Priming of Future States in Complex Motor Skills

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Abstract. The ability to anticipate future states of perceived actions is an important faculty for motor control and the generation of coordinated social interaction. Here, we studied whether the perception of a static posture of a complex movement automatically activates representations of future states of this particular movement event. We did this by using a priming paradigm with photographs of a high-jump movement. Participants judged whether a picture depicted a posture from the approach or flight phase of that movement. To evaluate expertise-dependent effects of priming, non-athletes and athletes were compared. Results revealed faster responding when prime and target pictures were assigned to the same motor response (response priming), and when the temporal order of prime and target matched the temporal order of the depicted postures in a real high jump (temporal-order priming). Whereas experts showed a temporal-order effect even within the same response category, such an effect occurred for novices only between response categories. A second experiment confirmed that these between-group differences are due to domain-specific motor expertise (i.e., high jump) rather than to general motor experiences. Altogether our results suggest that motor expertise results in a more fine-grained posture-based movement representation.

Keywords: anticipation of future states, motor expertise, response priming, perception of body postures, motor control

A major aspect of successful human interaction is the ability to predict what another person in a shared environment is likely to do next. This ability is necessary to attune one's own actions to an interacting partner. In daily life, this anticipatory control of action seems to be handled by our sensory-motor system with the greatest of ease. However, anticipatory control becomes much more complex if a person acts under time pressure, which is especially the case in sport scenarios. Think of a goalkeeper, who has to anticipate the shoot direction of a penalty kick in order to start the defending action in time. A variety of studies have shown that skilled performers are better in predicting a forthcoming action than novices (Abernethy & Zawi, 2007; Agliotti, Cesari, Romani, & Urgesi, 2008; Müller & Abernethy, 2006; Sebanz & Shiffrar, 2009). These studies indicate that the anticipation of future actions is an important component of skilled action performance (e.g., Starkes & Ericsson, 2003).

A common method for investigating action anticipation in sport is the so-called occlusion paradigm. In the early occlusion experiments by Abernethy and Russell (1987), participants watched videos of sport scenes (e.g., badminton strokes) which stopped at different points in time (temporal occlusion). After the end of each video clip, participants were asked to predict the perceived action (e.g., the landing position of the badminton stroke). The general finding was

that experts were better than novices in predicting a movement at an earlier point in time (for similar findings see Abernethy, 1990; Paull & Glencross, 1997; Renshaw & Fairweather, 2000; Williams, Ward, Knowles, & Smeeton, 2002).

In occlusion experiments, observers provide their judgments without time pressure. Critically, this kind of decision making is not the same as decision making under time pressure in real sport scenarios, where decisions about appropriate forthcoming actions have to be made within a very short time window, often intuitively, and without any explicit evaluation of the perceived information (automatic information-processing approach; see Raab & Johnson, 2008; Williams & Ward, 2007, for overviews). Thus, for successful motor performance, the prediction of forthcoming actions needs to be a very reliable, fast running process. As this process is not only important in sport scenarios, but permanently necessary in daily life when perceiving moving objects (e.g., driving cars) or persons (e.g., in a crowded mall), the prediction of movement trajectories is learned extensively during development (Konczak, Borutta, & Dichgans, 1997). Thus, movement prediction seems to have become an automatic process of movement perception.

Although there is some evidence that future states of an action are activated when perceiving movement

(Hubbard, 2005) or implied movement displayed at static pictures which depict people in daily actions (Freyd, 1983, 1987; Urgesi et al., 2010), there is only one study showing that experts of a particular movement (i.e., high jump) differ in movement prediction from novices when using static stimulus material (Güldenpenning, Koester, Kunde, Weigelt, & Schack, 2011). That study used photographic stimuli from a high-jump movement in a response-priming experiment with masked primes. In such priming experiments, responding to a particular target stimulus is typically faster and more accurate when the target stimulus has been preceded by a prime that requires the same response (response-congruency effect; Dehaene et al., 1998; Kunde, Kiesel, & Hoffmann, 2003; Neumann & Klotz, 1994). In the study of Güldenpenning et al. (2011), skilled high-jump athletes and novices had to classify a target picture as taken from the approach phase or from the flight phase of a high-jump movement. Before the target, a masked prime picture with a body posture from either the approach or the flight phase appeared. Surprisingly, no standard response-congruency effect could be observed; that is, there was no faster responding when prime and target were from the same response category (e.g., prime and target from the approach phase) than when they are from different response categories (e.g., prime from the approach phase and target from the flight phase).

However, skilled athletes responded faster to prime-target pairs reflecting the natural movement order, which includes a natural movement order between movement phases (i.e., an approach prime followed by a flight target) and a natural movement order within a movement phase (e.g., the first picture of the approach followed by the third picture of the approach). In contrast, novices only unconsciously processed a temporal order between movement phases, that is, a temporal order between the approach and the flight phase. Güldenpenning et al. (2011) argue that the availability of a fine-grained cognitive representation of the high-jump movement in athletes (Schack & Mechsner, 2006) prompts a precise movement anticipation (i.e., within the approach and within the flight phase). In contrast, in novices who lack specific movement expertise, primes activate only coarse representations of future postures of the movement (i.e., the approach is followed by the flight).

Even though it seems plausible that temporal-order processing is an important aspect of movement perception and control (see Güldenpenning et al., 2011), it is rather untypical that no standard response-priming effect occurred. Therefore, the question arises whether or not a strong temporal-order priming *generally* offsets response priming when processing a movement sequence. Alternatively, a lack of a response-priming effect could also be a *specific* aspect of unconscious processing.

Thus, to shed light on potential differences of conscious and unconscious processing of movement sequences, we conducted the high-jump experiment with consciously perceivable non-masked prime pictures (Experiment 1a).

Moreover, the study of Güldenpenning et al. (2011) did not control whether or not the between-group differences are due to domain-specific motor expertise (i.e., high jump) or rather are based on general motor experiences. Therefore, we additionally conducted a control experiment with the same participants (Experiment 1b) with a completely unknown movement. To avoid carryover effects, the order of Experiments 1a and 1b was counterbalanced across subjects and groups.

Experiment 1a

Experiment 1a investigates the effects of temporal-order priming and response priming of a complex action (i.e., high-jump movement) in a group of non-athletes and a group of high-jump athletes. Participant's task was to decide from which phase of the high-jump movement the target picture was taken (approach vs. flight). The preceding prime picture was either taken from the same movement phase (response-congruent condition; e.g., an approach prime followed by an approach target) or from the alternative movement phase (response-incongruent condition; e.g., an approach prime followed by a flight target). Moreover, the prime-target sequence could either reflect a natural temporal order (e.g., an approach prime followed by a flight target) or a reversed natural order (e.g., a flight prime followed by an approach target). An overview of the experimental manipulations concerning the factor *temporal order* and the factor *congruency* is illustrated in Figure 1. Here, it is emphasized that due to the categorical task (i.e., to classify the target depending on the movement phase), the temporal order of the prime-target pairs was task-irrelevant.

The following predictions were made: First, a response-congruency effect is expected; that is, faster response times under conditions in which prime and target are from the same movement phase, and slower response times if prime and target are from different movement phases. Second, faster response times are predicted under conditions in which the prime-target pairs reflect the natural order of the movement compared to when the order is reversed. Third, motor expertise should modulate these effects in a way that skilled athletes should show temporal-order priming effects both for prime-target pairs taken from *one* movement phase (temporal order *within* a movement phase) and for prime-target pairs taken from *both* movement phases (temporal order *between* movement phases). Novices should only show an effect of temporal-order priming *between* movement phases, as would be expected from basic knowledge about jumping (e.g., an approach logically precedes a take-off and a flight).

Method

Participants

Forty participants took part in exchange for pay or in exchange for course credit. Twenty students (nine female, two left-handed, mean age 24.9 years; range 21–29) from Bielefeld University, Germany, were assigned to the *non-athlete* group. Participants of the *non-athlete* group had no specific experiences in high jump, but they were physically active students (mean training frequency per week 3.2). Participants of the non-athlete group played, for example,
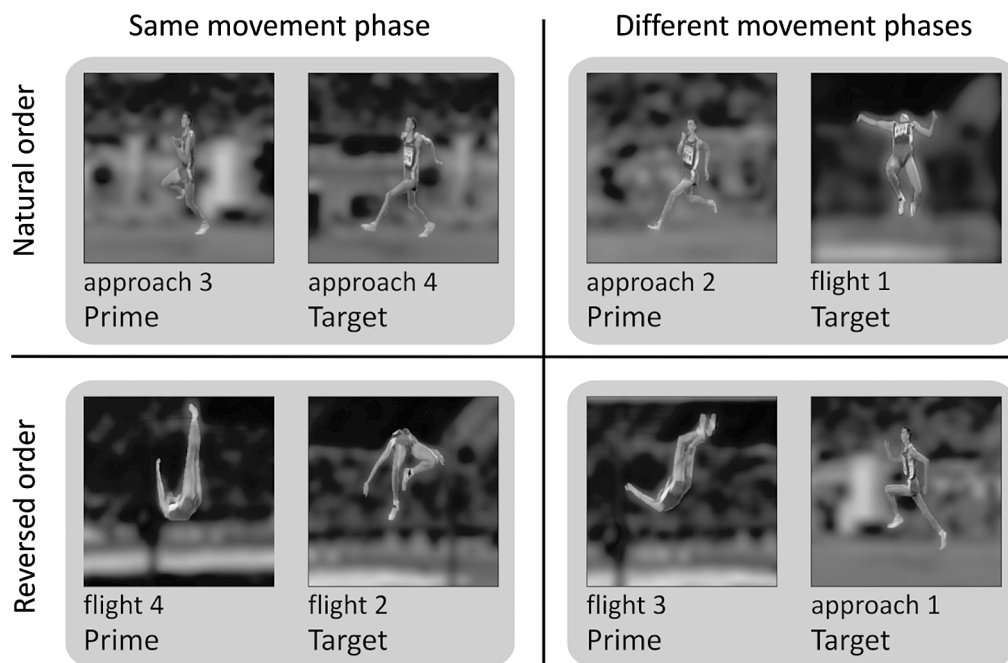
Figure 1. Overview of the combinations of prime-target pairs within a movement phase and between movement phases which either depict a natural or a reversed temporal order. Note that Figure 1 contains the whole stimulus set of Experiment 1a.

soccer, handball, basketball, or regularly performed swimming, running, or fitness training. Twenty students were assigned to the *athlete group* (nine female, one left-handed, mean age 24.1 years; range 20–31), due to their experiences in high jump (an average of 6.4 years of training in track and field with focus on high jump). The mean training frequency per week for the athlete group (including other sports) was comparable to the non-athlete group (3.7 training sessions per week). All participants were reported to have normal or corrected-to-normal vision, they were all naive with regard to the purpose of the experiment, and all provided written informed consent before testing started. The single experimental session lasted about 30 min. The experiment was performed in accordance with the ethical standards of the sixth revision (Seoul, 2008) of the 1964 Declaration of Helsinki.

Apparatus and Stimuli

For stimulus presentation, a Dell OptiPlex 760 computer with a 17-inch VGA-Display (vertical retraces 60 Hz) and the software Presentation® (Version 14.5, http://www.neurobs.com) was used. The software controlled the presentation of the stimuli and measured reaction times with a precision of 1 ms. Responses had to be given by pressing one of the two external buttons.

The stimuli were eight photo-realistic pictures of a high-jump movement of a male expert, taken from a video of an elite competition. Four pictures were of the approach phase and four were of the flight phase. Each stimulus was used

both as a prime and as a target picture. The combination of eight different primes with eight different targets resulted in 64 prime-target pairs. The stimuli had a size of 9.0×9.0 cm (250×250 pixels). The background of the stimulus pictures was darkened and blurred to reduce distraction from irrelevant background information (see Figure 1). All stimuli were presented centrally on a black background and subtended a visual angle of 6.5° in horizontal and in vertical from the viewing distance of 80 cm.

Design and Procedure

The present study used a $2 \times 2 \times 2$ mixed factorial design with the within-subject factors *congruency* (response-congruent movement phase vs. response-incongruent movement phase) and *temporal order* (natural movement order vs. reversed movement order). Participants' *expertise* was the between-subject factor (athletes vs. non-athletes). The impact of these factors was analyzed with reaction time (RT) and error rate (ER) measures as the dependent variables.

Participants sat in front of a computer screen (80 cm) and were instructed in written form to classify the presented target as an approach or as a flight picture as quickly as possible by pressing one of the two response buttons with the index finger. Moreover, participants were instructed to respond as accurately as possible. The response button assignment was counterbalanced across participants and groups. Before starting the experimental session, each participant performed 16 randomized practice trials. Data from
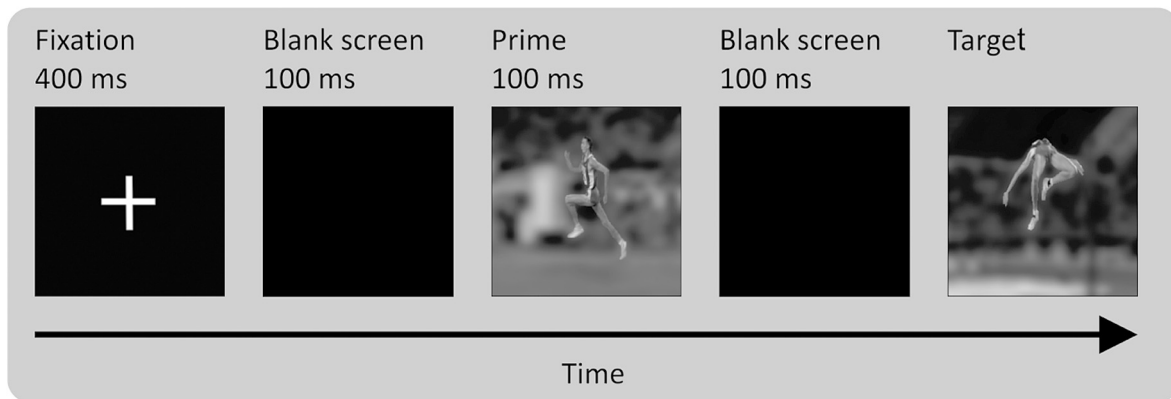
Figure 2. Procedure of the experiment. The depicted example illustrates an incongruent prime-target pair reflecting the natural movement order.

this block were not analyzed. The following test block consisted of 2×64 prime-target pairs. The presentation of prime-target pairs was randomized within each block.

Each trial started with the presentation of a central fixation cross (400 ms), followed by a blank screen (100 ms), the prime (100 ms), a second blank screen (100 ms), and the target (which remained on the screen until a response was given). Incorrect responses elicited the word "Fehler" (German word for "error"). An intertrial interval of 1,500 ms elapsed before the next trial started. The within-trial procedure of the experiment is illustrated in Figure 2.

Results and Discussion

RTs were screened for outliers using an overall cut-off. RTs below 200 ms and above 1,000 ms were excluded (1.6%). RTs for wrong answers (2.8%) were not used in the analysis of the RTs. RTs and associated ERs are illustrated in Figure 3 (athletes) and Figure 4 (non-athletes). We excluded trials with physically identical primes and targets from the congruent condition, because these would artificially inflate the response-congruency effect due to repetition priming. Instead, the data from identical prime-target repetitions were compared to the other conditions by means of paired t-tests.

The mean RTs from the factorial combinations of the within-subjects factors congruency and temporal order, and the between-subjects factor expertise were submitted to a mixed analysis of variance (ANOVA). The between-subjects factor expertise reached significance, $F(1, 38) = 6.31$, $p < .05$, $\eta_p^2 = .14$, indicating generally faster response times for athletes (454 ms) compared to non-athletes (511 ms). The within-subject factors congruency, $F(1, 38) = 36.08$, $p < .001$, $\eta_p^2 = .49$, and temporal order, $F(1, 38) = 51.64$, $p < .001$, $\eta_p^2 = .58$, were significant. Moreover, the interaction between temporal order, congruency, and expertise reached significance, $F(1, 38) = 5.87$, $p < .05$, $\eta_p^2 = .13$. None of the two-way interactions was significant (all p's > .10). To follow up the three-way interaction, two ANOVAs with the factors congruency and temporal order were performed separately for athletes and for non-athletes.

Athletes responded faster with congruent (440 ms) than with incongruent (468 ms) prime-target pairs, $F(1, 19) = 25.70$, $p < .001$, $\eta_p^2 = .58$, and with prime-target pairs reflecting the natural movement order (440 ms) than with prime-target pairs reflecting the reversed natural order (467 ms, $F(1, 19) = 75.37$, $p < .001$, $\eta_p^2 = .80$). The interaction between congruency and temporal order did not reach significance ($p > .50$).

Non-athletes also responded faster with congruent (500 ms) than with incongruent prime-target pairs (522 ms, $F(1, 19) = 12.48$, $p < .01$, $\eta_p^2 = .40$), and with prime-target pairs that reflected the natural (498 ms) than
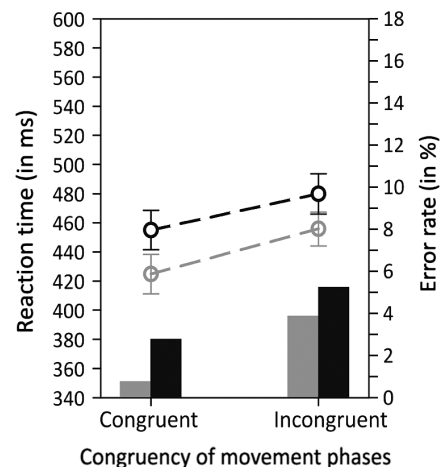

Figure 3. Overview of the RTs and ERs for athletes in Experiment 1a. The line plot illustrates the mean response times (RT) in milliseconds (± *SEM*) as a function of congruency and temporal order. The gray dashed lines illustrate the natural movement order whereas the black dashed lines illustrate the reversed movement order. The vertical bars illustrate the mean error rate (ER). The gray bars illustrate the ER for a natural movement order whereas the black bars illustrate the ER for a reversed movement order.
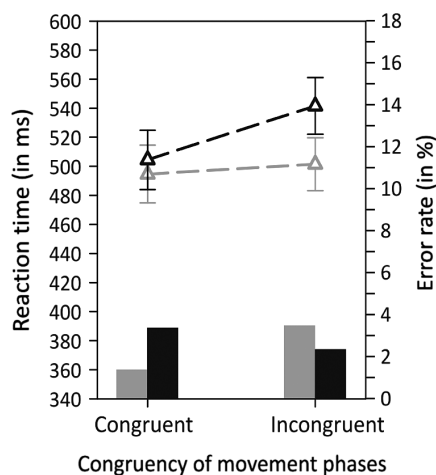
Figure 4. Overview of the RTs and ERs for non-athletes in Experiment 1a. The line plot illustrates the mean response times (RT) in milliseconds (± *SEM*) as a function of congruency and temporal order. The gray dashed lines illustrate the natural movement order whereas the black dashed lines illustrate the reversed movement order. The vertical bars illustrate the mean error rate (ER). The gray bars illustrate the ER for a natural movement order whereas the black bars illustrate the ER for a reversed movement order.

the reversed order (523 ms, $F(1, 19) = 14.58$, $p < .01$, $\eta_p^2 = .43$). However, also the interaction of congruency and temporal order reached significance, $F(1, 19) = 9.04$, $p < .01$, $\eta_p^2 = .32$. Paired *t*-tests showed that incongruent prime-target pairs reflecting the reversed natural order (542 ms) led to significantly slower response times than all other prime-target pairs (all other latencies < 505 ms; all $t(19) > 3.50$, all p's < .001). All other pairwise comparisons did not reach significance (all p's > .10).

Identical primes led to significantly faster response times than all other primes for both athletes (377 ms) and non-athletes (437 ms; all $t(19) > 5.4$, all p's < .001).

An ANOVA on error rates (ERs) revealed that responding was less errorprone with congruent 2.0%) compared to incongruent trials (3.7%, $F(1, 38) = 6.97$, $p < .05$, $\eta_p^2 = .16$) and with prime-target pairs reflecting a natural (2.3%) rather than a reversed order (3.4%, $F(1, 38) = 4.22$, $p < .05$, $\eta_p^2 = .09$). Moreover, the interaction between congruency and temporal order reached significance, indicating that the effect of temporal order was slightly more pronounced with congruent rather than incongruent prime-target pairs, $F(1, 38) = 5.63$, $p < .05$, $\eta_p^2 = .13$. No other interaction reached significance (al p's > .05). To appropriately compare the results of the separate RT analyses for athletes and non-athletes to those of the error analysis, two ANOVAs with the factors congruency and temporal order were computed, separately for athletes and non-athletes.

For athletes, ER was lower with congruent than with incongruent primes (1.7% vs. 4.5%, $F(1, 19) = 6.53$, $p < .05$, $\eta_p^2 = .26$), and with prime-target pairs reflecting the natural movement order (2.2%) than with prime-target pairs reflecting the reversed natural order (3.9%, $F(1, 19) = 5.29$, $p < .05$, $\eta_p^2 = .22$). The interaction between congruency and temporal order did not reach significance ($p > .50$).

For non-athletes, neither the main effect of congruency nor the temporal order reached significance (all p's > .35), but the interaction of these factors did so, indicating that the effect of congruency was larger with prime-target pairs in natural order than in reversed order, $F(1, 19) = 6.73$, $p < .05$, $\eta_p^2 = .26$. However, pairwise comparisons did not reveal any significant effect (all p's > .05).

The additive RT effects of congruency and temporal order in athletes might indicate that categorical information and temporal information about the movement are processed independently (Sternberg, 1969). The analysis of the ERs completely supports these RT effects. For non-athletes there was an effect of temporal order, but only between movement phases, that is when prime and target required different motor responses (cf. Figure 4). Another way to read the interaction is to say that there was an effect of response priming, but only with reversed movement order between prime and target. This data pattern fits to the assumption that the same types of priming, response priming and temporal-order priming, occur with both, non-athletes and athletes, but the movement representation of novices that is too coarse to allow discriminations within movement phases. This would explain the lack of a temporal-order effect within movement phases. It would also explain the lack of a response-priming effect with natural movement order, because the normally deteriorating impact of incongruent primes is counterbalanced here by the facilitatory impact of correct movement order (which is missing in response-congruent trials).

Although error rates were generally low, the data pattern in errors does not fully support the RT analysis, since the strong effect of temporal order in novices with incongruent trials came along with a (nonsignificant) negative effect of the temporal order in error rates, suggesting a kind of speed-accuracy trade-off. However, in view of the large RT difference (41 ms) and the small reversed difference in ERs (−1.1%) it seems unlikely that the whole RT effect can be explained by such a trade-off. We will come back to this issue in the Discussion section of Experiment 1b.

Experiment 1b

To examine whether the differences between the two groups of Experiment 1a are in fact due to domain-specific motor expertise (i.e., high jump) – and not to more general motor experience – we intentionally made the athlete group to novices. To this end, pictures of a specific movement from rhythmic gymnastics, the so-called *stag leap with back bend of the trunk* (see Figure 5), were used as photographic stimulus material. Identical to Experiment 1a, the *congruency* as well as the *temporal order* of the prime-target pairs was manipulated. Participants had to classify the targets being taken from the approach or from the flight. All participants from the first experiment also took part in this study. As both
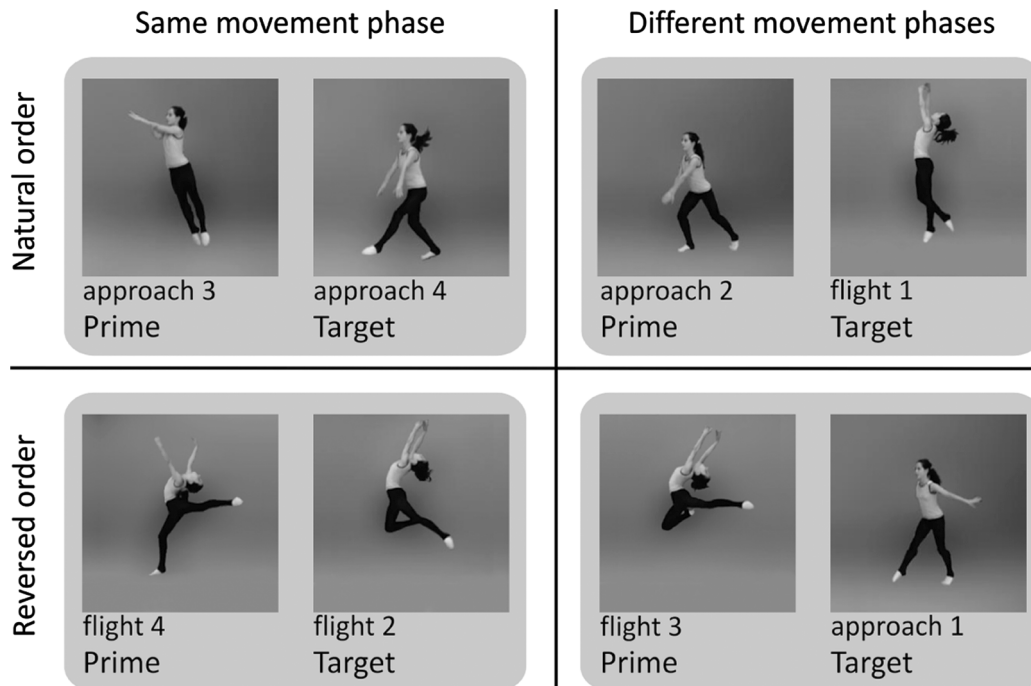
Figure 5. Overview of the combinations of prime-target pairs within a movement phase and between movement phases which either depict a natural or a reversed temporal order. Note that Figure 5 contains the whole stimulus set of Experiment 1b.

groups of participants had no specific knowledge concerning the *stag leap with back bend of the trunk* skill, effects should not differ between the groups. Moreover, for both groups of participants, a pattern of results similar to the one of the novices in Experiment 1a was expected.

Method

Participants

The participants in Experiment 1a also took part in Experiment 1b, in the same session.

Apparatus and Stimuli

The stimuli were eight photo-realistic pictures of a *stag leap with back bend of the trunk*, taken from a video of a national performing athlete. Four pictures were of the approach phase and four were of the flight phase (see Figure 5). Each stimulus was used both as a prime and as a target picture. The combination of eight different primes with eight different targets resulted in 64 prime-target pairs. The apparatus, the size of the pictures, and the manipulation of the background were identical to those of Experiment 1a.

Design and Procedure

The design and the procedure of the Experiment 1b were identical to those of Experiment 1a.

Results and Discussion

RTs were screened for outliers using an overall cut-off. RTs below 200 ms and above 1,000 ms were excluded (4.0%). RTs of wrong answers (4.3%) were not used in the analysis of the RTs. RTs and associated ERs are illustrated in Figure 6 (athletes) and Figure 7 (non-athletes). Similar to Experiment 1a, trials with physically identical primes and targets were excluded from the congruent condition and analyzed separately.

Mean RTs of each participant and condition were submitted to an ANOVA with the within-subjects factors congruency and temporal order, and the between-subjects factor expertise. The within-subjects factors congruency, $F(1, 38) = 32.21$, $p < .001$, $\eta_p^2 = .46$, and temporal order, $F(1, 38) = 23.41$, $p < .001$, $\eta_p^2 = .38$, were significant. Surprisingly, also the between-subjects factor expertise reached significance, $F(1, 38) = 16.19$, $p < .001$, $\eta_p^2 = .23$, indicating generally faster response times for high-jump athletes (462 ms), compared to non-athletes (547 ms). Moreover, the interaction between congruency and temporal order reached statistical significance, $F(1, 38) = 8.16$, $p < .01$, $\eta_p^2 = .18$. No other interaction reached significance (all p's $> .70$). Pairwise comparisons indicated that incongruent prime-target pairs reflecting the reversed natural order (533 ms) led to significantly slower response times than all other prime-target pairs (all other latencies < 502 ms; all $t(39) > 2.40$, all p's $< .05$). All other pairwise comparisons did not reach significance (all p's $> .10$).

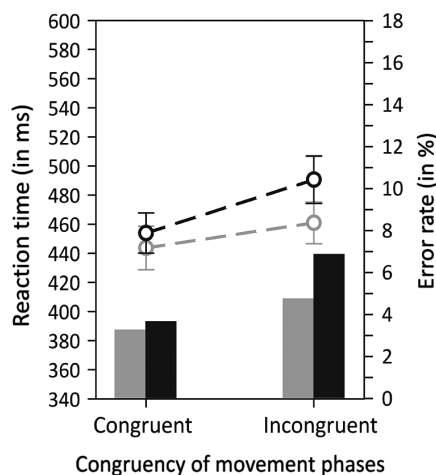Even though the RT analysis indicates that the pattern of the interaction between congruency and temporal order does

Figure 6. Overview of the RTs and ERs for athletes in Experiment 1b. The line plot illustrates the mean response times (RT) in milliseconds (± *SEM*) as a function of congruency and temporal order. The gray dashed lines illustrate the natural movement order whereas the black dashed lines illustrate the reversed movement order. The vertical bars illustrate the mean error rate (ER). The gray bars illustrate the ER for a natural movement order whereas the black bars illustrate the ER for a reversed movement order.

Figure 7. Overview of the RTs and ERs for non-athletes in Experiment 1b. The line plot illustrates the mean response times (RT) in milliseconds (± *SEM*) as a function of congruency and temporal order. The gray dashed lines illustrate the natural movement order whereas the black dashed lines illustrate the reversed movement order. The vertical bars illustrate the mean error rate (ER). The gray bars illustrate the ER for a natural movement order whereas the black bars illustrate the ER for a reversed movement order.
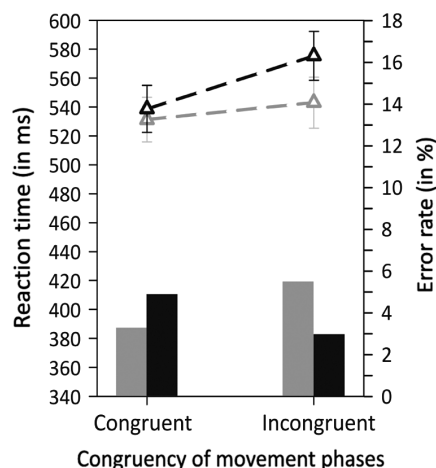
not differ significantly between groups (compare Figures 6 and 7), ANOVAs with the factors Congruency × Temporal order were performed separately for each group, in order to facilitate comparisons between Experiments 1a and 1b.

For athletes, responding was faster with congruent (449 ms) than with incongruent (476 ms) prime-target pairs, $F(1, 19) = 28.62$, $p < .001$, $\eta_p^2 = .60$. Moreover, responses to prime-target pairs reflecting the natural movement order (452 ms) were faster than to prime-target pairs reflecting the reversed natural order (472 ms, $F(1, 19) = 11.26$, $p < .01$, $\eta_p^2 = .37$). The interaction between congruency and temporal order missed significance ($p = .11$).

For non-athletes, the factor congruency, $F(1, 19) = 10.48$, $p < .01$, $\eta_p^2 = .36$, the factor temporal order, $F(1, 19) = 12.19$, $p < .01$, $\eta_p^2 = .39$, and the interaction of these factors reached significance, $F(1, 19) = 5.72$, $p < .05$, $\eta_p^2 = .23$. Paired t-tests showed that incongruent prime-target pairs reflecting the reversed natural order (575 ms) led to significantly slower response times than all other prime-target pairs (all other latencies < 544 ms; all $t(19) > 3.50$, all p's < .001). All other pairwise comparisons did not reach significance (all p's > .10).

Identical primes led to significantly faster response times than all other primes for both athletes (390 ms) and non-athletes (466 ms; all $t(19) > 6.5$, all p's < .001).

The ANOVA with the factors expertise, congruency, and temporal order on ERs only revealed a significant effect for the interaction between expertise, congruency, and temporal order, $F(1, 38) = 5.47$, $p < .05$, $\eta_p^2 = .13$. No main effect and no other interaction reached significance (all p's > .10). To further explore the source of the three-way interaction, two ANOVAs with the factors congruency and temporal order were performed separately for athletes and for non-athletes.

For athletes, there was no significant main effect and no significant interaction (all p's > .06).

For non-athletes, only the interaction between congruency and temporal order reached significance, $F(1, 19) = 84.06$, $p < .05$, $\eta_p^2 = .21$. Subsequent pairwise comparisons indicated a significantly *lower* error rate for incongruent prime-target pairs reflecting a reversed movement order (2.9%) compared to incongruent prime-target pairs reflecting the natural movement order (5.4%). No other comparison reached significance (all p's > .08).

The RT pattern in Experiment 1b revealed the same interaction between congruency and temporal order that we observed for novices on Experiment 1a: A larger effect of temporal order for incongruent than for congruent prime-target pairs. This pattern ensued in a statistically indistinguishable manner for both groups of participants (compare Figures 6 and 7), which both can be considered as novices for the type of movement used here. The interaction in RTs was very similar in both groups although the pattern in error rates differed. This suggests a considerable degree of independency of RTs and error rates, and therefore argues against an explanation of this pattern in terms of a speed-accuracy trade-off in Experiment 1a.

Interestingly, athletes responded generally faster than non-athletes, even though both groups of participants had no motor expertise with the *stag leap with back bend of the trunk*. Also the interaction of congruency and temporal order in RTs, though not statistically different between groups, was significant when tested in "novices" alone, whereas it just approached significance with athletes. This pattern of results

suggests that the availability of specific high-jump representations in athletes might also affect processing of a movement sequence (i.e., *stag leap with back bend of the trunk*) which is of similar structure (i.e., approach, take-off, flight) and which contains comparable concepts (e.g., extension of the hip).

Taken together, Experiment 1b supports the view that the ability to discriminate body postures within a movement phase is based on domain-specific motor expertise and not on general motor experiences. However, some transfer of specific movement knowledge (i.e., high jump) when processing a movement sequence which is of similar structure (i.e., approach, take-off, flight) cannot completely be excluded either. In contrast, participants with unspecific motor expertise seem to be able to discriminate the temporal order of body postures only between movement phases.

General Discussion

The present study aimed to investigate whether the perception of a certain event of the high-jump movement (a photograph depicting a high-jump posture) only primes the processing of a future state of this particular movement (a high-jump posture from later in time) or additionally primes the motor response of a certain category (i.e., movement phase). Moreover, it was of interest if motor expertise modulates the ability to precisely predict future states of the high jump.

The study shows that high-jump athletes reacted faster to prime-target pairs taken from the same movement phase (response-congruent condition) and slower when the prime and target were taken from different movement phases (response-incongruent condition). This result indicates that athletes applied the task instructions to the prime, categorized it as an approach or as a flight picture, and even prepared a motor response appropriate to the prime. This prime-induced motor activation mismatched with the required response if prime and target were taken from different movement phases (response-incongruent condition), which resulted in response competition, and hence slowed response times relative to congruent trials. Additionally, athletes showed a main effect of temporal order; that is, faster RTs if the sequence of the prime and target depicted the natural order of the movement, and slower RTs if the sequence depicted the reversed order of the movement. It is suggested that this effect is due to activated future states of the action in the participants (Güldenpenning et al., 2011; Schütz-Bosbach & Prinz, 2007; Urgesi et al., 2010) after they perceived the prime picture. This activation facilitated encoding of a target picture if it depicted a forthcoming action. In other words, athletes spontaneously "anticipated" each single body posture of the movement, which might be the prerequisite for an effect of temporal order not only *between* movement phases, but also *within* a movement phase.

In contrast, non-athletes were only able to process the temporal order for body postures *between* movement phases. Non-athletes distinguished between body postures

with a large distance (from an approach posture to a flight posture), but apparently they did not differentiate small steps of the movement (within the same response category, e.g., from "upright body" to "swing arms back" in the approach phase), as athletes do.

Importantly, athletes and non-athletes did not differ significantly in processing a movement sequence, if this movement is not within their domain of expertise (Experiment 1b). However, some transfer of specific movement knowledge (i.e., high jump) when processing a movement sequence which is of similar structure (i.e., approach, take-off, flight) cannot completely be excluded. Generally, Experiment 1b supports the assumption that specific motor expertise improves the ability to discriminate body postures within a movement phase.

In contrast to the study of Güldenpenning et al. (2011) which only showed a temporal order but no response priming, our study indicates that at least two organizing principles underlie an *elaborated* mental representation of a complex movement. First, the knowledge about the high-jump movement is represented in a particular event order. Second, the representation is organized in cognitive categories, that is, in movement phases (Schack, 2004). Thus, temporal-order priming does not generally offset a response priming when processing a movement sequence. In contrast, the lack of response priming seems to be rather a specific aspect of unconscious processing which might be worthwhile to further investigate.

Concerning chronological representations, even participants without motor expertise seem to have some temporal event knowledge about the movement order, which might be sufficient for a rough movement prediction (*between* movement phases). This rough movement prediction might be adequate when observing moving objects, namely to overcome the neuronal delay within the visual system (50–100 ms; cf. De Valois & De Valois, 1991). This neuronal latency might be bridged by extrapolating the trajectory of a moving object at an early perceptual level (Nijhawan, 1994). Instead, for efficient movement control a more precise anticipation is needed. We regard the anticipation of future states of our *own* body movements as anticipation of to-be-produced perceptual effects (the goal or subgoals of the action and its consequences on the organism; ideomotor hypothesis, Greenwald, 1970; Kunde, Koch, & Hoffmann, 2004). As these perceptual effects allow the online control of movement execution (e.g., correcting the step length during the approach phase of a high-jump movement in order to reach the optimal take-off), movement control should be better if representation and related effect anticipation is more precise. Thus, athletes with motor expertise are better in movement prediction than non-athletes without particular movement expertise and can make more evaluative use of the perceptual action feedback (Schack, 2004).

In conclusion, the present study demonstrates that domain-specific motor expertise can modulate the processing of a complex movement. As the pattern of results suggests, athletes automatically activate more differentiated representations of forthcoming movement segments than novices do which might be important for the online control of movement execution.

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