Acta Psychologica 139 (2012) 1–6

Contents lists available at SciVerse ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/ locate/actpsy

The role of volleyball expertise in motor simulation

Barbara Tomasino [a,*], Elisa Guatto [b], Raffaella Ida Rumiati [c], Franco Fabbro [a,d]

[a] IRCCS "E. Medea", San Vito al Tagliamento (PN), Italy
[b] Corso di Laurea in Fisioterapia, Medicina e Chirurgia, Università di Udine, Italy
[c] Cognitive Neuroscience Sector, SISSA, Trieste, Italy
[d] Dipartimento di Scienze Umane, Università di Udine, Italy

ARTICLE INFO

Article history:
Received 1 October 2011
Received in revised form 12 November 2011
Accepted 14 November 2011
Available online 9 December 2011

PsycINFO classification:
2330 Motor Processes
2340 Cognitive Processes
2221 Sensory & Motor Testing

Keywords:
Motor expertise
Implicit motor imagery
Motor system
Action processing

ABSTRACT

We explored the impact of motor *experience* on the interaction between implicit motor simulation and language-processing. In an action familiarity judgment task, expert volleyball players, fans and novices were presented with semantically correct sentences describing *possible* and *not possible* motor actions, all as *negative or positive* contexts, e.g., "Don't shank!" or "Assist!". As processing negated action-phrases is known to reduce simulation states, exposure to *negative or positive* contexts was used here to test how simulation varies according to motor feasibility (possible, impossible) and experience (experts and fans).

A significant *group* × *stimulus* × *context* interaction showed that athletes and fans, took longer to process negative than positive contexts for possible actions, compared to action-impossible sentences. In addition, experts were significantly faster and more accurate than fans and, in turn, they were both more accurate than novices. Thus, implicit motor simulation impacts on action-verb processing depending on (i) the domain-relevant expertise, (ii) the feasibility of the actions, and (iii) on whether scenes are presented in a negated context. These results suggest that the implicit triggering of motor representations is modulated by the context and it is tuned to people's motor repertoire, even when actions are described linguistically.

1. Introduction

Studies that compare groups with different levels of experience on specific actions are instrumental for testing theories of embodied cognition. Expertise-dependent differences in cognitive and neural operations during overt action production in sports have already been observed in action anticipation (Mueller et al., 1996), in visuo-motor transformation of tennis experts and non-experts (Le Runigo, Benguigui, & Bardy, 2005), and in action simulation (Aglioti, Cesari, Romani, & Urgesi, 2008; Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Cross, Hamilton, & Grafton, 2006). Linguistic processing of action-related words, too, is modulated by the individuals' experience of the actions conveyed in sentences or words (Beilock, Lyons, Mattarella-Micke, Nusbaum, & Small, 2008). Beilock et al. (2008) performed an fMRI study in which experts (elite ice-hockey players), fans and novices passively listened to sport-specific sentences describing ice-hockey actions and everyday actions. In addition, all participants performed a sentence comprehension task outside the scanner in which they had to decide whether an action sentence matched a picture. They were faster when action sentences were presented with matched pictures than mismatched pictures of everyday actions, whereas only experts and fans, but not novices, were faster with sport-specific sentences only. The authors proposed that this action-match effect corresponded to the experience-dependent activation of the left dorsal premotor cortex found in experts when they listened to sentences describing ice-hockey actions (Beilock et al., 2008). They also argued that extensive motor experience, by triggering automatic (implicit) motor simulation, allowed the linguistic association of described action scenarios with motor plans for execution (Beilock et al., 2008).

Motor simulation entails the rehearsal of a motor task and can be triggered both explicitly and implicitly (Jeannerod & Frak, 1999). Implicit motor simulation occurs when subjects, even when not instructed to do so, implicitly stimulate while performing another task. Examples can be found during mental rotation of body parts (Kosslyn, Thompson, Wraga, & Alpert, 2001; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999), handedness recognition of a visually presented hand (Parsons & Fox, 1998), judgment as to whether an action would be easy, difficult or impossible (Johnson-Frey et al., 2002), or action recognition performed by others (Jeannerod & Frak, 1999). As Beilock et al. (2008) used sentences describing ice-hockey actions or everyday actions, one can reasonably argue that their content triggered implicit motor simulation and activated the corresponding sensorimotor representations in the experts since stimuli were actions that could all be performed (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Barsalou, 2008; Borghi & Cimatti, 2010; Borghi & Scorolli, 2009; Buccino et al., 2005; Glenberg & Kaschak, 2002;

* Corresponding author at: IRCCS "E. Medea", Polo Regionale del Friuli Venezia Giulia, via della Bontà, 7, 33078 San Vito al Tagliamento (PN), Italy. Tel.: +39 0 434 842 711; fax: +39 0 434 842 797.
E-mail address: btomasino@ud.lnf.it (B. Tomasino).

0001-6918/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.actpsy.2011.11.006

Hauk, Johnsrude, & Pulvermuller, 2004; Postle, McMahon, Ashton, Meredith, & de Zubicaray, 2008; Raposo, Moss, Stamatakis, & Tyler, 2009; Ruschemeyer, Brass, & Friederici, 2007; Tettamanti et al., 2005; Tomasino, Weiss, & Fink, 2010).

What remains to be established is whether participants apply motor simulation only when they are presented with action-related sentences whose motor content can be experienced physically (Buccino et al., 2004; Calvo-Merino et al., 2005; Costantini et al., 2005; Stevens, Fonlupt, Shiffrar, & Decety, 2000), or also when the action sentences are semantically correct but describe actions that cannot be performed. Unspecific activations of motor areas have been observed in response to imageable concrete words (unrelated to actions) and to "non-words" with regular phonology (Postle et al., 2008; Shapiro et al., 2005).

In the present study, we explored how expert volleyball players, fans and novices decide whether the sentences they read refer (or not) to a possible action. Volleyball specific action sentences (e.g., "Cut shot!") and sentences semantically correct but describing actions that cannot possibly be performed (i.e., sentences which do not correspond to any volleyball-specific action representation, e.g., "Jump roll") were therefore presented. A second factor of the study was the context: thus sentences could take either the negative form (e.g., "Don't shank!") or a positive form (e.g., "Jump serve!"). Context-dependent effects have been observed both at a behavioral level, with significantly longer RTs for negative imperatives than positive imperatives (Tomasino et al., 2010), and at a neural level (Tettamanti et al., 2008; Tomasino et al., 2010), probably because the negative context reduces implicit simulation states. It is held that sentential negation blocks the mental representation of the information (Kaup, 2001; Kaup & Zwaan, 2003; MacDonald & Just, 1989). Accordingly, Tettamanti et al. (2008) found a reduction of activation in left fronto-parietal regions and effective connectivity in concept-specific embodied systems for action-related negative sentences. In a previous study we found that fMRI activations in the hand region of the primary motor and premotor cortices were reduced for negative hand action-related imperatives, such as "Don't grasp!" compared to "Grasp!" (Tomasino et al., 2010). Exposure to contexts can therefore be used as a measure of implicit motor simulation (Jeannerod & Frak, 1999).

Here, since participants responded by key-pressing, and all the sentences implied hand-arm movements, we expected to find context effects on reaction times. Accordingly, if participants processed the perceptual and action qualities described in the sentences, then responses should be slower for sentences presented as negative contexts (i.e., reducing motor simulation) but faster for sentences triggering motor simulation of hand-arm movements (Papeo, Vallesi, Isaja, & Rumiati, 2009; Scorolli & Borghi, 2007). Experts should be able to implicitly simulate feasible actions presented as positive contexts only, with longer reaction times for the negative context (Tomasino et al., 2010). By contrast, no simulation should occur for semantically correct but impossible actions. Weaker activations in the simulation circuit have been observed in the action observation domain for movements which cannot be performed (Cross et al., 2006), physically impossible movements (Costantini et al., 2005; Stevens et al., 2000), movements made by a non-conspecific (Buccino et al., 2004), or unfamiliar dance movements (Calvo-Merino et al., 2005). Experts and novices rock climbers were presented with an easy, an impossible, and a difficult route, and were asked to write down the sequence of holds composing each route in a recall test performed after a distraction task. No differences between the two groups on a recall test were found for the easy and impossible routes, whereas the performance of experts on the difficult route was better than that of novices (Pezzulo, Barca, Bocconi, & Borghi, 2010). The authors concluded that motor simulation is modulated by individuals' motor repertoire and expertise.

Fans might solve the task by using a strategy based on their observational knowledge about sport-specific actions (Abernethy & Zawi, 2007; Aglioti et al., 2008). Therefore they are expected to show a pattern of performance similar to that of athletes (Beilock et al., 2008). We also included a group of volleyball novices, who knew very little about this specialty. The study by Beilock et al. (2008) showed that, compared to hockey novices, ice hockey players and fans performed similarly on a sentence comprehension and picture identification task. Whether a graded pattern of motor simulation, dependent on the feasibility of the action to be processed and on the motor experience, could be observed during linguistic processing, is unclear, since previous studies on expert–novice differences in action words processing only investigated actions that could all be performed (Beilock et al., 2008). However it is reasonable to expect that similar findings could be observed even when actions are described linguistically.

2. Materials and methods

2.1. Participants

All sixty-three subjects were female Italian native speakers with comparable levels of education. All were right-handed on the Edinburgh Inventory (Oldfield, 1971), had normal or corrected-to-normal vision, and reported no history of neurological illness, psychiatric disease, or drug abuse. The study was approved by the local ethics committee. All subjects gave their informed consent to participate in the study.

Athletes. Twenty-one elite volleyball players (mean age 26.2 ± 4.9) were recruited from the Regional Professional League. They trained three times per week for 2 h each and had been playing volleyball on average for 10.7 ± 3.2 years.

Fans. Twenty-one fans (mean age 33.9 ± 8.4), recruited among friends/relatives of the athletes, had an average watching experience of 7.1 ± 2.6 years, (therefore knowing some technical expressions) were included.

Novices. Twenty-one novices with no playing or watching experience (mean age 25.61 ± 7.77) were recruited among those who reported not having ever played a volleyball match or watched one, not even on TV.

2.2. Stimuli

An elite volleyball coach generated four different lists of stimuli: 30 presented as positive possible, 30 as negative possible, 30 positive impossible, and 30 negative impossible, for a total of 120 stimulus phrases. Sixty Italian sentences describe possible technical volleyball-specific actions [i.e., possible, hereafter Ps], and 60 sentences describe impossible actions [i.e., impossible, hereafter IMPs]. Prior to the study, the list of stimuli was presented to three other volleyball coaches who agreed on familiarity, naturalness, and uniqueness to volleyball of the selected sentences. More specifically, Ps expressed volleyball specific motor acts, e.g., "Cut shot!", whereas IMPs expressed motor acts that cannot be performed since they do not belong to volleyball and, therefore, have no corresponding motor images (e.g., "Jump roll!"). Moreover, volleyball coaches judged as meaningless the 60 IMP sentences. Both the Ps and the IMPs were presented in two different linguistic contexts, half ($N = 30$ Ps and 30 IMPs) in a negative context (e.g., "Don't jump roll!"), and half ($N = 30$ Ps and 30 IMPs) in a positive one (e.g., "Cut shot!"). Both positive and negative linguistic contexts included the infinitive form of the verb preceded by "Non" or "Devi" (i.e., "Don't" or "Do"). Overall, the sentences were on average 29.63 ± 0.93 letters long, with no difference between the different types [IMPs_pos, 28.7 ± 7.4; IMPs_neg, 29.03 ± 7.3; Ps_pos, 28 ± 5.7; Ps_neg, 30.26 ± 4.2; All $Ps > .05$, n.s.]. Examples of stimuli ($N = 7$ for each category) are listed in the Appendix.

2.3. Task

In the categorization task, participants were asked to silently read a list of sentences and made binary decisions as to whether an action described in a given sentence was in fact technically feasible (a compatible relation between the used verb and its feasibility within the volleyball domain) or not (no relation between action description and its feasibility). The stimulus distribution comprised 50% feasible (60 possible) and 50% not feasible actions (60 impossible). Consistent with previous studies in which participants performed a comprehension task (Beilock et al., 2008), we adopted a task that required accessing the meaning of verbs that were presented in positive and negative contexts to investigate their effect on the participants' performance during verb processing. All experimental trials lasted 3.5 s and were followed by a variable inter-trial interval 1750 to 3250 ms long, with incremental steps of 500 ms randomly interspersed among the event trials in order to decrease expectation. Three pseudo-randomized stimulus sequences were alternated across participants, so that one participant would never hear "do jump roll" and "don't jump roll". To avoid any potential priming effect, we did not present the same verb in both the positive and negative contexts. Presentation of the stimuli and response collection were accomplished using the software Presentation® (Version 9.9, Neurobehavioral Systems Inc., CA, USA).

Participants were instructed to keep their hands still in a relaxed manner and respond as quickly as possible. They were asked to respond by pressing one of two keys on a keyboard with their right hand (yes/no answer for each stimulus). Prior to the experiment, all participants practiced the experimental task on 20 verbs which were not included in the experiment.

2.4. Statistical analysis

SPSS for Windows (version 12.0) was used for performing a repeated measure ANOVA with a between-subject factor "group" (athletes, novices and fans) and within-subject factors type of "stimulus" (IMPs, Ps) and "context" (positive and negative) on the subjects' error rates and reaction time (RTs) data. Outliers were removed by excluding the trials in which the participants' RTs were two standard deviations above or below their mean RTs for the condition in which the trial occurred (Ratcliff, 1993). All post hoc comparisons between single factors were carried out using LSD Fisher's test ($\alpha \leq .05$).

3. Results

3.1. Accuracy

We found a significant main effect of *group* ($F(2,60) = 86.5$, $p < .001$), with athletes (err % ± ds, 7.02 ± 6.01) being more accurate than fans ($p = .001$, 22.42 ± 8.77) and novices ($p = .001$, 34.64 ± 3.99), and fans being more accurate than novices ($p = .001$). The main effect of *stimulus* was significant ($F(1,60) = 9.49$, $p < .005$), with higher mean % of error rates for IMPs than Ps (25.82 ± 21.66 vs. 16.9 ± 14.23). This effect was driven by novices (*group × stimulus* interaction, $F(2,60) = 7.91$, $p < .005$). Post-hoc analyses revealed that only for novices (vs. experts and fans), was the stimulus significant, with higher mean % of error rates for IMPs than Ps ($p < .001$, 46.98 ± 10.1 vs. 22.3 ± 7.29; athletes: 5.79 ± 0.33 vs. 8.25 ± 2.24, n.s.; fans: 24.68 ± 7.52 vs. 20.15 ± 6.28, n.s.). The *stimulus × context* interaction was significant ($F(1,60) = 50.76$, $p < .001$). Post-hoc analyses revealed that the stimulus was significant for positive context only, with significantly higher mean % of error rates for IMPs than Ps presented in a positive context only ($p < .001$, Ps, 13.87 ± 5.68 vs. IMPs, 29.89 ± 24.28; negative, 21.74 ± 17.03 vs. 20.63 ± 9.45, n.s.). This interaction was driven by novices, as evidenced by a significant *group × stimulus × context* interaction ($F(2,60) = 9.13$, $p < 001$). Post-hoc analyses revealed that only for fans (vs. experts and novices), was the stimulus significant for positive context only, with significantly higher mean % of error rates for IMPs than Ps presented in a positive context only ($p < .01$, Ps, 15.71 ± 11.31 vs. IMPs, 30 ± 18.49; for negative context, Ps, 24.6 ± 16.07 vs. IMPs, 19.36 ± 12.54, n.s.), whereas for experts no significant difference was found (for positive context, Ps vs. IMPs, 6.66 ± 7.1 vs. 5.55 ± 7.1, n.s.; for negative context, Ps vs. IMPs, 9.8 ± 13.2 vs. 6.03 ± 7.9, n.s.). For novices significantly higher mean % of error rates for IMPs than Ps presented in both contexts were found (positive, Ps vs. IMPs, 17.14 ± 15.32 vs. 54.12 ± 19.96, $p < .005$; negative, Ps vs. IMPs, 27.46 ± 18.4 vs. 39.84 ± 19.62, $p < .05$). The main effects of context ($F(1,60) = .104$) and the context × group, ($F(2,60) = 1.12$) were not significant (See Fig. 1a).

3.2. Response times

We found a significant main effect of *group*, $F(2,60) = 4.46$, $p < .05$, with athletes (mean 1780.68 ± 368.3) being significantly faster than fans ($p < .001$, 2091.63 ± 343.1), but as fast as novices (n.s, 1893.57 ± 352.88), while there were no differences between fans' RT and those of novices (n.s.). The main effect of *context* was significant ($F(1,60) =$

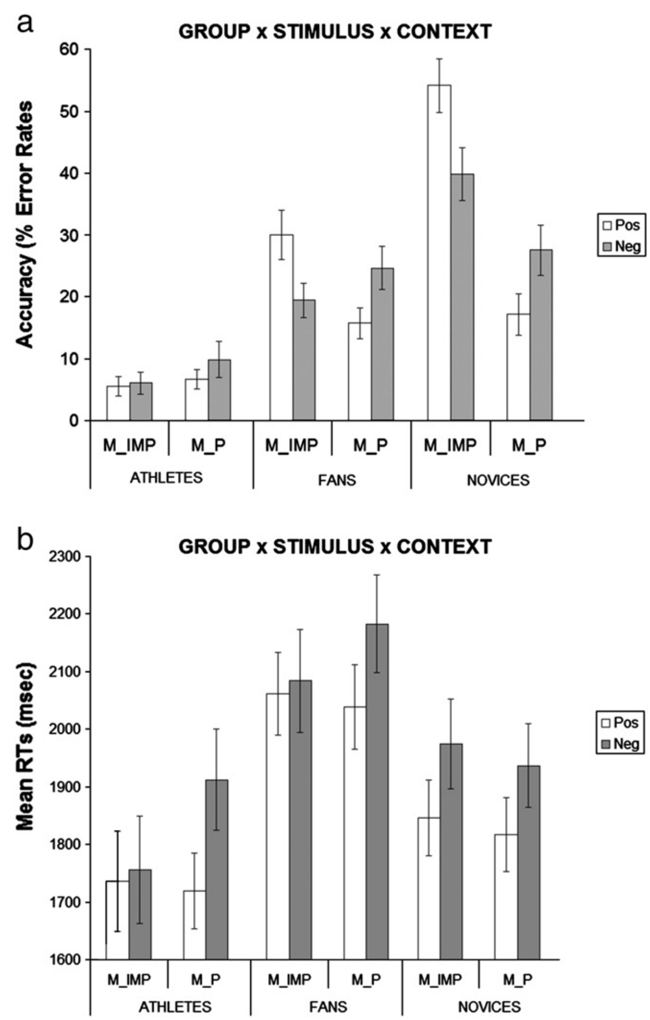

Fig. 1. Mean accuracy (a) and mean response times (b) of athletes, novices and fans during the categorization task of impossible sentences (which are semantically correct but could not be performed IMPs) and possible sport-specific action sentences (Ps) presented in positive (Pos) and negative (Neg) contexts. Error bars indicate the standard error (SEM).

57.17, $p<0.001$), with negative sentences being processed slower than positive sentences (1974.27 ± 147.27 vs. 1869.65 ± 147.85). The *stimulus* × *context* interaction, $F(1,60)=15.98$, $p<0.001$, showed that the effect of context depends on the type of stimulus (see Fig. 1b). Post-hoc analyses revealed that participants were significantly slower for negative Ps vs. IMPs ($p<.01$, 2010.64 ± 149.56 vs. 1937.89 ± 166.98), but as fast for positive Ps as IMPs (1858.1 ± 163.63 vs. 1881.2 ± 165.75). More importantly, the *group* × *stimulus* × *context* interaction was significant ($F(2,60)=5.11$, $p<.01$). Post-hoc analyses revealed that, for athletes and fans, context was significant for Ps only, with significantly slower responses for negative than positive Ps (athletes: $p<.001$, 1912.36 ± 404.11 ms vs. 1718.78 ± 301.66 ms; fans: $p<.001$, 2182.77 ± 97 vs. 2038.29 ± 334.37), and no difference between negative and positive IMPs (athletes: 1755.75 ± 428.93 vs. 1735.8 ± 398.4, n.s.; fans: 2083.76 ± 407.54 vs. 2061.69 ± 331.89). By contrast, for novices the effect of context was significant for both type of stimuli, with slower responses for negative than positive Ps ($p<.001$, 1936.8 ± 332.05 vs. 1817.21 ± 296.24) and IMPs ($p<.001$, 1974.17 ± 357.31 vs. 1846.103 ± 299.81). On the contrary, the main effect of stimulus, $F(1,60)=1.31$, $p=.25$, and all the other interactions (group × stimulus, $F(2,60)=1.97$, and group × context, $F(2,60)=.72$), were not significant (all $Ps>.05$, see Fig. 1b).

3.2.1. Speed accuracy trade-offs

The pattern of RT was not due to a speed–accuracy trade-off. For each condition, we failed to find any significant negative correlation between error-rates and response-times (across subjects in a given group). Instead, for athletes, both IMPs and Ps presented as negative imperatives lead to a significant positive correlation between error rates and RTs: subjects were slower and made more errors in those two conditions. No other significant effects were found (see Table 1).

4. Discussion

This study was designed to explore the interaction between sensorimotor experience and motor simulation in expert volleyball players, fans and novices. Overall, we found that the performance changed depending on the participants' motor experience. Athletes were significantly more accurate and faster than fans, probably because the motor simulation was more effortful for fans than for experts, consistently with previous studies in which shorter RTs were reported for fans than novices (Beilock et al., 2008); moreover, both athletes and fans were significantly more accurate than novices. However, we failed to observe significant differences between athletes and novices, suggesting that, while the former responded faster because of their expertise, the latter were faster because of their inexperience.

Novices and fans (vs. athletes) were significantly more accurate with possible than with impossible actions, suggesting that they attributed motor feasibility to actions that could not be performed (by saying that an impossible action was a possible one) more than the reverse. This effect however was influenced by the negative context, as revealed by a significant group × stimulus × context interaction. While for fans, this tendency was found for positive context only, i.e., they attributed motor feasibility to impossible actions when these were presented as positive imperatives, novices did so both for positive and negative contexts. By contrast, athletes showed a comparable performance with all types of stimuli. According to the predictive account of the motor system (Schubotz, 2007), humans predict events rather than just actions. It is claimed that the "sensorimotor system responds in a qualitatively similar way for movements that can and cannot be performed, with differences being purely quantitative and reflected mostly in stronger activity for actions that can be performed" (Schubotz, 2007). In the same vein, it is conceivable that, in our study, possible and impossible actions might have been processed in a quantitatively different way. This difference became apparent when motor experience was considered: fans and novices attributed motor feasibility to impossible actions when they were presented as positive imperatives. For novices this pattern was amplified, since they attributed motor feasibility to impossible actions when they were presented both as positive and negative imperatives. This result is in line with Schubotz (2007)'s view suggesting that proper reproducibility is not a prerequisite for our ability to simulate. It has been shown that the premotor system does not take into account the biomechanical constraints the observed impossible movements would involve if they were actually executed (Costantini et al., 2005). In that study, Costantini et al. (2005) found that while premotor areas code human actions regardless of whether they are biologically possible or impossible, sensorimotor parietal regions may be important for coding the plausibility of actions.

The factor *context* was significant, with slower RT for negative than positive contexts, thus replicating previous results (Kaup, Yaxley, Madden, Zwaan, & Ludtke, 2007; Ludtke, Friedrich, De, & Kaup, 2008; Tomasino et al., 2010).

The main result of the present study was the group × stimulus × context interaction. Since processing negated action-phrases might reduce simulation states (Tomasino et al., 2010), we predicted that exposing participants to *negative or positive* contexts would have provided us with a measure of simulation. Athletes and fans showed a difference in RTs between positive and negative sentences for possible compared to impossible actions. Processing action verbs or action-related sentences has been shown to influence even overt motor behavior (Buccino et al., 2005; Scorolli & Borghi, 2007). Scorolli and Borghi (2007), for instance, found a facilitation effect when subjects decided with a foot pedal whether verbs were related to foot actions. The authors argued that sentence processing activates motor simulation specific for the type of effector involved. In our study, participants processed hand action-related verbs and performed a hand motor response. Accordingly, RTs were faster for positive ("Do …") vs. negative ("Don't …") stimuli. The positive context might have triggered motor preparation or imaginary processes. The view that the imperative form of a verb might serve as an instruction (e.g., "sit!") was already proposed (Postle et al., 2008). These authors suggested that the pre-SMA-activation they found was due to the imperative form of a verb serving as an instruction cue: "*verbs serve as instruction cues by enabling the retrieval of an appropriate motor program, i.e., they [verbs] represent information required for motor planning*".

In contrast, in the negative context, similar to what happens with a command (e.g., "Don't Move/Shoot/Hit!"), we desist from performing the corresponding action. Sentential negation transiently reduces the access to mental representations of the negated information (Tettamanti et al., 2008). Thus, when processing negative contexts, e.g., "Don't …", an action needs to be withheld and the activation of the sensorimotor representation has to be reduced. These findings are consistent with previous fMRI studies (Tettamanti et al., 2008; Tomasino et al., 2010). In particular, in one of them in which a lexical decision task was used (Tomasino et al., 2010), while RTs were significantly longer for negative than positive imperatives, activity in the premotor and primary motor cortices bilaterally differentially decreased

Table 1
For each condition, correlations between error-rates and response-times (across subjects in that group) are reported.

	Athletes	Fans	Novices
IMPs_positive	$r=.233$, $p=.309$, n.s.	$r=-.034$, $p=.88$, n.s.	$r=-.25$, $p=.268$, n.s.
IMPs_negative	$r=.511$, $p=.018$	$r=-.269$, $p=.239$, n.s.	$r=-.169$, $p=.464$, n.s.
Ps_positive	$r=.234$, $p=.307$, n.s.	$r=-.090$, $p=.698$, n.s.	$r=-.291$, $p=.201$, n.s.
Ps_negative	$r=.468$, $p=.032$	$r=.029$, $p=.901$, n.s.	$r=-.121$, $p=.601$, n.s.

for action verbs presented as negative imperatives. Similarly, using TMS, Sohn, Dang, and Hallett (2003) showed that excitatory cortico-spinal excitability is suppressed during negative motor imagery (i.e., the mental simulation of suppressing a movement) processing.

The current pattern of results could also be explained as reflecting motor planning. It has been shown that motor planning processes and action-verb processing interact based on the findings that subliminal displays of action verbs had an effect on the neurophysiological correlates of motor planning/preparation and on the kinematics of the subsequent reaching movement (Boulenger et al., 2006). Likewise, in our study, positive imperatives could have caused excitation of response, while negative imperatives could have caused inhibition of response leading to a decrease of activity in motor areas due to the inhibition of sensori-motor representations. Interestingly, in the current study, we found that this effect was present for motorically possible actions. These types of sentences are technical descriptions of actions which correspond to volleyball-specific motor acts to a volleyball player and therefore have a corresponding motor image. For motorically impossible actions the negative context effect was not present in athletes and fans. Impossible actions are semantically correct sentences that do not correspond to any volleyball-specific motor act and therefore they do not have a proper motor image. The novices' pattern of performance suggests that they tried to simulate all actions, whether they were possible and impossible. All sentences were semantically correct and included a common familiar verb, which had a motor reference (e.g., in Jump roll, the verb "jump" might trigger the simulation of the corresponding "jumping" action). Accordingly, novices were not fully able to distinguish possible from impossible volleyball actions, and they tended to attribute motor feasibility to non feasible actions, thus their implicit strategy could have been trying to perform simulation every time they encountered a description of action, independently of its motor feasibility. Novices showed a nonspecific effect of context for all types of stimuli, which is not linked to the degree of motor knowledge. Experts and fans have similar levels of familiarity with volleyball terminology and differing levels of motor expertise; however, novices differ from experts and fans both in terms of levels of familiarity with terminology and of motor expertise.

Fans showed a pattern of performance similar to that of athletes. This finding is consistent with previous studies that explored the influence of visual and motor expertise on action anticipation abilities (Abernethy & Zawi, 2007; Aglioti et al., 2008; Farrow & Abernethy, 2003). Previous substantial experience in viewing or performing volleyball actions enhances volleyball language comprehension as it probably enables participants to associate sport-specific action sentences to the corresponding motor plans for their execution (Beilock et al., 2008). Our results are similar to the findings reported by Beilock et al. (2008), in which the authors argued that the sensorimotor experience gives rise to the automatic simulation of action possibilities associated with the stimuli one encounters (Beilock et al., 2008). In addition, we confirmed that the activation of sensorimotor representations may be modulated, in terms of processing times, by the linguistic context (i.e., "Do…" or "Don't…") (Tomasino et al., 2010). For experts and fans the effect of contexts is present for motorically possible action descriptions and not for semantically correct sentences describing movements which are not embodied and cannot be performed, thus not simulated (Cross et al., 2006).

5. Conclusions

In summary, presenting action-related verbs as negative or positive contexts seems to be a promising approach to investigate the interaction between language and motor systems (Tomasino et al., 2010). Our results, by showing the context-dependent effect, strengthen the idea of an indirect connection between the motor and language systems via sensorimotor representations (e.g., Buccino et al., 2001; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) and motor simulation (Decety et al., 1994; Glenberg & Kaschak, 2002; Tomasino, Fink, Sparing, Dafotakis, & Weiss, 2008; Tomasino, Werner, Weiss, & Fink, 2007; Zwaan & Taylor, 2006) and that motor representations are only engaged under specific conditions, with effects that are variable and context-dependent.

Acknowledgments

We would like to thank all the volunteers for participating in this study.

Appendix A. An example of the stimuli used (N = 7 for each category of the possible actions)

P_positive	Devi eseguire un bagher laterale di ricezione	*Receiving bagher side*
	Devi eseguire una rullata laterale	*Side roll*
	Devi tuffarti avanti a una mano	*Dig*
	Devi battere in salto	*Jump serve*
	Devi palleggiare indietro	*Set back*
	Devi fare un palleggio d'attacco in salto	*Jump set*
	Devi battere flottante	*Float serve*
P_negative	Non eseguire un muro a due	*Don't use two person's block*
	Non fare una difesa a mani alte	*Don't receive the attack with arms over the head*
	Non schiacciare in diagonale dell'opposto	*Don't do diagonal spike (attack)*
	Non fare un palleggio d'alzata in salto	*Dont'use back set*
	Non fare una difesa a una mano	*Don't receive the attack with one arm*
	Non difendere in tuffo a due mani	*Don't dig with both arms*
	Non battere flottante in salto	*Don't serve jump float*
IMP_positive	Devi eseguire un muro a quattro	*Use four person's block*
	Devi fare un bagher in elevazione	*Elevate bagher side*
	Devi fare una rovesciata	*Do a reverse*
	Devi murare all'indietro	*Use persons block back*
	Devi fare un attacco ortogonale dall'ala	*Make an orthogonal attack from the wing*
	Devi fare la rincorsa del bagher	*Bagher run-up*
	Devi eseguire una ricezione estrema	*Make an estreme receive*
IMP_negative	Non mettere le mani a stella invertita	*Don't put hands as a reversed star*
	Non schiacciare dalla terza linea	*Don't do a spike (attack) from the third line*
	Non fare una battuta in opposizione	*Don't do a opposition serve*
	Non fare una difesa obliqua	*Don't receive the attack oblique*
	Non partire in contropiede verso la rete	*Don't starting off guard toward the net*
	Non saltare in stile ventrale a rete	*Don't make a net-way ventral jump*
	Non fare una bracciata dorsale	*Don't make a stroke back*

References

Abernethy, B., & Zawi, K. (2007). Pickup of essential kinematics underpins expert perception of movement patterns. *Journal of Motor Behavior*, *39*, 353–367.
Aglioti, S. M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience*, *11*, 1109–1116.
Aziz-Zadeh, L., Wilson, S. M., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing actions. *Current Biology*, *16*, 1818–1823.
Barsalou, L. W. (2008). Grounded cognition. *Annual Review Psychology*, *59*, 617–645.
Beilock, S. L., Lyons, I. M., Mattarella-Micke, A., Nusbaum, H. C., & Small, S. L. (2008). Sports experience changes the neural processing of action language. *Proc. Natl. Acad. Sci. U.S.A.*, *105*, 13269–13273.

Borghi, A. M., & Cimatti, F. (2010). Embodied cognition and beyond: Acting and sensing the body. *Neuropsychologia*, *48*, 763–773.
Borghi, A. M., & Scorolli, C. (2009). Language comprehension and dominant hand motion simulation. *Human Movement Science*, *28*, 12–27.
Boulenger, V., Roy, A. C., Paulignan, Y., Deprez, V., Jeannerod, M., & Nazir, T. A. (2006). Cross-talk between language processes and overt motor behavior in the first 200 msec of processing. *Journal of Cognitive Neuroscience*, *18*, 1607–1615.
Buccino, G., Binkofski, F., Fink, G. R., Fadiga, L., Fogassi, L., Gallese, V., et al. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: An fMRI study. *European Journal of Neuroscience*, *13*, 400–404.
Buccino, G., Lui, F., Canessa, N., Patteri, I., Lagravinese, G., Benuzzi, F., et al. (2004). Neural circuits involved in the recognition of actions performed by nonconspecifis: An fMRI study. *Journal of Cognitive Neuroscience*, *16*, 114–126.
Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., & Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: A combined TMS and behavioral study. *Brain Research. Cognitive Brain Research*, *24*, 355–363.
Calvo-Merino, B., Glaser, D. E., Grezes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex*, *15*, 1243–1249.
Costantini, M., Galati, G., Ferretti, A., Caulo, M., Tartaro, A., Romani, G. L., et al. (2005). Neural systems underlying observation of humanly impossible movements: An fMRI study. *Cerebral Cortex*, *15*, 1761–1767.
Cross, E. S., Hamilton, A. F., & Grafton, S. T. (2006). Building a motor simulation de novo: Observation of dance by dancers. *Neuroimage*, *31*, 1257–1267.
Decety, J., Perani, D., Jeannerod, M., Bettinardi, V., Tadary, B., Woods, R., et al. (1994). Mapping motor representations with PET. *Nature*, *371*, 600–602.
Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception–action coupling affect natural anticipatory performance? *Perception*, *32*, 1127–1139.
Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin Review*, *9*, 558–565.
Hauk, O., Johnsrude, I., & Pulvermuller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, *41*, 301–307.
Jeannerod, M., & Frak, V. (1999). Mental imagery of motor activity in humans. *Current Opinion in Neurobiology*, *9*, 735–739.
Johnson-Frey, S. H., Rotte, M., Grafton, S. T., Hinrichs, H., Gazzaniga, M. S., & Heinze, H. -J. (2002). Selective activation of a parietofrontal circuit during implicitly imagined prehension. *Neuroimage*, *17*, 1693–1704.
Kaup, B. (2001). Negation and its impact on the accessibility of text information. *Memory and Cognition*, *29*(7), 960–967.
Kaup, B., Yaxley, R. H., Madden, C. J., Zwaan, R. A., & Ludtke, J. (2007). Experiential simulations of negated text information. *Quarterly Journal of Experimental Psychology*, *60*, 976–990.
Kaup, B., & Zwaan, R. A. (2003). Effects of negation and situational presence on the accessibility of text information. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *29*, 439–446.
Kosslyn, S. M., Thompson, W. L., Wraga, M., & Alpert, N. M. (2001). Imagining rotation by endogenous versus exogenous forces: Distinct neural mechanisms. *NeuroReport*, *12*, 2519–2525.
Le Runigo, C., Benguigui, N., & Bardy, B. G. (2005). Perception–action coupling and expertise in interceptive actions. *Human Movement Science*, *24*, 429–445.
Ludtke, J., Friedrich, C. K., De, F. M., & Kaup, B. (2008). Event-related potential correlates of negation in a sentence–picture verification paradigm. *Journal of Cognitive Neuroscience*, *20*, 1355–1370.
MacDonald, M. C., & Just, M. A. (1989). Changes in activation levels with negation. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *15*, 633–642.
Mueller, W. M., Yetkin, F. Z., Hammeke, T. A., Morris, G. L., III, Swanson, S. J., Reichert, K., et al. (1996). Functional magnetic resonance imaging mapping of the motor cortex in patients with cerebral tumors. *Neurosurgery*, *39*, 515–520.
Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*, 97–113.
Papeo, L., Vallesi, A., Isaja, A., & Rumiati, R. I. (2009). Effects of TMS on different stages of motor and non-motor verb processing in the primary motor cortex. *PLoS.One*, *4*, e4508.
Parsons, L. M., & Fox, P. T. (1998). The neural basis of implicit movements used in recognizing hand shape. *Cognitive Neuropsychology*, *15*, 583–615.
Pezzulo, G., Barca, L., Bocconi, A. L., & Borghi, A. M. (2010). When affordances climb into your mind: Advantages of motor simulation in a memory task performed by novice and expert rock climbers. *Brain and Cognition*, *73*, 68–73.
Postle, N., McMahon, K. L., Ashton, R., Meredith, M., & de Zubicaray, G. I. (2008). Action word meaning representations in cytoarchitectonically defined primary and premotor cortices. *Neuroimage*, *43*, 634–644.
Raposo, A., Moss, H. E., Stamatakis, E. A., & Tyler, L. K. (2009). Modulation of motor and premotor cortices by actions, action words and action sentences. *Neuropsychologia*, *47*, 388–396.
Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin*, *114*, 510–532.
Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, *3*, 131–141.
Ruschemeyer, S. A., Brass, M., & Friederici, A. D. (2007). Comprehending prehending: Neural correlates of processing verbs with motor stems. *Journal of Cognitive Neuroscience*, *19*, 855–865.
Schubotz, R. I. (2007). Prediction of external events with our motor system: Towards a new framework. *Trends in Cognitive Sciences*, *11*, 211–218.
Scorolli, C., & Borghi, A. M. (2007). Sentence comprehension and action: Effector specific modulation of the motor system. *Brain Research. Cognitive Brain Research*, *1130*, 119–124.
Shapiro, K. A., Mottaghy, F. M., Schiller, N. O., Poeppel, T. D., Flüß, M. O., Müller-Gärtner, H. -W., et al. (2005). Dissociating neural correlates for nouns and verbs. *Neuroimage*, *24*, 1058–1067.
Sohn, Y. H., Dang, N., & Hallett, M. (2003). Suppression of corticospinal excitability during negative motor imagery. *Journal of Neurophysiology*, *90*, 2303–2309.
Stevens, J. A., Fonlupt, P., Shiffrar, M., & Decety, J. (2000). New aspects of motion perception: Selective neural coding of apparent human movements. *NeuroReport*, *11*, 109–115.
Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., et al. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience*, *17*, 273–281.
Tettamanti, M., Manenti, R., la Rosa, P. A., Falini, A., Perani, D., Cappa, S. F., et al. (2008). Negation in the brain: Modulating action representations. *Neuroimage*, *43*, 358–367.
Tomasino, B., Fink, G. R., Sparing, R., Dafotakis, M., & Weiss, P. H. (2008). Action verbs and the primary motor cortex: A comparative TMS study of silent reading, frequency judgments, and motor imagery. *Neuropsychologia*, *46*, 1915–1926.
Tomasino, B., Weiss, P. H., & Fink, G. R. (2010). To move or not to move: Imperatives modulate action-related verb processing in the motor system. *Neuroscience*, *169*, 246–258.
Tomasino, B., Werner, C. J., Weiss, P. H., & Fink, G. R. (2007). Stimulus properties matter more than perspective: An fMRI study of mental imagery and silent reading of action phrases. *Neuroimage*, *36*(Suppl. 2), T128–T141.
Zacks, J., Rypma, B., Gabrieli, J. D., Tversky, B., & Glover, G. H. (1999). Imagined transformations of bodies: An fMRI investigation. *Neuropsychologia*, *37*, 1029–1040.
Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology General*, *135*, 1–11.