from the University of Padova took part in Experiment 4, 5 and 6. They were 5 males and 13 females aged between 21 and 33 (mean age 26 years old; *SD* = 4.12).

5.1.2. Apparatus and stimuli

The apparatus and the set up was the same as in previous experiments with the only differences that we compared the TTC estimation between a rabbit and a turtle in Experiment 4 (Fig. 4), between a cheetah and an elephant in Experiment 5 (Fig. 5A) and between Superman in a static pose or in a flying position (Fig. 6A). The pictures had the same length and were embedded in an invisible rectangle of 5.5 × 4.125 deg in Experiment 4 and 5, 4.125 × 7 deg in Experiment 6.

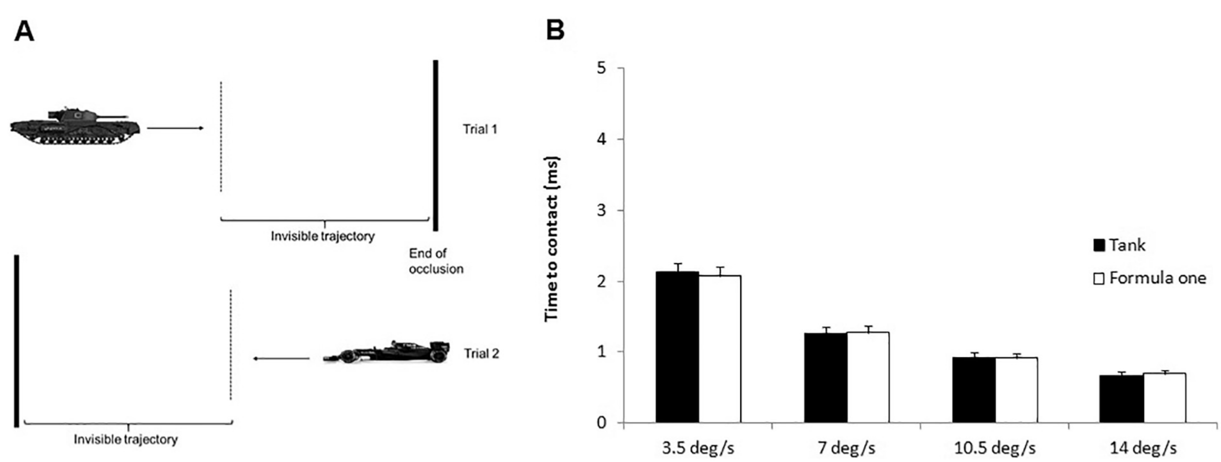

Fig. 3. A and B. (A) Examples of vehicles (tank, Formula one car) used for the time to contact task. (B) Mean time to contact as a function of Occlusion duration (3.14, 1.57, 1.05 and 0.79 s) and Pictures (tank, Formula one car).

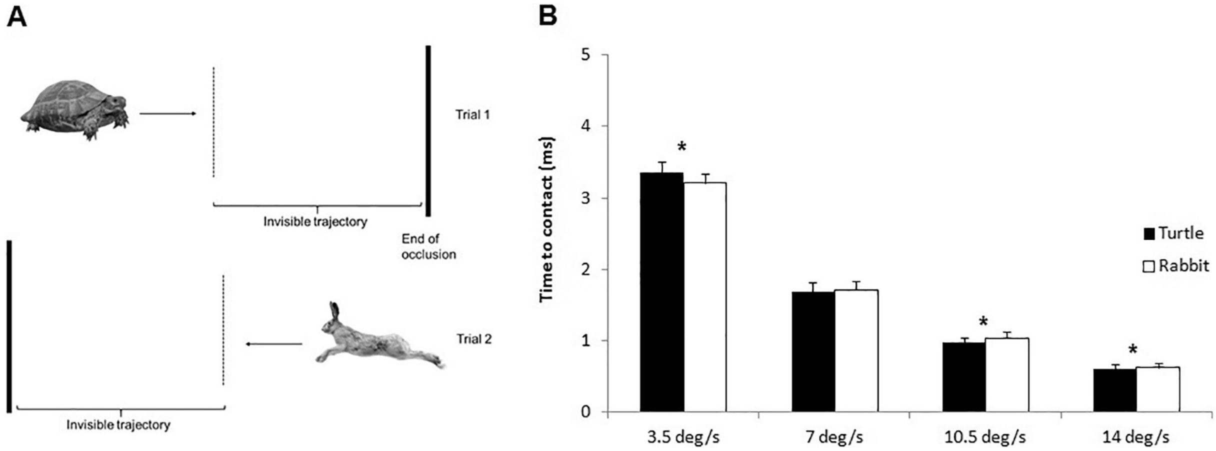

Fig. 4. A and B. (A) Examples of vehicles (turtle, rabbit) used for the time to contact task. (B) Mean time to contact as a function of Occlusion duration (3.14, 1.57, 1.05 and 0.79 s) and Pictures (turtle, rabbit).

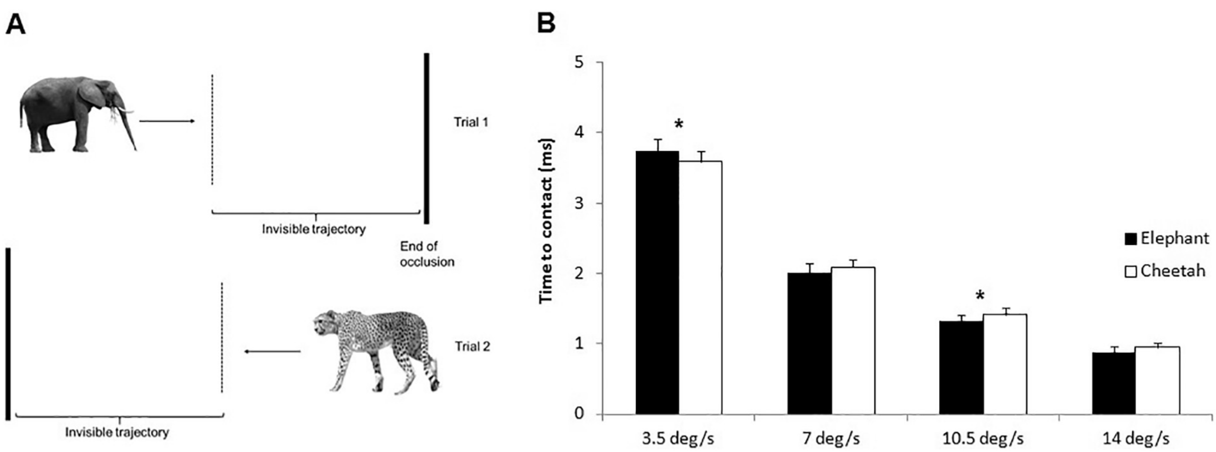

Fig. 5. A and B. (A) Examples of vehicles (elephant, cheetah) used for the time to contact task. (B) Mean time to contact as a function of Occlusion duration (3.14, 1.57, 1.05 and 0.79 s) and Pictures (elephant, cheetah).

5.1.3. Procedure

The procedure was the same as in previous Experiments. Participants were explicitly told that they have to press the response button when they thought that the leading edge of the animal reached the black line. Participants underwent three different sessions one week apart and the order of experiments was randomised between

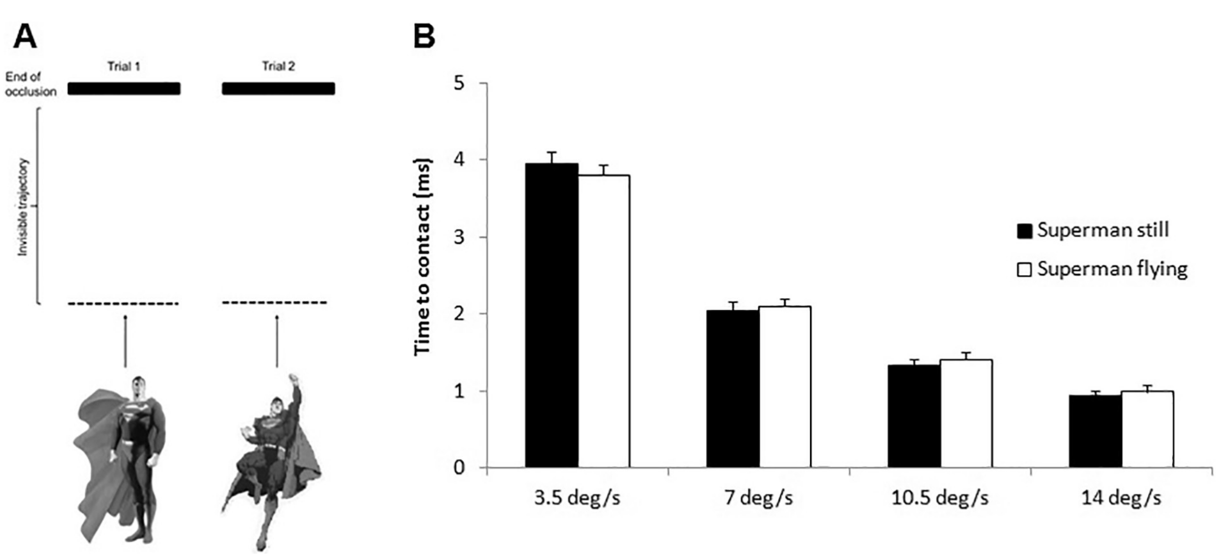

Fig. 6. A and B. (A) Examples of vehicles (Superman still, Superman flying) used for the time to contact task. (B) Mean time to contact as a function of Occlusion duration (3.14, 1.57, 1.05 and 0.79 s) and Pictures (Superman still, Superman flying).

participants.

5.2. Results

We first analysed the mean TTC of the invisible trajectory estimates of Experiments 4 and 5 as in Experiment 1. In Experiment 4 the ANOVA showed a significant main effect of the *Occlusion Duration* ($F_{(3,51)} = 552$, $p < 0.001$, $\eta_p^2 = 0.97$) but not of *Picture* ($F_{(1,17)} = 1.78$, $p = 0.2$, $\eta_p^2 = 0.09$) and *Direction* ($F_{(1,17)} = 2.6$, $p = 0.13$, $\eta_p^2 = 0.13$). Most interesting the interaction *Picture* × *Occlusion Duration* resulted significant ($F_{(1.64,27.9)} = 10.1$, $p = 0.001$, $\eta_p^2 = 0.37$) (Fig. 4B and Table 1). *t*-Test comparison revealed that when the occlusion duration was long (actual TTC: 3.14 s), the TTC estimated with the turtle was longer than the TTC estimated with a rabbit ($t_{(17)} = 3.42$; $p_{corr} = 0.001$; *Cohen's* $d = 0.33$). When the occlusion duration was short (actual TTC: 1.05, 0.79 s), the TTC estimated with the turtle was shorter than the TTC estimated with the rabbit (actual TTC: 1.05 s, $t_{(17)} = 3$; $p_{corr} = 0.001$; *Cohen's* $d = 0.3$; actual TTC: 0.79 s, $t_{(17)} = 3.38$; $p_{corr} = 0.01$; *Cohen's* $d = 0.27$).

In Experiment 5 we found a significant main effect of the *Occlusion Duration* ($F_{(3,51)} = 573$, $p < 0.001$, $\eta_p^2 = 0.97$) but not of *Picture* ($F_{(1,17)} = 0.09$, $p = 0.76$, $\eta_p^2 = 0.005$) and *Direction* ($F_{(1,17)} = 0.43$, $p = 0.52$, $\eta_p^2 = 0.02$). The interaction *Picture* × *Occlusion Duration* resulted significant ($F_{(3,51)} = 5.5$, $p = 0.002$, $\eta_p^2 = 0.24$) (Fig. 5B and Table 1). When the occlusion duration was long (actual TTC: 3.14 s), the TTC estimated with the elephant was longer than the TTC estimated with a cheetah ($t_{(17)} = 2.25$; $p_{corr} = 0.1$; *Cohen's* $d = 0.31$). When the occlusion duration was 1.05 s, the TTC estimated with the elephant was shorter than the TTC estimated with the cheetah ($t_{(17)} = 3.06$; $p_{corr} = 0.02$; *Cohen's* $d = 0.27$).

The same analyses of Experiment 2 were conducted for Experiment 6. The ANOVA showed a significant main effect of the *Occlusion Duration* ($F_{(3,51)} = 857$, $p < 0.001$, $\eta_p^2 = 0.98$) but not of *Picture* ($F_{(1,17)} = 0.42$, $p = 0.52$, $\eta_p^2 = 0.02$). The interaction *Picture* × *Occlusion Duration* resulted significant ($F_{(3,51)} = 4.47$, $p = 0.007$, $\eta_p^2 = 0.2$) (Fig. 6B and Table 1). With long occlusion duration (actual TTC: 3.14 s) the TTC estimated with the static Superman was longer than the TTC estimated with the flying Superman ($t_{(17)} = 2.44$; $p_{corr} = 0.07$; *Cohen's* $d = 0.32$) but the *t*-test Bonferroni corrected did not reach significance with α set at 0.05.

6. Results collapsing the data of the six experiments

The six experiments conducted seem to confirm our hypothesis: the semantic meaning of an image that expresses the concept of high or slow speed influences the TTC. Indeed, in the previous six experiments, with long occlusion duration (actual TTC: 3.14 s), the TTC estimation was longer with the pictures that express the concept of low speed. When the occlusion duration was shorter, the reverse effect was found in some conditions, but it does not seem consistent. To present the results with a more powerful analysis and explore the consistency of our results, a repeated measure ANOVA was conducted with *Occlusion Duration* (3.14, 1.57, 1.05, 0.79 s) and *Picture* (fast vehicle vs. slow vehicle) as within subject factors and *Pictures Pair* (bicycle/motorbike, hot-air balloon/rocket, tank/formula one, turtle/rabbit, elephant/cheetah, static Superman/flying Superman) as a between subject's factor.[1]

A significant main effect of the *Occlusion Duration* ($F_{(3,306)} = 2321$, $p < 0.001$, $\eta_p^2 = 0.96$) but not of *Picture* ($F_{(1,102)} = 0.03$, $p = 0.86$, $\eta_p^2 < 0.001$) was found. The only significant interaction was *Picture* × *Occlusion Duration* resulted significant ($F_{(2.45,249.77)} = 29.7$, $p < 0.001$, $\eta_p^2 = 0.23$) (Fig. 7, Table 1). The TTC estimated with long occlusion duration (actual TTC: 3.14 s) with the object that express the concept of slow speed was longer than the TTC estimated with the object that express the concept of high speed ($t_{(107)} = 6.1$; $p_{corr} < 0.001$; *Cohen's* $d = 0.16$) whereas the reverse effect was obtained in the other occlusion duration (actual TTC: 1.57 s, $t_{(107)} = 3.11$; $p_{corr} = 0.007$; *Cohen's* $d = 0.11$; actual TTC: 1.05, $t_{(107)} = 4.57$; $p_{corr} < 0.001$; *Cohen's* $d = 0.16$, actual TTC: 0.79 s $t_{(107)} = 2.53$; $p_{corr} = 0.037$; *Cohen's* $d = 0.1$).

6.1. Descriptive results

Previous papers also showed that the occlusion duration affects the estimated TTC in a way that short occlusions duration produce late TTC estimates, whereas long occlusions duration produce early response (Bennett et al., 2010; Makin, 2018; Makin & Bertamini, 2014; Tresilian, 1995). With long occluder duration (actual TTC: 3.14 s) there was an underestimation of the TTC (estimated TTC - actual TTC = ∼−0.2 s). With short occlusion duration (actual TTC: 1.05, 0.79 s) our results showed a slight overestimation of the TTC (occluder duration: 1.05, estimated TTC - actual TTC = ∼0.066 s; occluder duration: 0.79, estimated TTC - actual TTC = ∼0.0039 s).

Generally, the transition point between the underestimation and overestimation of the TTC is about 1 s (Benguigui, Broderick, & Ripoll, 2004), but we observed an overestimation of the TTC even when the occlusion duration was 1.57 (estimated TTC - actual TTC = ∼0.09 s).

7. Experiment 7

Experiment 7 was conducted to disentangle the possible effect of the semantic elaboration during the visible and occluded trajectory. In other words, we tested if the effects on the TTC found in the previous experiments (i.e., short TTC obtained with long occlusion duration with the object that expresses the concept of high speed) were a by-product of speed illusion (visible trajectory) or they were actually elicited during the implicit timing task (namely during the invisible trajectory).

The idea that semantic elaboration and expectation alter perception keeps recurring in psychology. However, there are many doubts that top-down effect can actually alter perception (Firestone & Scholl, 2014). Therefore, it is possible that semantic elaboration biases perceptual judgment, memories or responses, in a way that lies outside of visual processing itself. For example, Bruner and Goodman (1947) reported that poorer children perceived coins as larger than richer children, however later was found that this effect was not a perceptual effect but rather a bias in memory (Carter & Schooler, 1949). According to Firestone and Scholl (2014) statement, we expect that the top-down effect due to the semantic elaboration does not affect the speed perception during the visible trajectory (perceptual effect), but biases the implicit timing task (TTC) (memory of speed).

7.1. Method

7.1.1. Participants

Two samples of eighteen students from the University of Padova took part in this experiment. In the first sample they were 3 males and 15 females aged between 19 and 24 (mean age 22 years old; *SD* = 2), in the second sample they were 5 males and 13 females aged between 21 and 33 (mean age 26 years old; *SD* = 4.12). All of the participants were naive with respect to the purpose of the experiment and gave informed consent according to the Declaration of Helsinki prior to their inclusion.

7.1.2. Apparatus and stimuli

The first sample of participants performed three blocks in which they compared which one of two different picture presented in two different intervals was moving faster. In Block 1 participants compared the speed of the pictures used in Experiment 1 (bicycle vs. motorbike),

[1] For Experiments 1, 3, 4 and 5 we collapsed the factor "Direction" and excluded this factor from the analyses to be consistent with Experiment 2 and 6 in which only one direction was considered.

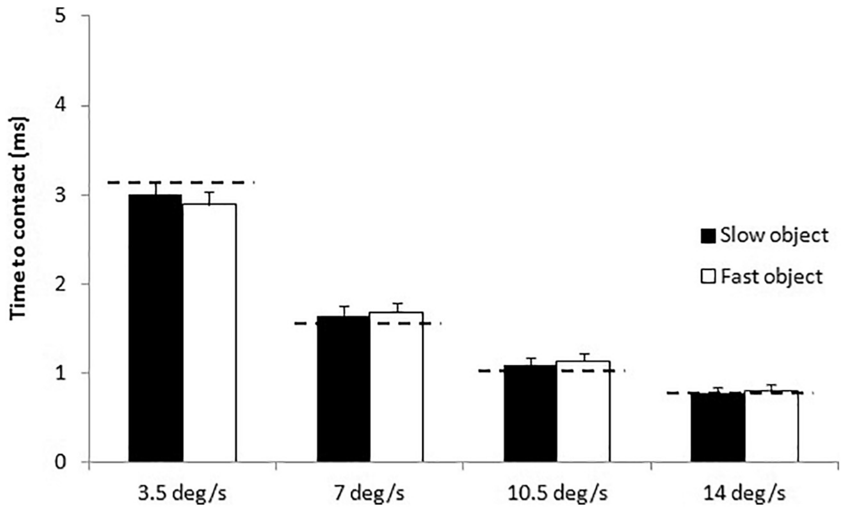

Fig. 7. Mean time to contact as a function of Occlusion duration (3.14, 1.57, 1.05 and 0.79 s) and Pictures (slow, fast objects). Dashed lines represent actual TTC.

in Block 2 they compared the speed of the pictures used in Experiment 2 (hot-air balloon vs. rocket) and in Block 3 they compared the speed of the pictures used in Experiment 3 (tank vs. formula one). The second sample of participants did the same task and performed three blocks in which they compare the speed of the two paired pictures presented in Experiment 4, 5 and 6 (block 4: turtle vs rabbit; block 5: elephant vs. cheetah; block 6: static Superman vs flying Superman). The size of the pictures, the starting position and the lengths of the visible trajectory, the speeds and the direction of the motion were the same as previous experiments.

7.1.3. Procedure

Participants were instructed to report, by pressing a keyboard button, which one of two different pictures was moving faster in a two-interval forced choice task even though they always have the same physical speed (3.5, 7, 10.5 and 14 deg/s; participants were not aware of that). The order of picture presentation was random, (for example, in block 1 the motorbike could appear first and then in the second interval the bicycle or vice versa).

The picture disappeared entirely and smoothly behind an invisible occluder such as in previous experiments (the black line that indicated the end of the invisible trajectory was removed). After 0.5 s the second picture appeared and travelled the same path at the same velocity of the first stimulus.

Block 1, 3, 4 and 5 consisted of 80 randomly presented trials: 2 *Directions* (left vs. right) × 4 *Levels of speed* (3.5, 7, 10.5, 14 deg/s) × 10 Repetitions, Blocks 2 and 6 consisted of 80 randomly presented trials: 4 *Levels of speed* (3.5, 7, 10.5, 14 deg/s) × 20 Repetitions (the direction was always upward see Experiment 2). Each experimental block was preceded by 10 practice trials.

7.2. Results

When participants chose the picture that represents the concept of fast speed (motorbike, rocket, formula one, rabbit, cheetah or Superman flying) the response was codified as 1 otherwise 0.

In each block, we run a series of one sample two-tailed *t*-test (in which we applied Bonferroni for the number of comparisons) in which we compared the proportion of "fast vehicle/animal seen as faster" (direction was averaged) with the chance level (0.5) at each level of speed used. In Block 1 the proportion of "fast vehicle seen as faster" was never different from the chance level. In Block 2 the proportion of "fast vehicle seen as faster" was lower than 0.5 at 7 deg/s ($t_{(17)} = 4.03$, $p_{corr} = 0.003$, *Cohen's* $d = 0.95$), and 14 deg/s ($t_{(17)} = 4.3$, $p_{corr} = 0.001$, *Cohen's* $d = 1$). In Block 3, the proportion of "fast vehicle seen as faster" was lower than 0.5 at 10.5 deg/s ($t_{(17)} = 2.8$, $p_{corr} = 0.042$, *Cohen's* $d = 0.66$), and 14 deg/s ($t_{(17)} = 3.8$, $p_{corr} = 0.006$, *Cohen's* $d = 0.89$). In blocks 4 and 5, the proportion of "fast animal seen as faster" was never different from 0.5, whereas in block 6 the flying superman was seen as moving faster than the static Superman at 14 deg/s ($t_{(17)} = 5.5$, $p_{corr} < 0.001$, *Cohen's* $d = 1.3$). The result obtained at 7, 10.5 and 14 deg/s are not consistent across blocks, therefore we collapsed data from the six blocks to compared the perceived speed of the objects that are supposed to be seen as faster with the objects that are supposed to be seen as slower and we run again the *t*-test for each speed used. None of the *t*-test resulted significant ($p_{corr} > 0.17$).

The proportion of "fast objects seen as faster" was never higher than 0.5 at 3.5 deg/s. This is very interesting because it suggests that the shorter TTC obtained with the pictures that represent the idea of fast speed is not due to a speed illusion. Instead, at higher speed, the pictures that represent the idea of slow speed are sometimes seen as moving faster and one can speculate that this illusory speed could be then used during the invisible trajectory (in the time to contact task) such as in Battaglini et al. (2013) shortening the TTC. However, this result does not seem to be confirmed averaging the performance across blocks, therefore this interpretation cannot be confirmed by our data.

8. Discussion

The present work investigated how the symbolic meaning of the stimulus could influence the TTC estimation in a prediction of motion paradigm in translational motion. According to our hypothesis, i.e. the object that embedded the idea of low speed should lead to a longer TTC estimation, whereas the object that embedded the idea of high speed should lead to a shorter TTC. This is true when the occlusion duration was long (actual TTC 3.14 s), but surprisingly it is perceived as the opposite when the occlusion duration was longer. Moreover, we also tested whether the implied motion embedded in a picture is necessary to alter the TTC estimation. We obtained a significant interaction in Experiment 4 and 5 suggesting that the implied motion is not fundamental to alter the TTC estimation in a participant, however, in Experiment 5 with long occlusion duration (3.14 s) the *t*-test Bonferroni corrected did not reach significance with α set at 0.05 limiting the speculation on the implied motion effect on the TTC.

A mechanism that could explain our data with long occlusion duration, and which is also in accordance with the prediction, is that people elaborate the symbolic meaning of pictures and this elaboration would act at the memory stage (semantic memory) (Mioni et al., 2015, 2018). Then, the retained memory speed influenced by the symbolic

Table 2
Proportion of "fast expected object seen as faster" for each level of speed.

	3.5 deg/s	7 deg/s	10.5 deg/s	14 deg/s
Block 1	0.46	0.44	0.52	0.49
Block 2	0.53	0.40[a]	0.46	0.38[a]
Block 3	0.50	0.49	0.44[a]	0.39
Block 4	0.51	0.51	0.46	0.46
Block 5	0.47	0.54	0.49	0.47
Block 6	0.46	0.57	0.57	0.65[a]

[a] Indicates values significantly different from chance (0.5).

meaning is used during occlusion in order to estimate the time to contact (Battaglini et al., 2013; Battaglini, Campana, Camilleri, & Casco, 2015). This effect, that is evident only when the stimuli were occluded for a long time (slow speed, actual TTC 3.14 s), seems to be consistent with a previous study that showed that the knowledge of gravity influenced the TTC estimation only when the occlusion time is long (above 2 s) (Baurès & Hecht, 2011). We speculate that the semantic elaboration of the stimulus required more time and a deeper cognitive elaboration to produce an effect on TTC. In two different contexts, Mioni and colleagues showed comparable results using similar stimuli but with different tasks. In Mioni et al. (2015) participants pressed more times "long" when the bicycle was presented but only when the stimulus was presented for a longer temporal interval (1200 and 1400 ms) and no differences between motorbike or bicycle on perceived duration was observed when the stimuli were presented for briefer temporal intervals (between 400 ms and 1000 ms). Similarly, children between 6 and 8 years-old under-estimated the motorbike (fast speed) compared to the bicycle (slow speed) in particular when the duration was 36 s compared to 11 s and under-estimated the car (fast speed) compared to the truck (slow speed) at 21 s compared to 11 s (Mioni et al., 2018). Here, we used vehicles that simulated the movement along a road and participants might have embodied the feeling of actually moving along a road riding a motorbike or a bicycle; participants might have been more sensitive to the stimulus content presented at a slower speed. Our results were interpreted in accord with an inferential/reconstructive process that occurred in memory and acted on temporal judgments, or rather, that knowing the relationship between action speed and event duration influenced temporal processing. If so, participants may have corrected the estimated duration based on the semantic meaning of speed stored in memory (Kahneman, 2011).

When the occlusion duration was short (< 3.14 s), collapsing the data from the six Experiments, we observed a reverse effect, i.e. longer TTC with the objects that express the concept of high speed. Alternative explanations have been proposed: An effect of the transposition principle and an effect of the implicit knowledge of the weight. However, results ruled out these interpretations.

An interpretation that can explain the reverse effect is that - slow expected vehicle when moving fast violated expectations and so their speed or memory of speed (their TTC) might be overestimated (underestimated) compared to the speed or memory of speed (TTC) of the fast expected vehicle. To our knowledge there are no articles reporting this kind of effect in speed or time perception, however this effect may be somehow similar to the size-weight illusion (SWI): Participants that are asked to lift two identically weighted target, report that the smaller one is heavier than the larger one (Buckingham, Byrne, Paciocco, van Eimeren, & Goodale, 2014).

In Experiment 7, it was explored whether the effect of the symbolic meaning of the pictures on the TTC was a by-product of speed illusion (visible trajectory) or was actually elicited during the implicit timing task (namely during the invisible trajectory). The vehicle that expresses the concept of high speed was never seen as moving faster than the slow expected vehicle at 3.5 deg/s, suggesting that at slow speed and long occlusion duration the symbolic meaning of the picture affects only the invisible trajectory during the TTC task. In three out of six blocks instead, it was found that the object that expresses the concept of slow speed is actually seen as moving faster at 10.5 and 14 deg/s indicating a speed misperception (see Table 2). We suggest that when participants have to compare the speeds of a fast expected vehicle and a slow expected one, they tend to overestimate the velocity of the slow expected vehicle because it deviates more from its prototypical speed, in a similar way to what happens with the size-weight illusion. However, a second analysis averaging the results obtained in the six blocks did not show any significant differences. Further researches with a more appropriate paradigm/analysis (for example fitting data with a psychometric function) must be conducted to explore whether there is a bias in the speed judgment of two objects that express the opposite concept of speed (fast vs. slow speed). So far, the interpretation of the reverse effect found in the TTC experiments remains an open question. Probably, as stated above, seeing a typical slow object moving at high speed, violate a participant's expectation creating a bias in the object speed memory that affects the TTC estimation even though it might not affect the perceptual speed judgment. Our findings in the TTC experiment with the long occlusion duration are in line with the embodied cognition approach, which suggests a dynamic interplay between perceptual processing and semantic stimulus elaboration. Studies suggested that implicit knowledge can penetrate early stages of visual analysis and concepts are represented in the same neural network required for a specific kind of perception or action (for a review see Collins & Olson, 2014). According to this view neuroimaging and electrophysiological studies reported that semantic knowledge about objects leads to changes that are indicative of better stimulus processing (Barsalou, 2008; Holmes, Franklin, Clifford, & Davies, 2009; Sagiv & Bentin, 2001).

A limitation of the present study is the reduced number of stimuli used (six couples of stimuli, two pair of stimuli in each experiment). Even if we acknowledge the low number of stimuli, we believe that our results can support the hypothesis of a general effect of symbolic meaning of speed on TTC and exclude random effects due to the idiosyncrasies of the pictures. Consistently across all the six experiments when the occlusion duration was long (actual TTC 3.14 s) the object that embedded the idea of low speed lead to a longer TTC estimation compared to the object that embedded the idea of high speed should lead to a shorter TTC. Future studies should further investigate the effect of symbolic meaning of speed with briefer occlusion duration.

On the whole, the six experiments confirmed our prediction showing that when the occlusion duration is long (actual TTC: 3.14 s) one can manipulate the TTC estimation presenting objects that recall different meanings of speed (fast vs. slow). At shorter occlusion duration the effect seems to be present but the polarity is reversed, future studies need to be conducted to confirm the existence and to explain clearly the mechanisms that bias the TTC estimation in favour (shorter TTC) of the picture that expresses the concept of slow speed.

Our results could have interesting implications for real-world situations. For example, in the situation in which a busy street has to be crossed, investigating the relationship between time perception, symbolic and real speed representations might have important implications for understanding children's behaviour (Plumert & Kearney, 2014). This work does not resolve all issues on how the symbolic meaning of speed affects time perception, and leaves some open questions, especially regarding the mechanism by which the symbolic meaning of speed affects TTC at different speeds. However, it should be emphasized that the paper reports new empirical observations, offers some explanations for them, and invite time researchers to further explore the topic, maybe testing this effect in auditory domain.

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