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## Probing Representations of Gymnastics Movements: A Visual Priming Study

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### Abstract

In this study, we designed a visual short-term priming paradigm to investigate the mechanisms underlying the priming of movements and to probe movement representations in motor experts and matched controls. We employed static visual stimuli that implied or not human whole-body movements, that is, gymnastics movements and static positions. Twelve elite female gymnasts and twelve matched controls performed a speeded two-choice response time task. The participants were presented with congruent and incongruent prime-target pairs and had to decide whether the target stimulus represented a gymnastics movement or a static position. First, a visual priming effect was observed in the two groups. Second, a stimulus–response rote association could not easily account for our results. Novel primes never presented as targets could also prime the targets. Third, by manipulating three levels of prime-target relations in moving congruent pairs, we demonstrated that the more similar prime-target pairs, the greater the facilitation in target. Lastly, gymnastics motor expertise impacted on priming effects.

**Keywords:** Visual priming; Perception; Implied movement; Movement representation; Motor expertise

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## 1. Introduction

Perceiving and recognizing actions performed by conspecifics are of prime importance in our daily life and social life. It allows us to understand others' intentions and react fittingly. Consequently, it can be said that identifying the actions of others is the pillar of social interaction development. Throughout the last decade, it has been established that action perception entails covert motor activity, suggesting that observers use their own motor system to perceive the actions of others (Buccino et al., 2004; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Casile & Giese, 2006; Jeannerod, 2001; Rizzolatti, Fogassi, & Gallese, 2001). In other words, observing others' actions activates the corresponding motor representations in observers provided these viewed actions belong to their own motor repertoires. Consequently, as demonstrated by Calvo-Merino et al. (2005, 2006), motor expertise influences the activation of these representations during action observation. They found stronger bilateral parietal and left hemisphere motor cortex activations in expert dancers when observing familiar dance movements in comparison with movements that the performers had not experienced physically before, even if they were visually familiar to them. Notably, these reviews and neuroimaging studies in humans have provided extensive evidence in favor of the common coding theory, according to which action perception and action production are commonly represented (Prinz, 1997).

According to the visual priming literature, it is recognized that visual perception of action is impacted by prior exposure to motor-related actions such as action verb reading, action execution, or action observation (e.g., Bidet-Ildei, Chauvin, & Coello, 2010; Bidet-Ildei, Sparrow, & Coello, 2011; Casile & Giese, 2006; Costantini, Committeri, & Galati, 2008; Daems & Verfaillie, 1999; Guldenpenning, Kunde, Weigelt, & Schack, 2012; Verfaillie & Daems, 2002). More specifically, being shortly exposed to action observation increases forthcoming perceptual performance (Bidet-Ildei et al., 2010; Costantini et al., 2008; Daems & Verfaillie, 1999; Guldenpenning et al., 2012; Guldenpenning, Steinke, Koester, & Schack, 2013; Verfaillie & Daems, 2002). From the few priming studies available, studies aimed to shed some light on the nature of action representations underlying the priming process. On one hand, some research has examined whether representations of actions are viewpoint specific or not (Daems & Verfaillie, 1999), whether they are effector-and-target independent or dependent (Costantini et al., 2008). In a similar vein, the study by Bidet-Ildei et al. (2010) has probed whether action execution and action observation are coded according to a common representation. On the other hand, studies have investigated whether action representations encompass information on the future states of an action by examining whether it was possible to prime a forthcoming action (Bidet-Ildei, Tamamiya, & Hiraki, 2013; Guldenpenning et al., 2012, 2013; Verfaillie & Daems, 2002).

With regard to the second point, research teams investigated whether individuals exposed to an action anticipated the future sequence of this action which subsequently led to an easier recognition of this anticipated sequence. Using a long-term priming paradigm, Verfaillie and Daems (2002) offered a positive answer to this question. Similarly,

Guldenpenning et al. (2012) reached the same conclusion in a short-term priming paradigm among individuals possessing different motor skill levels: motor expert performers (i.e., student-athletes) and non-motor expert performers (i.e., non-athletes). However, they found that students-athletes possessed greater anticipatory skills compared to nonathletes; they were believed to have developed a more accurate representation of the action than their novice counterparts due to the time spent in motor training. Finally, using dynamic movement stimuli (i.e., video sequences), Bidet-Ildei et al. (2013) investigated whether observing and performing a pointing movement subsequently facilitated perceptual anticipation. After motor and visual priming, the subjects were asked to anticipate the final position of a pointing movement embedded in a point-light display which disappeared from the screen when 60% of this movement was completed. The findings only showed a visual priming effect.

With regard to the first point, Bidet-Ildei et al. (2010) sought additional evidence for the existence of a common motor representation when perceiving and executing the same action (Prinz, 1997). Using priming paradigms and dynamic movement stimuli (i.e., video sequences), they investigated whether observing and performing a running activity subsequently improved the perception of this activity. Perception was assessed by judging the running direction of an ambiguous point-light display embedded within a mask composed of moving dots. This research team reported a motor priming effect irrespective of participant gender. They also showed a visual priming effect provided there was a gender congruency between the participant and the person seen during the priming condition. In this case, motor and visual priming effects were similar. This gender-dependent effect suggests that the visual priming effect is closely dependent on the observer's motor experience. Taken as a whole, these findings support Prinz's common coding theory; that is, a direct linkage between the representations of perceived action and self-generated action.

Along the same lines, Costantini et al. (2008) aimed to deepen our knowledge of the representation of observed actions. Using an association of priming and go/no-go tasks, they examined whether representations of observed actions were effector- and target-dependent or independent representations. They employed static action stimuli, that is, static images that implied human movements. These actions were object-oriented and performed by the lower and upper limbs which were disconnected from the body. They reported a priming effect induced by the repetition of an action even when this action was performed with different effectors and over different target objects. This result suggests the existence of representations of actions which are abstract enough to be activated while observing similar actions irrespective of the effectors used to produce these actions and irrespective of the targets to be reached.

Finally, Daems and Verfaillie (1999), using long-term priming paradigms, focused on the representations underlying human action and posture identification. Employing static stimuli, they observed a priming effect in the perception of actions and postures when an identical point of view was used in the prime (i.e., priming action) and target (i.e., primed action). They also revealed a long-term priming effect in the perception of anatomically possible human postures but no effect when postures were impossible to perform, even when the prime and target postures shared the same orientation. The impossibility of

achieving these postures was due to biomechanical constraints of the body. Their findings suggest that the representations underlying the identification of human actions and postures are viewpoint specific.

Before shedding some light on the priming of forthcoming actions, we preferred to start from the beginning and focused on the mechanisms underlying the priming of human movements. Priming studies focusing on this topic are few (i.e., Bidet-Ildei et al., 2010; Costantini et al., 2008; Daems & Verfaillie, 1999), and considerably heterogeneous in terms of (a) paradigms (shortterm priming vs. longterm priming vs. shortterm priming combined with a go/no-go task), (b) stimuli (dynamic vs. static), actions (object-oriented action versus non-object-oriented action, actions implying either the whole body or hand and legs disconnected from the body), and (c) perceptual tasks (meaningful-meaningless action judgment task: Costantini et al., 2008; possible-impossible action decision task: Daems & Verfaillie, 1999; directional judgment task: Bidet-Ildei et al., 2010). Thus, we decided to design a visual shortterm priming paradigm to probe the representations of human whole-body movements and to investigate the mechanisms of visual shortterm priming. In the present study, the stimuli we used were static stimuli that implied movements or not. Stimuli implying movements depicted the middle part of gymnastics moves whereas the stimuli which did not hint at movements represented static positions. To the best of our knowledge, no study using visual short term priming and implied whole-body movements has been conducted. Thus, the goals of the present research were fourfold.

First, taking into account the findings of previous studies which have shown that prior exposure to action observation impinged on visual perception performance (Bidet-Ildei et al., 2010; Costantini et al., 2008; Daems & Verfaillie, 1999), we verified whether a visual priming effect was observed with visible primes depicting human whole-body movements. We expected to find shorter RTs in congruent trials than in incongruent trials.

Second, to shed more light on visual priming mechanisms, we examined whether the priming effect was due either to a rote stimulus–response learning (Abrams & Greenwald, 2000; Damian, 2001; Neumann & Klotz, 1994) or to a prime-induced response activation (Dehaene et al., 1998; Naccache & Dehaene, 2001). Rote stimulus–response learning refers to the fact that priming arises from a previously acquired mapping between a target stimulus and a response key, whereas prime-induced response activation reflects a genuine unconscious categorization of the primes. In the latter account, after the subjects unconsciously apply the task instruction to the prime, they prepare a motor response appropriate to the prime. If the prime-target pair is congruent, the response elicited by the prime is compatible with that required by the target and subsequently answering is facilitated (fast responses). Conversely, if the prime-target pair is incongruent, the response generated by the prime competes with the one prompted by the target and must be inhibited to answer accurately to the target (slow responses). This response conflict is reflected by a slowing down in providing answers and refers to the response competition theory (Molden, 2014; Wentura & Rothermund, 2003). The inclusion of prime stimuli never presented as target stimuli (i.e., non-target primes) could allow us to decide between both accounts. If the prime-induced response activation interpretation is correct, we should observe a priming effect which extends to non-target primes, thus resulting in

an interference effect for all primes, whether novel or old. If the stimulus–response learning interpretation is correct, we should not observe a priming effect when considering non-target primes. We expected to corroborate the prime-induced response activation account. In the following sections, a non-target prime will be referred to as novel prime (NP), whereas a prime stimulus used both as prime and target will be identified as old prime (OP).

Third, based on Bodner and Dypvik's (2005) work, which found that in addition to congruency effects, similar prime-target pairs facilitated target processing, we investigated whether the degree of prime-target congruency among congruent trials facilitated the perception of human movements. We thus manipulated the association strength between the prime and target by using three levels of prime-target relation among move congruent trials: (a) prime and target were physically identical: same move and same agent; (b) prime and target depicted the same move but the agents were different; and (c) prime and target featured different moves with different agents. We expected to find that the more congruent the prime-target pairings, the greater the facilitation in target processing, that is, the shorter the RTs.

Finally, to gain a better understanding of priming mechanisms, we examined whether motor expertise impacted on priming effects. Based on the close link between action perception and action production (Common Coding Theory, Prinz, 1997) and Calvo-Merino et al. findings (Calvo-Merino et al., 2005, 2006), we expected to find shorter RTs in motor experts compared to non-experts in congruent and incongruent trials, as well as in congruent trials where the degree of congruency had been manipulated. Highly surprisingly, with the exception of Guldenpenning et al. (2012, 2013), who included skilled athletes practicing in a non-elite context in their studies investigating priming of forthcoming actions, none of the studies investigated the influence of motor expertise on priming.

## 2. Materials and methods

### 2.1. Subjects

Twelve right-handed French elite female gymnasts ( $M_{\text{age}} = 13.7$ ,  $SD = 2.9$ ) and twelve gender- and age-matched controls ( $M_{\text{age}} = 13.5$ ,  $SD = 3.1$ ) participated voluntarily in the study. The elite female gymnasts all competed at the national level and trained 4 hours per day, 6 days per week. Generally, these athletes had commenced gymnastics at the age of three or four. In contrast, the non-experts had no previous experience in practicing any type of sports or, at most, they possessed a minimal experience in practicing physical education at school. To guarantee that the female gymnasts possessed motor and visual familiarity of the movements employed in the study, they were invited to evaluate on a Likert-scale, graded from 0 to 10 ("0" never and "10" very often), how often they saw the movements and how often they performed the movements. Gymnasts who had scored below "8" were excluded from the study. As for non-experts, a short interview was



conducted in which they were invited to give general information about their sporting history. An evaluation on a graduated scale ranging from 0 to 10, similar to the one used with the gymnasts, was completed. Subjects who had practiced a sport, apart from compulsory physical education sessions at school, and who had scored above 3 were excluded.

The subjects were also assessed using the Edinburgh Handedness Inventory (Oldfield, 1971) and all were considered to be right-handed. All the participants had normal or corrected-to-normal vision and were kept blind to the goals of the study. They gave written informed consent and separate parental consent was also obtained for all the subjects under the age of 18. In both informed consents, subjects and parents were told about the description, duration, goals, and potential risks of the experiment. Informed consents were written in language easily understood by young children and contact information was given in order for the participants and their parents to ask potential questions about the experiment. More important, the subject rights were explained: Subjects can withdraw from the study at any time without providing any explanations and without any consequences. Benefits of participation were also mentioned. In the present study, the subjects received gift cards for their participation. These cards worth 30 Euros allowed them to buy some sport clothes in specific shops. Finally, the participants and parents were given 1 week to decide whether to participate or not to the experiment. The study was approved by the local institutional ethics committee and has been conducted according to the principles expressed in the Declaration of Helsinki.

## 2.2. *Stimuli and apparatus*

A set of 36 images was used in this study (see Fig. 1). Of these, 24 images depicted a movement, more specifically the middle part of a gymnastics move, whereas the 12 remaining images represented a static position. Two different movements were selected: a split leap forward (i.e., a grand jete: a skill in gymnastics beam/floor routine) and a Tkatchev (i.e., handstand on high bar, giant circle backward, counter straddle-reverse hetch over high bar to hang: a complex flight skill in gymnastics bar routine). These movements were selected because in gymnastics, they are classified respectively as a dance element and an acrobatic element. Thus, they are completely different in the form and are advanced gymnastics skills only mastered by elite gymnasts. The static position was a kneeling position (see Fig. 1). Throughout this manuscript, the static position is referred to as “a resting position.” Pictures of the static/resting position and each movement were collected from gymnastics websites or personal gymnasts’ Facebook pages. Permissions to use these pictures were obtained from each gymnast. They were exclusively used for research purposes. None of the photographed gymnasts participated in the current study. The background of these photos was reworked using Adobe Photoshop software: It was changed and replaced by a dark and uniform background. The size of the images was 800 pixels × 800 pixels. So all in all, there were 36 stimuli including: 1 move/grand jete performed by 12 gymnasts, 1 move/Tkatchev performed by 12 gymnasts, and 1 resting/kneeling position executed by 12 gymnasts. Each photograph was of a different gymnast.

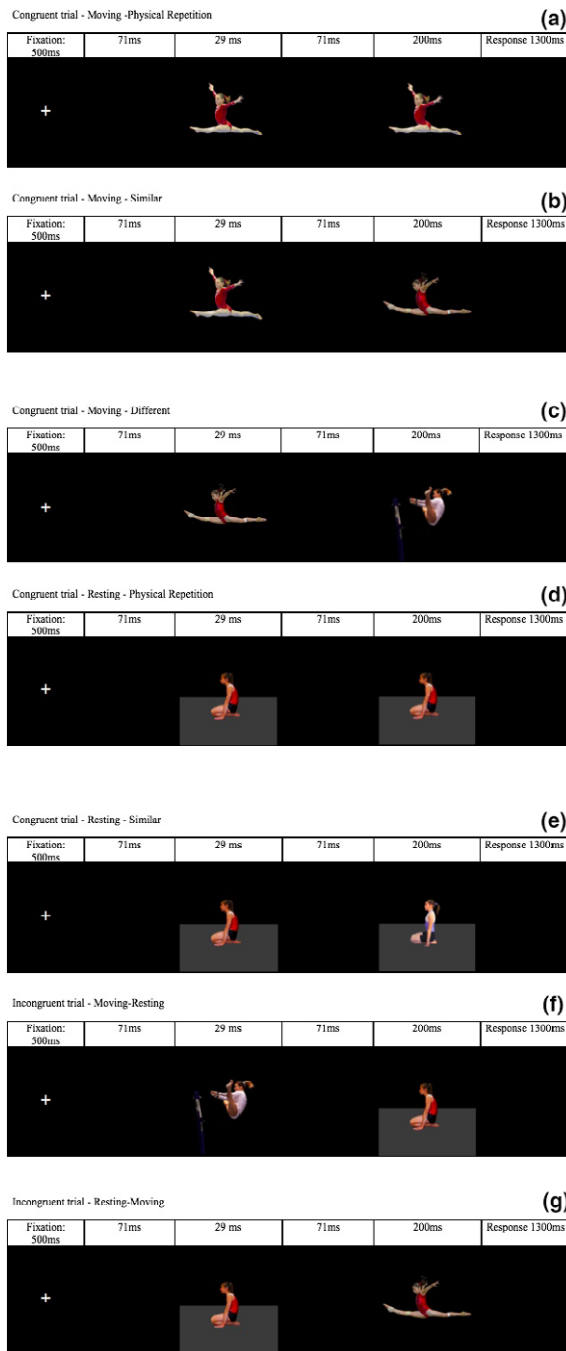


Fig. 1. Experimental procedure and stimuli. Illustration of the seven types of trials (congruent and incongruent) used in this study: (a) Congruent trial—Moving—Physical repetition, (b) Congruent trial—Moving—Similar, (c) Congruent trial—Moving—Different, (d) Congruent trial—Resting—Physical repetition, (e) Congruent trial—Resting—Similar, (f) Incongruent trial—Moving—Resting, and (g) Incongruent trial—Resting—Moving.



From the set of 36 images, 600 prime-target pairs were created. In half of the trials, the prime-target was congruent and in the other half, it was incongruent. A prime is congruent with a target when both share common characteristics; in the present study, that is when both depicted a move or a resting position. Prime-target pairing was incongruent when the prime showed a move and the target a resting position and vice versa.

When the prime was congruent with the target, there were 300 pairings composed of different levels of congruity.

1. 60 Moving Physical Repetition (Moving PR): prime and target were physically identical: same move and same agent.
2. 60 Moving Similar (Moving S): prime and target depicted the same move but the agents were different.
3. 60 Moving Different (Moving D): prime and target featured different moves. The prime was a grand jete in beam/floor routine, whereas the target showed a Tkatchev in bar routine or vice versa. In both cases, the agents were different.
4. 60 Resting Physical Repetition (Resting PR): prime and target were physically identical: same resting position and same agent.
5. 60 Resting Similar (Resting S): prime and target depicted the same resting position but the agents were different.

Moving/Resting Physical Repetition pairs displayed the highest congruity whereas Moving Different pairs exhibited the lowest congruity. Moving/Resting Similar pairs fell between the two.

When the prime was not congruent with the target, there were 300 pairings composed of two kinds of pairs.

1. 150 Moving-Resting: the prime was a move, whereas the target was a resting position. Agents were different.
2. 150 Resting-Moving: the prime was a resting position, whereas the target was a move. Agents were different.

Half of the set of the stimuli/images were used as novel primes (NP). Thus, 18 stimuli served exclusively as primes and were never presented as targets (i.e., 6 grand jete, 6 Tkatchev, and 6 kneeling position). This was done in order to avoid automatic stimulus-response learning. The other 18 stimuli were practiced as primes and targets and when they were used as primes, they were referred to as old primes (OP).

All the images were displayed on a 42 -inch full HD TV screen (1,920 × 1,080). To ensure a more accurate control of the display duration of the images, the chosen screen was a progressive scan plasma technology with a refresh rate of 120 Hz and an FFD technology capacity of 3,200 Hz (Feed Forward Driving). A computer was connected to the screen using a 10 m HDMI cable (HDMI 2.0). The computer was a PC with a windows 7 64 bits operating system (Processor: I7-3720QM–2.6 GHz; RAM: 32Go; Video card: Nvidia Quadro K4000M). Subjects were seated in front of the screen at 1.3 m. A Matlab (2012b) script using Psychophysics Toolbox functions (version 3.0.10) has been developed to manage the experimental set-up, display the images, and record the data

(reaction times). The size of the images was  $800 \times 800$  pixels. All images were displayed in the middle of the screen on a white background. The display duration of the images on the screen was carefully controlled using a high speed camera (Olympus 1,000 Hz). The temporal accuracy of the experimental set up was  $\pm 1$  ms.

### 2.3. *Experimental procedure*

The experimental procedure comprised two parts: a training session and a conscious visual priming task.

#### 2.3.1. *Training session*

Prior to data collection, there was a 5 min-training session during which the subjects had an opportunity to familiarize themselves with the task to be performed, that is, the conscious visual priming task. The stimuli used in this training session were different to those used in the experiment.

#### 2.3.2. *Conscious visual priming task*

The subjects were invited to perform a speeded two-choice response time task, that is, to perform a categorization task on the target stimulus. Did the stimulus depict a move or a resting position? There were six 8-min blocks of 100 trials. Each block was separated by a 5-min rest period. The order of the 600 trials with 300 congruent prime-target pairs and 300 incongruent prime-target pairs was randomized across the six blocks. Inter-trial intervals were around 2,500/3,500 ms since it was the time Psychophysics Toolbox software required to load visual stimuli between trials. Each trial, which lasted 2,171 ms, comprised six stages which were shown via a video display (see Fig. 1). In stage 1, the subjects were asked to fix their attention on a target point placed on a screen situated 1.30 m in front of them. Then, a 71 ms black screen appeared (stage 2). It was followed by a 29 ms prime (stage 3), a 71 ms black screen (stage 4), a 200 ms target (stage 5), and a black screen lasting 1,300 ms. In this last stage, the subjects were instructed to press with their index fingers the W key on a keyboard if the target was a move and the N key if the target was a resting position, as fast and as accurately as possible. More specifically, instructions that were given to the subjects were as follows: “You are going to press with your index fingers the W key if the second image depicts a move and the N key if the second image describes a resting position, and this, as fast and as accurately as possible. This experiment was designed to measure how quickly you can react to a stimulus without making errors.”

### 2.4. *Data processing*

During the conscious visual priming task, reaction times (RTs) and percentages of response errors were measured. RTs were recorded using an external USB keyboard on which subjects had to press keys. The keyboard was synchronized to processing script and consequently directly recorded by Matlab. Responses exceeding 1,300 ms and incorrect answers were discarded from further RT analysis.

## 2.5. Statistical analysis

All statistical analyses were performed using Statistica 7.1. First, we carried out preliminary analyses. We calculated the rates of incorrect answers and responses exceeding 1,300 ms for expert and non-expert participants. Then, we averaged correct response RTs and rates of response errors across trials for each subject and each type of prime-target pairs.

Second, planned comparisons were conducted as we have hypothesized specific pairwise comparisons. The reader is reminded that planned comparisons can be conducted instead of an ANOVA (or even notwithstanding “non-significant” omnibus ANOVA  $F$  values) provided these comparisons have been specified before the data collection (Abrami, Cholmsky, & Gordon, 2000; Kwon, 1996; Ruxton & Beauchamp, 2008; Seltman, 2015). These planned analyses were computed on reaction time and error rate values. Data normality distribution was checked with the Kolmogorov–Smirnov test. When data displayed a serious deviation from normality, they were transformed. This was the case for error rates, which were converted to arcsinh values. To address the problem of multiple comparisons when planned comparisons are run, two types of computation are implemented. If planned comparisons are orthogonal, there is no need to adjust the alpha level (Sokal & Rohlf, 1995). However, if they are not orthogonal, a correction of  $p$  value for multiple testing should be applied. The false discovery rate (FDR) will be used (Benjamini & Hochberg, 1995). Finally, effect sizes (ES) were reported (Long & van Stavel, 1995).

## 3. Results

### 3.1. First analysis: Preliminary analyses on RTs and error rates

Rates of trials that were discarded for error were 2.51% for experts and 3.03% for non-experts and no significant difference was found between these two kinds of participants,  $t(22) = -0.213$ ,  $p > .80$ . Rates of trials that were discharged for exceeding the 1,300 ms time were 0.25% for experts and 1.85% for non-experts. No significant difference was found between these two groups,  $t(22) = -2.010$ ,  $p > .05$ . In both cases, percentage values were transformed into arcsinh values as data did not fit a normal distribution model.

Correct response RTs and rates of response errors were also computed for each type of prime-target pairs and for motor experts and non-experts (see Table 1).

### 3.2. Second analysis: Checking for a priming effect (Goal 1)

To check for a priming effect at reaction time and error levels for both groups, we performed four planned comparisons. Alpha levels did not need any adjustments as these comparisons were orthogonal (Sokal & Rohlf, 1995).

First, we conducted two planned comparisons between RTs in congruent trials versus incongruent trials for experts and non-experts. We found in experts shorter RTs in congruent trials than in incongruent trials (603.9 vs. 649.2),  $t(22) = 70.615$ ,  $p < .000001$ ,

Table 1  
 Mean reaction times (RTs) in milliseconds and mean error rates in percentages for experts and non-experts and for the seven types of trials used in this study

	Moving PR		Moving Similar		Moving Different		Resting PR		Resting Similar		Moving-Resting		Resting-Moving	
	Experts	Non-Experts	Experts	Non-Experts	Experts	Non-Experts	Experts	Non-Experts	Experts	Non-Experts	Experts	Non-Experts	Experts	Non-Experts
RTs	562.9	631.9	599.2	657.7	632.1	697.5	556.9	613.9	590.0	626.6	648.2	706.2	643.8	712.2
SD	19.7	19.7	18.5	18.5	18.3	18.3	18.9	18.9	17.8	17.8	16.4	16.4	16.4	16.4
Error %	0.83	2.54	0.69	2.17	1.67	3.35	0.84	1.69	0.83	1.56	5.38	5.22	2.73	2.32
SD	1.11	1.11	0.84	0.84	1.16	1.16	0.62	0.62	0.59	0.59	1.18	1.18	0.87	0.87

Note. SD, standard deviation.

ES = 2.67. The same pattern was observed in non-experts (663.6 vs. 709.2),  $t(22) = 71.465$ ,  $p < .000001$ , ES = 2.69 (see Fig. 2).

Second, after transforming the error rates into arcsinh values, we computed two planned comparisons between converted error rate values in congruent trials versus incongruent trials for experts and non-experts. We found that for experts the error rate was 2.79% greater in incongruent trials than congruent trials,  $t(22) = 17.606$ ,  $p = .000374$ , ES = 3.79. For non-experts, the same pattern held true: the error rate was greater by 1.46% in incongruent trials,  $t(22) = 12.290$ ,  $p = .001997$ , ES = 3.17 (see Fig. 3).

### 3.3. Third analysis: Visual priming mechanisms (Goal 2)

To determine whether the priming effect was due either to the rote stimulus–response learning or to the prime induced response activation, we performed four planned comparisons. Alpha levels did not need to be adjusted as these comparisons were orthogonal (Sokal & Rohlf, 1995).

First, we conducted two planned comparisons between RTs in congruent trials versus incongruent trials for OP and NP for experts. We found that expert subjects responded faster in congruent trials compared to incongruent trials, respectively, when primes were OP (601.1 vs. 648.7,  $t(22) = 84.235$ ,  $p < .000001$ , ES = 2.71) and NP (606.7 vs. 649.8,  $t(22) = 35.054$ ,  $p = .000006$ , ES = 2.58) (see Fig. 4).

Second, the same analysis was completed for non-experts. We found that non-expert subjects responded faster in congruent trials compared to incongruent trials respectively

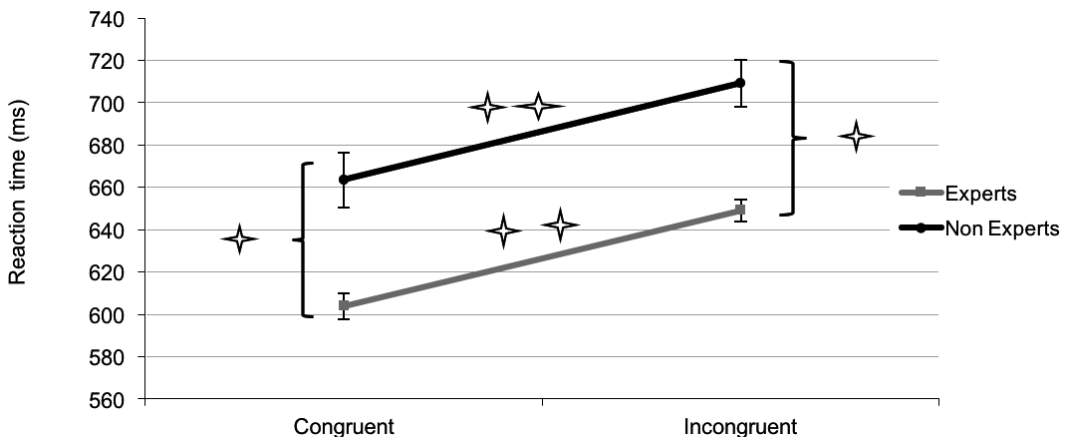


Fig. 2. Reaction times (in milliseconds) for the expert and non-expert groups for congruent and incongruent trials. Error bars correspond to  $\pm 1$  SEM. Asterisks indicate a statistically significant difference for congruent versus incongruent in experts and non-experts (\*\* $p < .000001$ ) and also for experts versus non-experts in congruent and incongruent trials (\* $p < .03$ ).

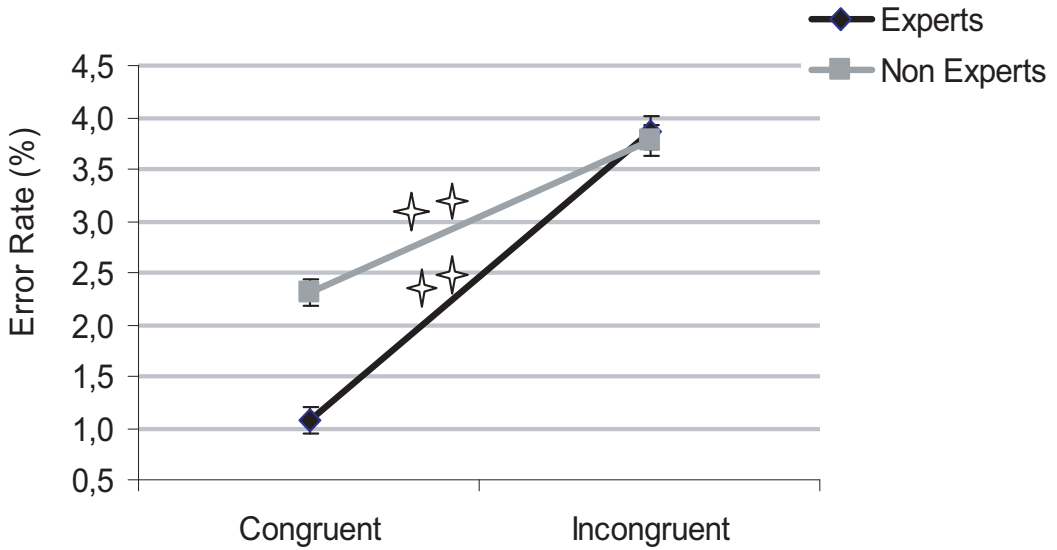


Fig. 3. Error rates (in %) for the expert and non-expert groups for congruent and incongruent trials. Error bars correspond to  $\pm 1$  SEM. Asterisks indicate a statistically significant difference for congruent versus incongruent in experts and non-experts (\*\* $p < .002$ ). No statistically significant difference was found for experts versus non-experts in congruent and incongruent trials.

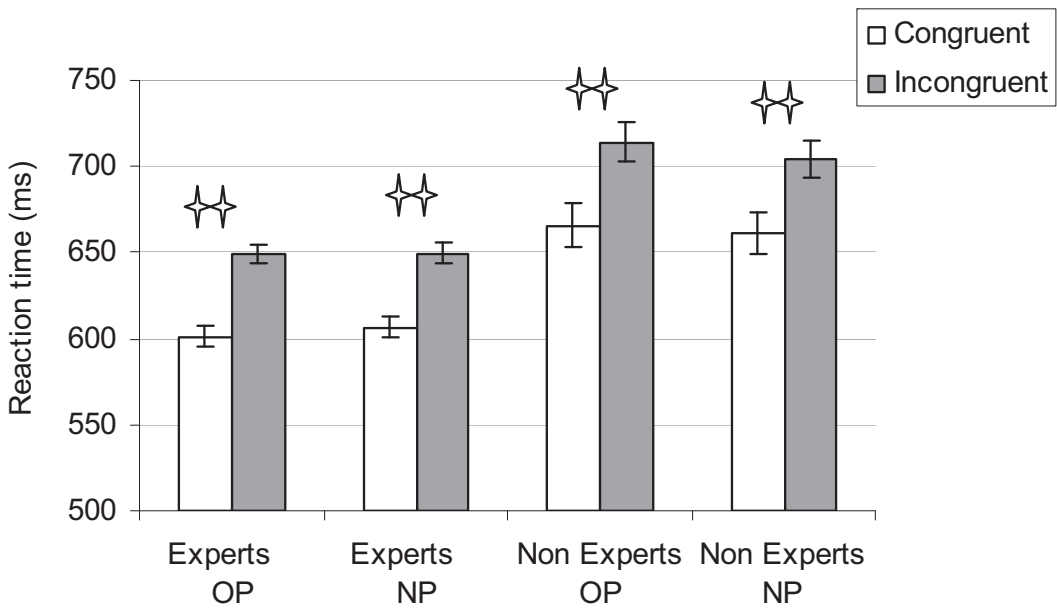


Fig. 4. Reaction times (in milliseconds) for congruent and incongruent trials, for old primes (OP) and novel primes (NP), and for expert and non-expert groups. Error bars correspond to  $\pm 1$  SEM. Asterisks indicate a statistically significant difference for congruent versus incongruent trials for both groups and prime types (\*\* $p < .000001$ ).

when primes were OP (666.0 vs. 714.3,  $t(22) = 87.150$ ,  $p < .000001$ ,  $ES = 2.76$ ) and NP (661.2 vs. 704.0,  $t(22) = 34.613$ ,  $p = .000006$ ,  $ES = 2.56$ ) (see Fig. 4).

#### 3.4. Fourth analysis: Facilitation of target processing in congruent trials (Goal 3)

To check whether the degree of prime-target congruency among congruent trials facilitated the perception of human movements, we performed planned comparisons at reaction time and error levels in both experts and non-experts. We distinguished three levels of prime-target relations in moving congruent pairs, ranging from Moving Physical Repetition, Moving Similar to Moving Different. Alpha levels needed some adjustments as these comparisons were not orthogonal. The False Discovery Rate was used (Benjamini & Hochberg, 1995) and we found a Benjamin and Hochberg corrected significance level of .05.

First, we conducted, both in experts and non-experts, three planned comparisons between RTs in (a) Moving Physical Repetition trials versus Moving Similar trials, (b) Physical Repetition trials versus Moving Different trials, and (c) Moving Similar trials versus Moving Different trials. The expert subjects responded faster in Moving Physical Repetition trials than in Moving S (562.9 vs. 599.2,  $t(22) = 36.785$ ,  $p = 000004$ ,  $ES = 1.90$ ) and Moving D trials (562.9 vs. 632.1,  $t(22) = 88.776$ ,  $p < .000001$ ,  $ES = 3.64$ ). They also answered quicker in Moving S trials compared to Moving D trials (599.2 vs. 632.1,  $t(22) = 24.161$ ,  $p = .000065$ ,  $ES = 1.79$ ) (see Table 1 and Fig. 5). We found the same patterns of findings in non-expert subjects. They responded faster in Moving Physical Repetition trials than in Moving S (631.9 vs. 657.7,  $t(22) = 18.583$ ,  $p = 000282$ ,  $ES = 1.35$ ) and Moving D trials (631.9 vs. 697.5,  $t(22) = 80.008$ ,  $p < .000001$ ,  $ES = 3.45$ ). They also answered quicker in Moving S trials compared to Moving D trials (657.7 vs. 697.5,  $t(22) = 35.528$ ,  $p = .000005$ ,  $ES = 2.17$ ) (see Table 1 and Fig. 5).

Second, after transforming the error rates into arcsinh values, we computed the same analyses. These analyses did not reveal any statistically significant planned comparisons.

#### 3.5. Fifth analysis: Priming and motor expertise (Goal 4)

To demonstrate the superiority of experts over non-experts, we conducted planned comparison, at reaction time and error levels, in congruent and incongruent trials as well as in congruent trials where the degree of congruency had been manipulated. Alpha levels did not need to be adjusted as these comparisons were orthogonal (Sokal & Rohlf, 1995).

First, we computed two planned comparisons between RTs in experts versus non-experts for each congruity factor (i.e., congruent, incongruent). We showed that experts responded, respectively, 59.6 and 59.9 ms faster than non-experts in congruent trials,  $t(22) = 5.615$ ,  $p = .027$ ,  $ES = 3.35$ , and in incongruent trials,  $t(22) = 6.972$ ,  $p = .015$ ,  $ES = 3.73$  (see Fig. 2).

Second, we performed three planned comparisons between RTs in experts versus non-experts for each of the three conditions (i.e., Moving Physical Repetition, Moving



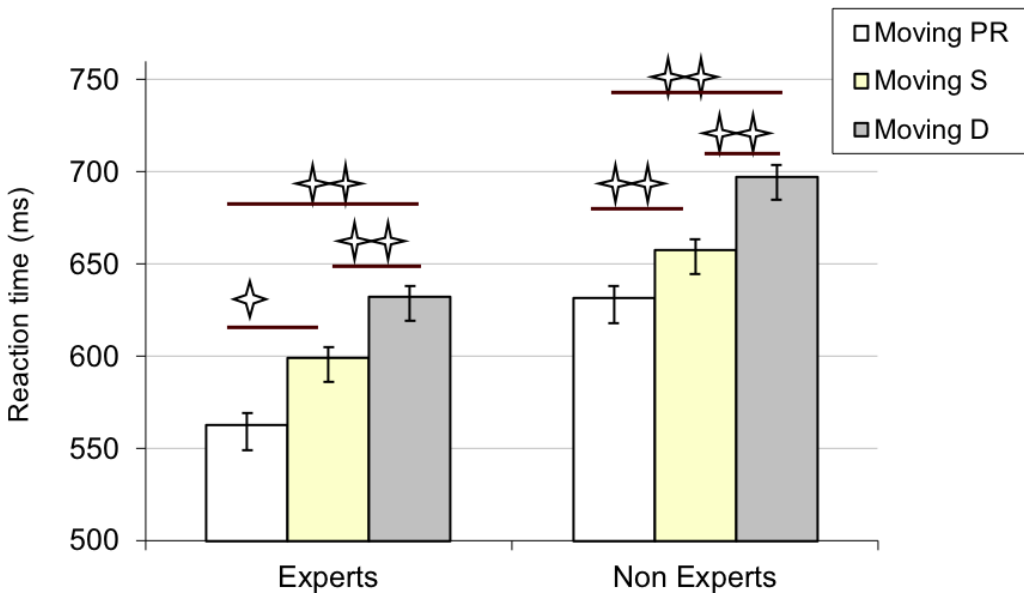


Fig. 5. Reaction times (in milliseconds) for the expert and non-expert groups, and for the Moving PR, Moving S, and Moving D conditions. Error bars correspond to  $\pm 1$  SEM. The asterisk indicates a statistically significant difference between each of the three conditions in both groups (\*\* $p < .0005$ ).

Similar, and Moving Different). We found that experts responded faster than non-experts in: (a) Moving PR trials,  $t(22) = 6.133$ ,  $p = .021442$ , ES = 3.50; (b) Moving S trials,  $t(22) = 4.995$ ,  $p = .035897$ , ES = 3.16; and (c) Moving D trials,  $t(22) = 6.390$ ,  $p = .019163$ , ES = 3.57 (see Fig. 6).

Third, after transforming the error rates into arcsinh values, we computed the same analyses as those described above. No statistically significant planned comparisons were revealed (see Fig. 3).

### 3.6. Sixth analysis: Reason for the superiority of experts over non-experts in priming

To determine whether the superiority of experts over non-experts in priming was due either to their motor competence/familiarity or to their fast choice-reaction time, we performed two planned comparisons. Alpha levels did not need to be adjusted as these comparisons were orthogonal (Sokal & Rohlf, 1995). If the choice-reaction time hypothesis proves correct, when compared to non-experts, we shall find a shorter answer time in motor experts both when subjects are exposed to move as well as to resting position stimuli. The logic underlying this hypothesis is as follows: Motor expert performers and their non-expert counterparts possessed a motor familiarity with the resting positions, whereas only experts were motorically familiar with the moves selected in the present study.

Thus, we computed two planned comparisons between RTs in experts versus non-experts in Moving and Resting congruent trials. We found that experts responded faster

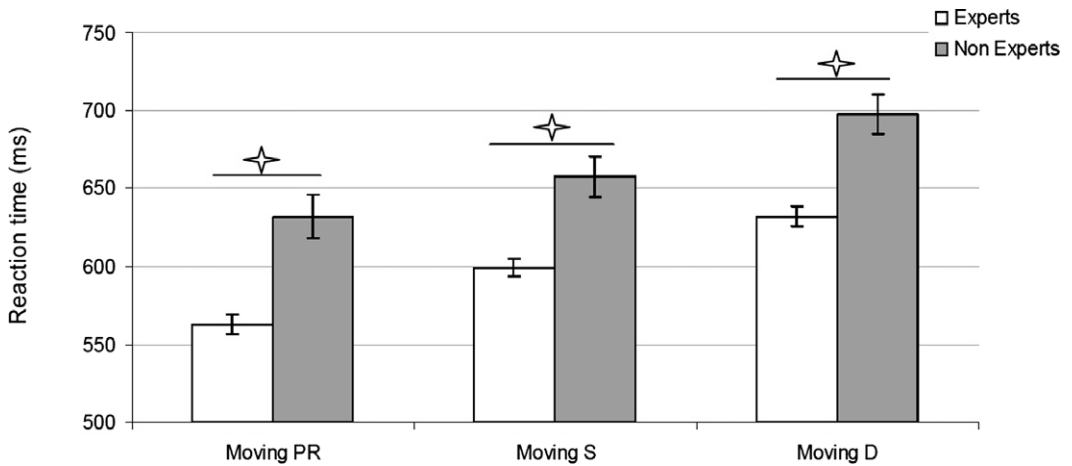


Fig. 6. Reaction times (in milliseconds) for the expert and non-expert groups in the Moving PR, Moving S, and Moving D conditions. Error bars correspond to  $\pm 1SEM$ . Asterisks indicate a statistically significant difference between groups in the different conditions ( $*p < .05$ ).

than non-experts in Moving trials ( $t(22) = 6.077$ ,  $p = .02197$ ,  $ES = 3.49$ ) and that there was not statistical difference between experts and non-experts in Resting trials ( $t(22) = 3.440$ ,  $p = .077$ ) (see Fig. 7).

## 4. Discussion

### 4.1. Implied movement priming mechanisms

First, as expected, the present results provide strong evidence for an implied movement priming in elite gymnasts and matched controls. Both groups responded faster in congruent trials than in incongruent. This finding is in agreement with previous studies which aimed to shed some light on the nature of action representations underlying the priming process (Bidet-Ildi et al., 2010; Costantini et al., 2008; Daems & Verfaillie, 1999). However, to the best of our knowledge, our study is the only one to have used a short-term priming paradigm where stimuli are static whole-body movement. We also found an implied movement priming at the error level. Experts and non-experts made more mistakes in incongruent trials than in congruent trials.

Second, we observed a priming effect for old as well as novel prime stimuli that were never presented as targets and for whom no stimulus–response chains could therefore have been acquired. This observation rules out that priming arises from a previously acquired mapping between a target stimulus and a response key and consequently does not corroborate the rote stimulus–response learning account (Abrams & Greenwald, 2000; Damian, 2001; Neumann & Klotz, 1994). Hence, these findings support the prime-induced response activation account (Dehaene et al., 1998; Naccache & Dehaene, 2001).

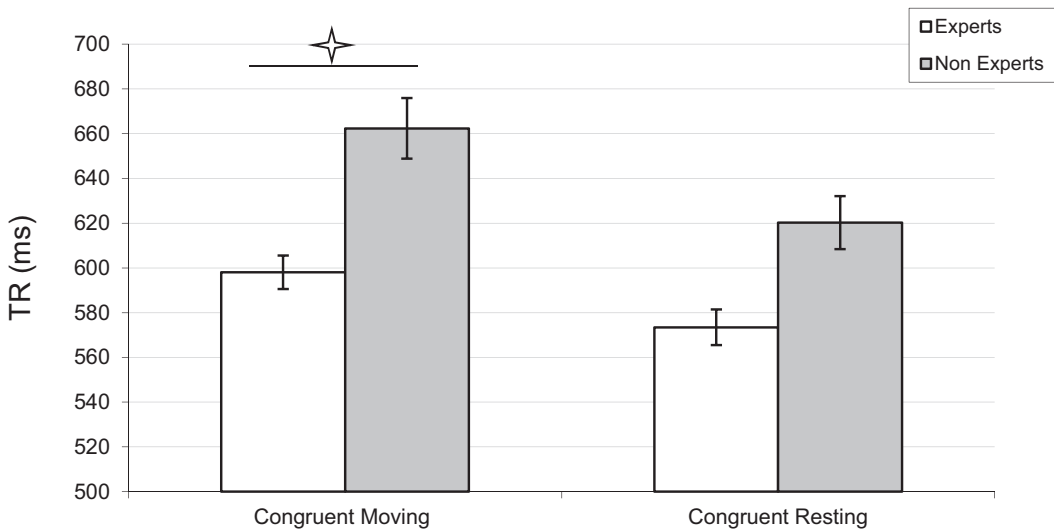


Fig. 7. Reaction times (in milliseconds) for the expert and non-expert groups in the Congruent Moving and Congruent Resting conditions. Error bars correspond to  $\pm 1$  SEM. Asterisks indicate a statistically significant difference between groups in the Congruent Moving condition ( $*p < .05$ ).

Subjects unconsciously applied the task instructions to the visible prime whether old or new. They extracted information from the prime and treated this information, that is, categorized as the prime stimulus as a move or a resting position and even prepared a motor response appropriate to the prime. This activation occurring prior to the target onset leads the subjects to elicit either a response facilitation in congruent trials or a response conflict in incongruent trials. This refers to the response competition theory (Molden, 2014; Wentura & Rothermund, 2003).

#### 4.2. Facilitation of target processing in congruent trials

In trials with prime-target move congruency, we manipulated three levels of prime-target similarity to distinguish facilitation effects between these three levels. Features that varied in these congruent pairs were moves (similar vs. dissimilar) and agents (identical vs. different). Primes and targets had either the same move and agent (perfect move-and-agent congruency, Moving PR pairs), the same move but different agents (perfect move congruency, Moving S pairs), or different moves and agents (partial move congruency, Moving D pairs). We observed that the more congruent the prime-target pairings, the greater the facilitation in target processing; that is, the shorter the RTs. This effect observed in congruent trials was previously reported in long-term priming studies using identification tasks of pictures of visual objects (Biederman & Cooper, 1991; Srinivas, 1993), visual word identification, and completion tests (Curran, Schacter, & Bessenoff, 1996; Marsolek, Kosslyn, & Squire, 1992). In contrast, in the current study, this facilitation effect did not extend to error rates.

These results may also confirm the existence of both low-level and abstract facilitation effects, which is in line with Buckner and Koutstaal (1998) and Kristjansson and Campana (2010) reviews. More specifically, Kristjansson and Campana (2010) came to the conclusion that small changes in the stimuli used in visual priming studies can modify the perceptual processing level at which priming takes place. When there is a perfect move-and-agent congruency, that is, Moving PR condition, we suggest that the facilitation effect occurs at a low level. More specifically, it can be assumed that the subjects first focused their attention on the primes and then performed the two-choice response time task on the basis of visual features, such as color and shape, in a highly automated manner as the target constituted a full replication of the prime perceptual features. Findings showing that the Moving PR condition was associated with shortest RTs are in line with our aforementioned suggestion. Conversely, when the move-and-agent congruency is partial (i.e., the stimuli between the prime and target are physically distinct: Moving Similar and Moving Different conditions), the facilitation effect is unlikely to take place at a low level since the features of the prime and target stimuli within a trial are different. For Moving Different trials, different agents performed moves which are different. For Moving Similar trials, different agents performed the same move but different techniques/styles were used to perform a similar move. For the split leap forward, different arm positions, different front legs shooting straight out to the front (i.e., right leg or left leg), different degrees of extension of the feet and legs when gymnasts are high up in the air are observed. For the Tkatchev, the different techniques are represented by different degrees of extension of the feet and legs, different degrees of hip flexion, and different distances from the bar when gymnasts are about to catch the high bar. Consequently, information seems to be processed at a higher level, at an abstract level. Based on Schmidt generalized motor program theory (Schmidt, 1975, Schmidt & Lee, 2005) and on findings showing that the activation of the mirror neuron system does not depend on the sensory modality of the perceived action (Gazzola, Aziz-Zadeh, & Keysers, 2006; Kohler et al., 2002), we can suppose that the representation of a particular move is coded in an abstract way. This means that the general pattern of the move is coded rather than each individual aspect of it. Then, it allows the subjects to identify a particular class of moves based on invariant features even if the observed moves are performed with different amplitudes, different limb positions or by different agents. Our hypothesis is in line with Costantini et al.'s (2008) findings, which revealed the existence of an abstract priming effect. They showed that observed actions primed the execution of the same actions performed by different effectors and over different target objects. They suggested that watching an action activated an abstract representation of this action.

To confirm the existence of both low-level and abstract facilitation effects in the present study, additional fMRI experiments using the same paradigm should be conducted. To investigate whether cortical areas involved in visual priming code low-level or abstract properties of visually presented movements, a method based on the repetition suppression principle could be used (Grill-Spector, Henson, & Martin, 2006; Krekelberg, Boynton, & van Wezel, 2006). This method refers to the neural attenuation for repeated presentations of a stimulus. As explained by Hasson, Skipper, Nusbaum, and Small (2007), if a cortical area codes abstract properties of a visual stimulus, this area will display a reduced neural activity when a novel stimulus from the same category is

presented. Conversely, if a cortical area codes low-level properties of a stimulus, this area will display a reduced neural activity when confronted to an identical stimulus.

#### 4.3. *Priming and motor expertise*

We found that experts responded faster than non-experts in congruent and incongruent trials as well as in moving congruent trials exhibiting three levels of prime-target similarity ranging from a highest congruity (Moving PR pairs), an intermediate congruity (Moving S pairs), to a lowest congruity (Moving D pairs). Taken together, these findings clearly indicate that priming/facilitation effects were stronger in elite gymnasts than in their matched controls. Gymnast superiority on priming is not surprising since, over the past two decades, literature from different scientific fields has provided evidence that motor experts differ from non-expert performers in cognitive, motor, physiological, and neural attributes. More specifically, in action perception, early research in sport psychology showed that highly skilled athletes, less skilled athletes, and untrained sedentary subjects processed perceptual information distinctly and that the former were more efficient in predicting forthcoming actions (for a review, see Starkes & Ericsson, 2003). More recently, research teams probed neuronal correlates in experts versus non-experts when passively observing sport scenes (Calvo-Merino et al., 2005, 2006; Kim et al., 2011; Pilgramm et al., 2010). It has been shown that activation of areas involved in action observation is modulated by the observer motor expertise. Given that observing others' action activates the corresponding motor representations in observers provided these viewed actions belong to their own motor repertoires (Buccino et al., 2004; Calvo-Merino et al., 2005, 2006; Casile & Giese, 2006; Jeannerod, 2001; Rizzolatti et al., 2001), the superiority of experts over their non-expert counterparts, as reflected by faster responses, could be accounted for by the difference in the representations of observed movements between these two populations. This suggestion is in agreement with that put forward by Guldenpenning, Koester, Kunde, Weigelt, and Schack (2011), Guldenpenning et al. (2012), and Schack and Mechsner (2006). To explain their findings, Schack's research team claimed that experts had developed a more accurate representation of the action than their novice counterparts due to the time spent in motor training. Their action representation allowed them to discriminate postures between movement phases as well as within a movement phase whereas representation of non-experts only allowed them to discriminate postures between movement phases. Along the same lines, Schack and Mechsner (2006) found differences in tennis serve representation between elite players and that of low-level players and non-players. In elite players, the representation was well organized in a distinctive hierarchical structure displaying similarities between elite players and matching the functional and biomechanical demands of the serve. Conversely, the representation of low-level players and non-players was less structured and adapted to functional and biomechanical demands. Altogether, these findings provide evidence that motor experts possess more refined representations than non-expert performers, suggesting that experts access representations more easily than their control counterparts which is reflected by faster perception and identification of priming stimuli (Foster & Liberman, 2007).

However, as the current results stand, it remains unclear whether the superiority of the gymnasts had anything to do with their being gymnasts, or with their being elite athletes regardless of the specific sports they were engaged in, or with their fast choice-reaction times as shown by Voss, Kramer, Basak, Prakash, and Roberts (2006) in athletes practicing interceptive sports. Further investigation is needed to answer these questions. For instance, recruiting in future priming studies elite gymnasts and elite athletes who do not practice gymnastics, such as basket ball players, rowers, or taekwondo athletes, will shed some light on these interrogations.

## **5. Conclusion**

The current study provides important findings: presence of priming/facilitation effects, evidence for the prime-induced response activation account, existence of both low-level and abstract facilitation effects, and superiority of gymnastics motor experts over non-expert performers. However, a question remains. Are faster response times of the gymnasts due to their being gymnasts or to their being elite athletes regardless of the specific sport they engage in or to their fast choice-reaction times? Our current protocol does not allow us to answer this question, which warrants further investigation.

Likewise, our study also calls for additional experiments using the same paradigm in which functional brain-imaging time resolved (e.g., high-density scalp EEG) and space resolved (fMRI) tools will be used in order to confirm our interpretations and to precisely account for the neural bases of these movement representations. Furthermore, these behavioral priming effects encourage us to explore in future experiments if they will still be present under conditions of unconscious perception when masking the prime stimuli.

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## **Conflict of interest**

All the authors declare that they have no conflict of interest. (In case animals were involved) Ethical Approval: This article does not contain any studies with animals performed by any of the authors. (In case humans were involved) Ethical Approval: All

procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. (In case humans were involved) Informed consent: Informed consent was obtained from all individual participants included in the study.

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