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Sentence plausibility influences the link between action words and the perception of  
biological human movements

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## Abstract

The present study aimed to assess the role of sentence plausibility in the functional link between action words and visual judgments of point-light human actions. Following the oral presentation of action verbs included in a plausible or implausible sentence, participants were asked to detect the presence of congruent or incongruent biological movements. Sentence plausibility was manipulated by inverting the positions of the subject and the complement (e.g., the neighbor is running in the garden vs the garden is running in the neighbor). The results showed that for both plausible and implausible sentences, the detection of human movements is greater following presentation of congruent action verbs. These results suggest that the presentation of action verbs affects the subsequent perception of point-light human movements, regardless of the associated semantic context. However, the link between action verbs and judgment of biological movements is strengthened when plausible sentences are presented, as illustrated by the increase in visual detection capacity in plausible congruent conditions. Concerning the analysis of the detection speed, the performance is only affected in plausible sentences with slower response times associated with the presentation of an incongruent action verb. These findings are discussed in light of an embodied mechanism and the domain of biological movement perception.

**Key words:** biological motion, action sentence, sentence plausibility.

## INTRODUCTION

Humans are very sensitive to the biological motion (BM) produced by living organisms. When daily life actions are presented as “point-light displays” representing the movement of an actor’s limbs, observers only need a few milliseconds ( $\approx 100$  ms) to recognize various human actions (Johansson, 1973) and to access the actor’s characteristics, such as gender (Kozlowski & Cutting, 1977; Troje, Sadr, Geyer, & Nakayama, 2006), identity (Beardsworth & Buckner, 1981; Loula, Prasad, Harber, & Shiffrar, 2005), emotions (Atkinson, Dittrich, Gemmell, & Young, 2004; Chouchourelou, Matsuka, Harber, & Shiffrar, 2006) and intentions (Iacoboni et al., 2005; Martel, Bidet-Ildei, & Coello, 2011).

Recently, it was demonstrated that BM perception might be related to higher abstract concepts, such as action word processing (Bidet-Ildei, Sparrow, & Coello, 2011) or numeral cognition (Badets, Bidet-Ildei, & Pesenti, 2015). For instance, Bidet-Ildei et al. (2011) showed that the perception of a human action can be facilitated by prior exposure to an action-related word. In this experiment, participants read action verbs and then immediately determined whether a point-light human action was embedded in a high-density dynamical mask. When the action verb was congruent with the point-light action, the data analysis revealed a facilitation of point-light detection. According to an embodied view of cognition, which postulates that language, abstract thought and symbol processing emerge from sensorimotor experience (Barsalou, 1999; Wilson, 2002), this finding suggests that activating action representation with language can influence how individuals perceive actions performed by others. However, the role of linguistic context in this effect remains an open issue. In the present work, we assess this issue by using a procedure similar to that used by Bidet-Ildei et al (2011), except that action verbs were inserted in a sentence, which can represent an excellent paradigm to assess linguistic context (Aravena et al., 2012; Troyer, Curley, Miller, Saygin, & Bergen, 2014).

Previous studies have tested the role of sentences in the relationship between action and language (Aravena et al., 2014; Aravena et al., 2012; Gilead, Liberman, & Maril, 2013; Taylor & Zwaan, 2008; van Dam, Brazil, Bekkering, & Rueschemeyer, 2014; van Dam, van Dijk, Bekkering, & Rueschemeyer, 2012a; Zwaan, Taylor, & de Boer, 2010). For example, motor facilitation of manual rotation following sentences that described an action of manual rotation was dependent on the adverb used in the sentence that either maintained the focus on the action or shifted the focus to the feeling of the agent (Taylor & Zwaan, 2008). In the same vein, the automatic enhancement of the grip force associated with the presentation of action verbs related to actions that are produced with the hands or the arms was only observed when the verbs were embedded in affirmative and not negative sentences (Aravena et al., 2012). Altogether, these various experiments showed that the relationship between action-sentences and action production is related to the linguistic context of action word presentation. However, the role of linguistic context on the link between language and BM detection has never been investigated; thus, this objective was the aim of the present work. To assess this issue, the current experiment manipulated the sentence plausibility associated with the presentation of action words. Specifically, participants had to detect a BM after the oral presentation of an action verb was embedded in plausible (e.g., “the football player is running on the field”) or implausible (e.g., “the field is running on the football player”) sentences. Given that the relationship between action verbs and BM can be assessed by the difference between congruent and incongruent conditions (Bidet-Ildei et al., 2011), we can hypothesize that the action verb embedded in a plausible sentence (e.g., “the football player is running on the field”) should trigger a bigger difference in responses for the detection of congruent vs incongruent point-light human actions (i.e., point-light running movement) than the same action verb embedded in an implausible sentence (e.g., “the field is running on the football player”). We focused on two classical variables ( $d'$  and response times).  $d'$  was used to assess

the modification of visual sensitivity, whereas response times were used to assess the facilitation or interference effect based on the congruent-incongruent action verb when presented in the plausible-implausible sentences.

## **Method**

### ***Participants***

Twenty-five university students (6 women, 19 men, mean age: 19.1 years, standard deviation: 1.2 years) participated in the study. None of the students reported sensory or motor deficits, and all had normal or corrected-to-normal vision. The students were ignorant of the purpose of the experiment and gave their informed consent prior to their inclusion. They were awarded with course credit for their participation.

### ***Material***

BM stimuli were reproduced from Bidet-Ildei and colleagues (2011). The stimuli consisted of four avi format animations showing point-light sequences representing either BMs or scrambled motions embedded in a mask consisting of moving scrambled dots. BMs represented the side-view of a man facing left while running (without translation) or throwing a virtual ball with his arm. The animations comprised 13 points of light located on the main body joints (shoulders, elbows, wrists, hips, knees and ankles) and the head. However, 10 to 13 dots were simultaneously visible during the duration of the animation due to transiently hidden points. Therefore, we considered that each stimulus consisted of eleven dots, on average. They were presented in the center of a screen and sustained a  $4.5^\circ$  (Horizontal, H) \*  $11^\circ$  (Vertical, V) visual angle. Scrambled movements comprised eleven dots positioned at a random location in the same spatial window of the BMs. The dynamics of scrambled movements were based on each biological equivalent to obtain a scrambled running and a

scrambled throwing movement. The animation sequences (biological or scrambled) consisted of 24 and 22 frames for the running and throwing movements, respectively. Each frame lasted a duration of 25 ms, which resulted in a total duration of 600 ms and 550 ms for the running and throwing movements, respectively. The duration of the stimuli comprised one complete cycle of each motor performance and was controlled by MATLAB software using the coordinates provided by a point-light action corpus that was accessible on the following website: <http://astro.temple.edu/~tshiple/mocap/dotMovie.html> (see Shipley & Brumberg, 2004 for further details about the stimuli). Each point-light display consisted of white dots ( $97 \text{ cd/m}^2$ ,  $\varnothing$ :  $0.65^\circ$  of visual angle) that were presented on a dark background ( $0.14 \text{ cd/m}^2$ ). Using the avi file MATLAB routine (<http://www.mathworks.com/>), each sequence was converted to an avi file (640\*512 pixels with a frame rate of 40 frames/s). The mask comprised 55 scrambled dots, which was based on a previous experiment that showed that 55 moving scrambled dots sufficiently masks point-light human movements while simultaneously allowing for detection (Bidet-Ildei, Chauvin, & Coello, 2010). Each dot in the mask appeared randomly on the screen and was animated with an angular motion and amplitude depending on the individual velocity vector of the point-light display. Velocity vectors were sampled from one of the eleven points of the target stimuli (running or throwing) (x and y coordinates were processed independently). As a consequence, two animation sequences in a human action (11 moving dots) embedded in 55 scrambled moving dots (running and throwing) and two animation sequences consisting of 66 scrambled moving dots (scrambled running, and scrambled throwing) were built. Biological and scrambled point-light stimuli sustained a  $21.7^\circ$  (H) \*  $19^\circ$  (V) visual angle.

Before the stimuli presentation, participants had to listen to a sentence describing an action using closed supra-aural headphones (Sennheiser HD 202). Importantly, the actions evoked in the sentences represented plausible or implausible actions. All sentences had been previously

recorded in French with a tape microphone (MARANTZ professional PMD 660) associated with a cardioid microphone (Sennheiser MK4). Sentence segmentation was performed with Audacity software (<http://audacity.sourceforge.net/>). The plausible sentences described twenty daily life actions implying either a running (e.g., “the football player is running on the field”) or a throwing movement (e.g., “the girl is throwing the doll”). Implausible sentences consisted of the same twenty sentences, although the positions of the subject and the complement were inverted (“The field is running on the football player”/ “the doll is throwing the girl”). All sentences were presented in French (see Appendix 1 for a complete list). Notably, plausible and implausible sentences contained action verbs that were related to point-light stimuli according to a congruent or an incongruent semantic relationship. For example, a point-light running movement might be presented after a sentence containing the verb “to run” or the verb “to throw”.

### *Apparatus*

Participants sat comfortably in a dimly lit room facing a 16” CRT computer screen (Nokia 4472a, spatial resolution: 1280\*800 pixels, sampling rate: 60 Hz) that was placed on a horizontal table at a viewing distance of 50 cm. The visual angle of the screen subtended at eye-level was 26° vertical\*32° horizontal. Participant responses were given with a SRbox that was positioned on the table close to the body, and participants could easily provide their response during the experiment by pressing one of the keyboard keys.

### *Procedure*

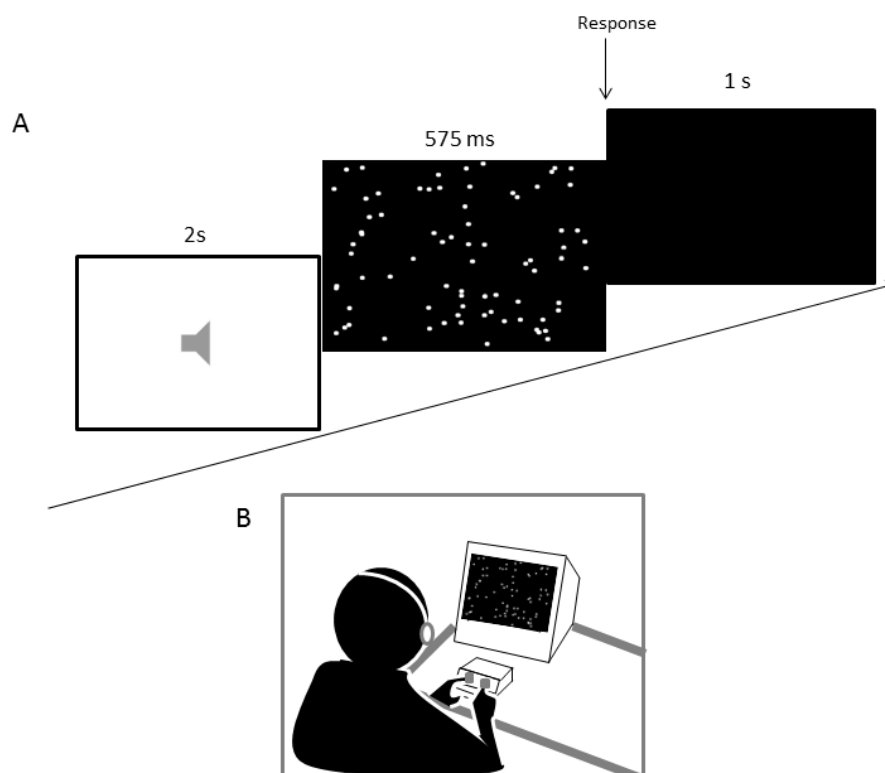
Before beginning the experiment, participants were familiarized with point-light sequences of biological and non-biological movement that were presented alone and embedded in a mask.



In this familiarization, we used sit-down and walking stimuli. The stimuli used for this familiarization were not used in the main experiment.

In the experimental session, the participants had to judge the presence or absence of a point-light human action in an entire image of moving dots embedded in a mask (detection task) as quickly and accurately as possible. The visual stimulus contained either a human action (running, throwing) or only scrambled moving dots (scrambled running, or scrambled throwing) embedded in a dynamic mask of 55 dots. Before the stimuli presentation, participants had to listen to a sentence containing a verb presented in a plausible or implausible context (see material). No specific task was imposed on the participants during the sentence listening, but instructions emphasized listening to sentences with great attention. Stimuli presentation and manual response registration were controlled by E-prime software (version 2.0, <http://www.pstnet.com/>). Responses (Yes, No) were recorded by pressing the left button (response “no”) or right button (response “yes”) of an SRbox. Because BM was always presented with the same translation (directed with the left side), the response buttons (yes/no) were not counterbalanced between participants to avoid stimulus-response incompatibility effects.

Each stimulus (biological or scrambled motion) was associated with the various sentences resulting in a session of 160 trials (40 sentences \* 4 stimuli) with a total duration of approximately 15 min. To control for the attention given to the sentences, participants completed a short questionnaire (see Appendix 2) at the end of the experiment.



**Fig. 1** Experimental procedure. A) The temporal events of a trial. A sentence was displayed for an average of 2 s before a biological or a scrambled stimulus was presented embedded in a dynamic mask for an average of 575 ms. Participants responded whether they perceived a human action in the stimulus by pressing the corresponding key (yes–no) on the response box. B) Experimental setup.

### *Data analysis*

Analyses assessed hits (i.e., responding “Yes” when the stimulus is present), omissions (i.e., responding “No” when the stimulus is present), correct rejections (i.e., responding “No” when the stimulus is absent) and false alarms (i.e., responding “Yes” when the stimulus is absent) for each subject. Next, the  $d'$  value, which is a standard measure of sensitivity in signal detection theory (Macmillan & Creelman, 2005), was calculated based on the verb congruency (congruent vs incongruent) and sentence plausibility (plausible vs implausible).

The  $d'$  value represents the participants' sensitivity to the stimulus and is measured by the distance between the signal and noise distribution (i.e., the probability of hits minus the probability of false alarms). When  $d'$  is high, there is increased capacity to detect the stimulus. When  $d'$  is equal to 0, detection is random.

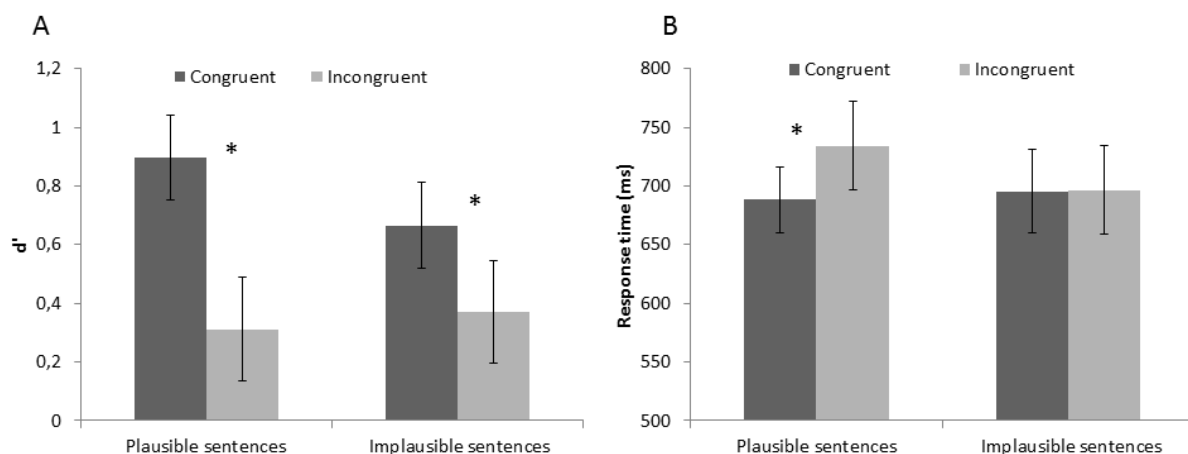
Moreover, we computed a median response time for hits (i.e., the amount of time required to provide a good response from the onset of the stimulus presentation) based on the different priming conditions.

Statistical analyses were performed using a two-way analysis of variance (ANOVA), with within-subjects factors (2 contexts [plausible vs implausible] \* 2 congruences [congruent vs incongruent]). Effect sizes were computed using partial eta-square estimates. Duncan's tests were used to make post-hoc comparisons.

## **Results**

### *Analysis of $d'$*

The statistical analysis of  $d'$  values (see Figure 2A) revealed no significant effect for the plausibility of the sentence ( $F(1,24)=1.19$ ;  $p=0.28$ ), but a significant effect was observed for verb congruency ( $F(1,24)=19.84$ ;  $p<0.01$ ;  $\eta_p^2=0.45$ ). The  $d'$  values were higher for the congruent (Mean (M) = 0.78, Standard deviation (SD) = 0.67) compared with the incongruent condition (M=0.34, SD= 0.8). Notably, we obtained an interaction between these factors ( $F(1,24) = 4.76$ ;  $p<0.05$ ;  $\eta_p^2=0.16$ ). The plausible congruent condition differed significantly from each of the other conditions ( $p<0.05$ ), which indicated that congruent verbs facilitated more BM perception when they were embedded in a plausible sentence.



**Fig. 2** Mean  $d'$  values (A) and response times (B) based on the congruency and the plausibility of the sentence. An asterisk indicates a significant difference at  $p < 0.05$ . Error bars represent one standard error.

### *Response time*

The statistical analysis (see Figure 2B) revealed no significant effect of the plausibility of the sentence ( $F(1,24)=1.30$ ;  $p=0.26$ ) or the verb congruency ( $F(1,24)=0.96$ ;  $p=0.33$ ). Importantly, the analysis revealed a significant interaction between these factors ( $F(1,24)=5.03$ ;  $p < 0.05$ ,  $\eta_p^2 = 0.17$ ). Post-hoc comparisons indicated a difference in point-light judgments, but only when action words were included in a plausible sentence ( $p < 0.01$ ). No effect appeared with sentences that were not plausible ( $p=0.92$ ). Moreover, the “plausible incongruent” condition differed significantly for each of the other conditions ( $p < 0.05$  for each comparison), although there was no significant difference between them ( $p > 0.5$  for each comparison). This indicates that the presentation of an incongruent action verb in a plausible sentence interferes with the subsequent detection of point-light human movements.

## DISCUSSION

The current experiment was designed to examine whether the context of action verb presentation could modify visual judgments of human BM. Our results show that the plausibility of sentences is an important factor that modulates the link between action verbs and BM perception. Moreover, the context effect induced by sentence plausibility is different for the detection capacity ( $d'$  analysis) and the speed of information processing (analysis of response times). Concerning the detection of BM, we observed that the  $d'$  values were systematically higher after presentation of congruent action verbs, but they still increased when action verbs were embedded in a plausible sentence. In contrast, the response time analysis revealed that BM processing was affected only when action verbs were embedded in plausible sentences, and in this case we obtained an effect of interference, i.e., the detection of BM occurred more slowly when incongruent action verbs were included in a plausible sentence.

Overall, these findings confirm previous studies that have shown that language processing can affect visual perception of BM (Bidet-Ildei et al., 2011; Springer & Prinz, 2010), and more generally, those findings that have demonstrated a link between language and visual perception of movement (Jiang, Jiang, & Parasuraman, 2015; Kaschak et al., 2005). Moreover, these results are in line with previous works that have shown that the context affects the relationship between action and language (Aravena et al., 2014; Aravena et al., 2012; Gilead et al., 2013; Taylor & Zwaan, 2008; Troyer et al., 2014; Zwaan et al., 2010). More specifically, by using a priming procedure that relates an action verb to perception of BM, the present work demonstrates that sentence plausibility affects the relationship between action verb processing and BM detection which is consistent with the notion that action verb

processing is flexible and context-dependent (van Dam et al., 2014; van Dam, van Dijk, Bekkering, & Rueschemeyer, 2012b).

As noted by an anonymous reviewer, the difference between the effects obtained for  $d'$  and response times might be interpreted as evidence that sentence plausibility affects the visual sensitivity and speed of processing differently because they may be based on different mechanisms. Specifically, visual sensitivity refers to the capacity of the visual system to detect a signal, whereas the response times refer to the speed of detection, which is related to not only the visual system but also other brain functions, such as response planning and execution. More studies are required to assess this assumption on different mechanisms.

As an alternative explanation, it is also possible to consider that both results are related to a common mechanism, i.e., the increase of signal activation with a plausible context. Concerning  $d'$ , it is likely that the improved signal detection might be related to the previous evocation of this signal. The more the signal is activated with prime, the easier the subsequent detection. Concerning the speed of processing, it is known that the processing of a signal can facilitate the subsequent processing of a congruent signal, or it can interfere with the subsequent processing of an incongruent signal. For example, the presentation of a running movement facilitates the subsequent detection of a point-light running movement embedded in a mask (Bidet-Ildei et al., 2010). In this perspective, we might consider that increasing the signal can increase facilitation or interference effects.

Following an embodied view of cognition, the modification of the signal evoked by action verb processing within the semantic context might be explained by the use of a common mechanism between action-language processing and the observation of human point-light movement i.e., the motor resonance (Bidet-Ildei et al., 2011; Bidet-Ildei & Toussaint, 2015). Motor resonance classically refers to the activation of the mirror neuron system related to the observation of another human's action (Liuzza, Setti, & Borghi, 2012), as is the case when

humans observe human BM (e.g., Lozano, Hard, & Tversky, 2008). However recent studies have shown that motor resonance also can be evoked during action word processing (Andres, Finocchiaro, Buiatti, & Piazza, 2015; Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Bidet-Ildei et al., 2011; Heard, Masson, & Bub, 2015; Kemmerer & Gonzalez-Castillo, 2008). Consequently, we can hypothesize that the link between action-sentence comprehension and observation of human BM might be constrained by the motor resonance evoked in the sentence. Given that motor resonance increases when perceived action corresponds to the perceiver's motor repertoire (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005), and that, in the present work, plausible sentences refer to usual human actions, we can hypothesize that motor resonance evoked by plausible sentences is stronger than motor resonance evoked by implausible sentences. Therefore, differences in motor resonance might explain the heightened sensitivity when action verbs are embedded in plausible sentences. In the same manner, the implication of motor resonance in the relationship between action verb processing and BM might explain why response times are only affected when action verbs are embedded in plausible sentences. Therefore, the slower response times observed when the action verb is incongruent with the subsequent BM could be interpreted as an effect of inhibition of the action representation, which is not relevant to perform the task. However, following this view, it might be surprising to learn that the effect of interference obtained when incongruent action verbs are embedded in plausible sentences was not associated with a facilitation effect in the case of congruent action verbs embedded in plausible sentences. This lack of a facilitation effect might be due to a "ceiling effect" that renders accelerated response times impossible.

To conclude, the present experiment demonstrated that the plausibility of sentence context can affect the relationship between action verb and BM perception. This finding is revealed for

the first time with a biological movement paradigm that emphasizes the highly specified human skill of detecting a general movement with only few indices, such as movement dots. Notably, such a perception mechanism can be influenced by a word embedded in a sentence, and consequently can represent an excellent example of embodied cognition.

## COMPLIANCE WITH ETHICAL STANDARDS

All aspects of this study were performed in accordance with the ethical standards set out in the 1964 Declaration of Helsinki and its later amendments. The study was approved by the local ethics committee of the laboratory—Center for Research in Cognition and Learning (CeRCA)—and was conducted in accordance with national norms and guidelines for the protection of human subjects. All participants gave their informed consent prior to their inclusion in the study. All authors declare that they have no conflicts of interest.

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## APPENDIX

### Appendix 1: List of plausible and implausible sentences

Plausible sentences in French (in English)	implausible sentences in French (in English)
<b>le footballeur court sur le terrain</b> (the football player is running on the field)	<b>le terrain court sur le footballeur</b> (the field is running on the football player)
<b>l'athlète court dans le stade</b> (the athlete is running in the stadium)	<b>le stade court dans l'athlète</b> (the stadium is running in the athlete)
<b>le gendarme court sur le trottoir</b> (the policeman is running on the sidewalk)	<b>le trottoir court sur le gendarme</b> (the sidewalk is running on the policeman)
<b>le chasseur court dans la forêt</b> (the hunter is running in the forest)	<b>la forêt court dans le chasseur</b> (the forest is running in the hunter)
<b>le voisin court dans le jardin</b> (the neighbor is running in the garden)	<b>le jardin court dans le voisin</b> (the garden is running in the neighbor)
<b>le comédien court dans le studio</b> (the comedian is running in the studio)	<b>le studio court dans le comédien</b> (the studio is running in the comedian)
<b>le gamin court sur le chemin</b> (the kid is running on the way)	<b>le chemin court sur le gamin</b> (the way is running on the kid)
<b>l'inspecteur court dans la gare</b> (the detective is running in the station)	<b>la gare court dans l'inspecteur</b> (the station is running in the detective)
<b>le vendeur court dans la rue</b> (the seller is running in the street)	<b>la rue court dans le vendeur</b> (the street is running in the seller)
<b>le sportif court dans le gymnase</b> (the sportsman is running in the gym)	<b>le gymnase court dans le sportif</b> (the gym is running in the sportsman)
<b>le garçon lance le ballon</b> (the boy is throwing the ball)	<b>le ballon lance le garçon</b> (the ball is throwing the boy)
<b>la fille lance la poupée</b> (the girl is throwing the doll)	<b>la poupée lance la fille</b> (the doll is throwing the girl)
<b>le dompteur lance la viande</b> (the tamer is throwing the meat)	<b>la viande lance le dompteur</b> (the meat is throwing the tamer)
<b>l'homme lance le bâton</b> (the man is throwing the stick)	<b>le bâton lance l'homme</b> (the stick is throwing the man)
<b>la femme lance le livre</b> (the woman is throwing the book)	<b>le livre lance la femme</b> (the book is throwing the woman)
<b>le clown lance la chaussure</b> (the clown is throwing the shoe)	<b>la chaussure lance le clown</b> (the shoe is throwing the clown)

<p><b>le touriste lance la valise</b> <i>(the tourist is throwing the suitcase)</i></p> <p><b>le cow-boy lance le lasso</b> <i>(the cowboy is throwing the lasso)</i></p> <p><b>le cuisinier lance la crêpe</b> <i>(the cook is throwing the pancake)</i></p> <p><b>le marin lance la bouée</b> <i>(the seaman is throwing the buoy)</i></p>	<p><b>la valise lance le touriste</b> <i>(the suitcase is throwing the tourist)</i></p> <p><b>le lasso lance le cow-boy</b> <i>(the lasso is throwing the cow-boy)</i></p> <p><b>la crêpe lance le cuisinier</b> <i>(the pancake is throwing the cook)</i></p> <p><b>la bouée lance le marin</b> <i>(the buoy is throwing the seaman)</i></p>
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## Appendix 2: English translation of the questionnaire proposed

- 1- Do you participate in physical activities? For how many hours?
- 2- Among the sentences, some of them were about a football player, right or wrong?
- 3- Among the sentences, some of them were about a collector, right or wrong?
- 4- Among the sentences, some of them were not plausible, right or wrong?
- 5- Please cite the verbs that are used in the sentences.