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Effect of gender matching and attentional focus on the link between action observation and action verb processing

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Several studies have demonstrated the existence of a link between action observation (AO) and language. However, the optimizing parameters for this link have not been explored until now. To answer this question, the present study proposed two experiments for assessing the role of motor repertory and attentional focus. Sixty participants performed a priming task in which they had to decide if a verb was or was not an action verb after they saw a point-light display (PLD) representing an action. Only one difference distinguished the experiments. In experiment one, the PLD was either in accordance or not with the gender kinematics of the observer, whereas in the second experiment, the PLD either focused on or was unfocused on the main limbs implied in the action. The results show that motor repertory affects the link between action observation and action verb processing, whereas attentional focus does not. Implications of these results are highlighted in the discussion, notably to better understand the mechanisms that explain the link between action observation and action verb processing.

Keywords AOT, PLD, Action verbs, Focus attentional, Motor repertoire

Numerous studies in cognitive psychology[1] and cognitive sciences[2] have reported a link between action and language. In particular, research has demonstrated that action and language are grounded in the same neuronal processes, and that each can influence the other[3–6]. Several models have been proposed to explain this connection, suggesting either a shared neuronal system for both activities[7,8]or the co-activation of two distinct systems based on Hebbian principles and multiple associations[43]. Interestingly, this link appears both when the action is produced[9–11] but also just simulated[12,13] or simply observed [e.g.,14,15].

In the present study, our focus was not to confirm the existence of the action-language link, but rather to explore methods for optimizing it. To explore this question, we propose a priming task where participants had to process action verbs after they observed an action. In the literature, several studies have shown that action verb processing is affected by the observation of action, which is manifested by better performances when the observed action is congruent to the subsequent action verb than when the observed action is incongruent with the subsequent action verbs[3]. This effect is classically interpreted as the activation of common sensorimotor representations in both action observation and action verb processing as evidenced by similar results in behavioral tasks[16] as well as the activation of common brain circuits in neuroimaging studies[13,14] and electrophysiological findings[17]. Our aim is therefore to contribute to a deeper understanding of this link which lays the groundwork for potential applications in language rehabilitation. Numerous studies have demonstrated the utility of action observation in improving language rehabilitation after stroke[18–22]. However, the underlying mechanisms driving this effectiveness remain unclear. We believe that gaining a better understanding of moderators influencing the link between action observation and action-language processing in typical humans will be invaluable for refining rehabilitation approaches for patients.

Additionally, from a purely theoretical perspective, exploring moderators in the link between action observation and action language could enrich our understanding of action representation content. This, in turn, could contribute to refining the models proposed to explain the relationship between action observation and action verb processing such as the model of reenactment[23] or the model of semantic resonance[3]. In the

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present work, we focused specifically on two potential parameters of optimization that are known to affect action observation and language processing: the motor repertory and attentional focus. Concerning the motor repertory, several studies[24–26] have shown a facilitation of processing observed actions when participants have a motor experience of the action[27,28]. Moreover, humans have the ability to recognize their own action, which is known as the motor signature of action[25]. Finally, the literature also shows that respect for the motor repertory improves brain activations related to action observation[26] or language[29]. One manipulation used in the literature to investigate the role of motor repertory is the correspondence of gender between the observer and the stimuli perceived. Actually, it is known that the kinematics of movements differ between males and females[30], and humans are capable of discerning gender based on this kinematics when observing actions[31]. Furthermore, research has demonstrated that individuals are more sensitive to action observation corresponding to their own gender. Specifically, the visual presentation of a gender-matching action enhances subsequent capacity to perceive a point-light display representing the action within a mask[32]. Consistent with this notion, recent studies[33] have revealed differences in neural activation between men and women when exposed to stimuli depicting male or female bodies. These findings suggest the existence of an egocentric reference for perception within the same gender, with divergent behavioural responses to stimuli depicting bodies of the opposite sex. Specifically, women tend to attribute greater importance to an egocentric reference, whereas men exhibit heightened attention and an increased search for visual information [see also34]. So, within the embodied view of cognition[23] and considering various memory frameworks such as Act-In[35] or ATHENA[36], the alignment of motor repertoire may closely correspond to the pool of sensorimotor traces stored in memory. Therefore, this alignment could facilitate the enactment of the most accurate representation possible. Concerning attentional focus, studies carried out on motor learning by observation have shown that action observation produces a selective attentional focus on the important parameters of action[37]. Moreover, previous studies in eye-tracking have shown that the fixation of one important point of movement can reduce the ambiguity of an action and improve the anticipation of finality[38]. Finally, several studies have shown that action-verb processing respects the somatotopy of the motor cortex[14,39,40], suggesting that some parts of the action are more important than others. For example, the processing of action verbs that are more related to the face as a "cry" activates the part of the premotor cortex that is in charge of planning and controlling facial movements[11,14].

Therefore, it seems that both motor repertory and attentional focus can affect action observation and action verb processing. In this context, we can suggest that these parameters could be interesting candidates to optimize the priming effect observed when action-verb processing follows the observation of an action.

To study the potential effect of these parameters, we performed two parallel studies in which we assessed the impact of motor repertory (Experiment 1) and attentional focus (Experiment 2) in a priming task in which participants had to process verbs after the visual presentation of an action. To investigate this point, we propose to use the point-light display (PLD) paradigm[41] which is a very interesting tool to assess the role of kinematics and to manipulate the parameters of actions[42]. Given the extensive use of the Point-Light Display (PLD) paradigm in experiments investigating the relationship between action observation and action language processing[20,39,43], it appears to be a suitable tool for assessing the potential roles of motor repertoire and attentional focus in this link. The PLD paradigm effectively directs observers' attention to kinematics, a critical parameter in this relationship[39]. Additionally, it simplifies the manipulation of attentional focus through color changes in certain points of the sequence. Finally, previous research has demonstrated that leveraging kinematics is adequate to utilize the benefits of gender matching[30,31]. The manipulation of motor repertory was made by proposing the same PLD actions, which were produced either by a woman or by a man, to each participant. Therefore, depending on the sex of the participant, some of the perceived PLD actions corresponded to the sex of the observer or the others did not. For the manipulation of attentional focus, we proposed to observers PLD presented in a classical view (all points are white in a dark background) and PLD presented in a focus view (the points representing the main limbs of the action were coloured in green, whereas the others were coloured in white). We initially hypothesized a straightforward effect of congruence, characterized by better performance in congruent conditions compared to incongruent ones, as demonstrated in previous literature. This effect was anticipated to be evident in both response times and potentially accuracy. Additionally, we expected simple effects of gender matching and attentional focus, potentially resulting in better performance in matching conditions compared to mismatching ones, and in focused PLD conditions compared to unfocused ones. These effects could manifest in either accuracy, response times, or both. Finally, we hypothesized an interaction between the congruence effect and the influence of our moderators, resulting in enhanced performance in congruent conditions associated with focused PLD and/or gender matching, and disruption for incongruent conditions associated with focused PLD and/or gender matching. Once again, this interaction could impact accuracy, response time or both.

The objective of this paper was to investigate the role of the motor repertory and attentional focus in the link between action observation and action verb processing. For this, two experiments were performed in parallel (Experiment 1 for testing the role of motor repertory and Experiment 2 for testing the role of attentional focus).

Experiment 1
Methods
Participants

Thirty right-handed students (15 women and 15 men) aged 25.83 years (SD= 6.77) were recruited to participate in this experiment. The sample size was chosen with Gpower, from the paper of Beauprez & Bidet-Ildei[39]. Actually, wtih a report effect size at 0.5 and an intra correlation at 0.9, the recommended sample size was twenty-four participants to have a power of 0.80. As our protocol was slightly different, we decided to include 30 participants. All declared no language disorder or visual (not corrected) disorder and volunteered to participate. All participants signed an informed written consent. The experimental paradigm of the study was approved by the Ethics Committee of Tours-Poitiers ("CER TP N°2022-01-02") and all methods were performed in accordance with the declaration of Helsinki.

Materials and procedure
In our experiment, we used the PLD paradigm. The stimuli are constructed from the motion captures contained in the PLAViMoP database and adjusted with the PLAViMoP software to obtain a strictly identical presentation of the action kinematics (see Fig. 1A, B). Each PLD contained thirteen white points (representing the head and the joints of the performer) on a black background. These kinematics actions have been selected for a minimum recognition at 55% and with a mean deviation of 0.06% between women or men kinematics, and a mean average difference of recognition at 3% (See https://osf.io/rvsf8/?view_only=c425d1a775754cfd999fdb28991a2375 for the detail for each action). Thirty actions (x2 gender) were selected. 15 have been used as stimuli and the others were chosen randomly in the PLAViMoP database. For the verbal stimuli, the fifteen verbs which are associated with the selected actions were naturally kept, and fifteen "nonaction" verbs (e.g., seem) were arbitrarily chosen from Beauprez & Bidet-Ildei 2018[39]. All verbs were presented in the infinitive.

Experimental design
The method was identical to that used in Beauprez & Bidet-Ildei (2018)[39]. The participants were seated in a quiet room and sifted in front of a computer. They had to perform two tasks, a priming task and a recognition task, for a total duration of approximately 20 minutes. In the priming task, participants saw a fixation cross for 500 ms followed by a PLD (approximately 2000 ms) and then a verb (see Figure 1C). Participants had to decide for each verb whether it was an action verb, and they were requested to respond as accurately and quickly as possible. The response was given with the right or the left hand by pressing the "a" and "p" key of a AZERTY keyboard, respectively. When the verb presented was an action verb, the verb could be associated with a congruent (for

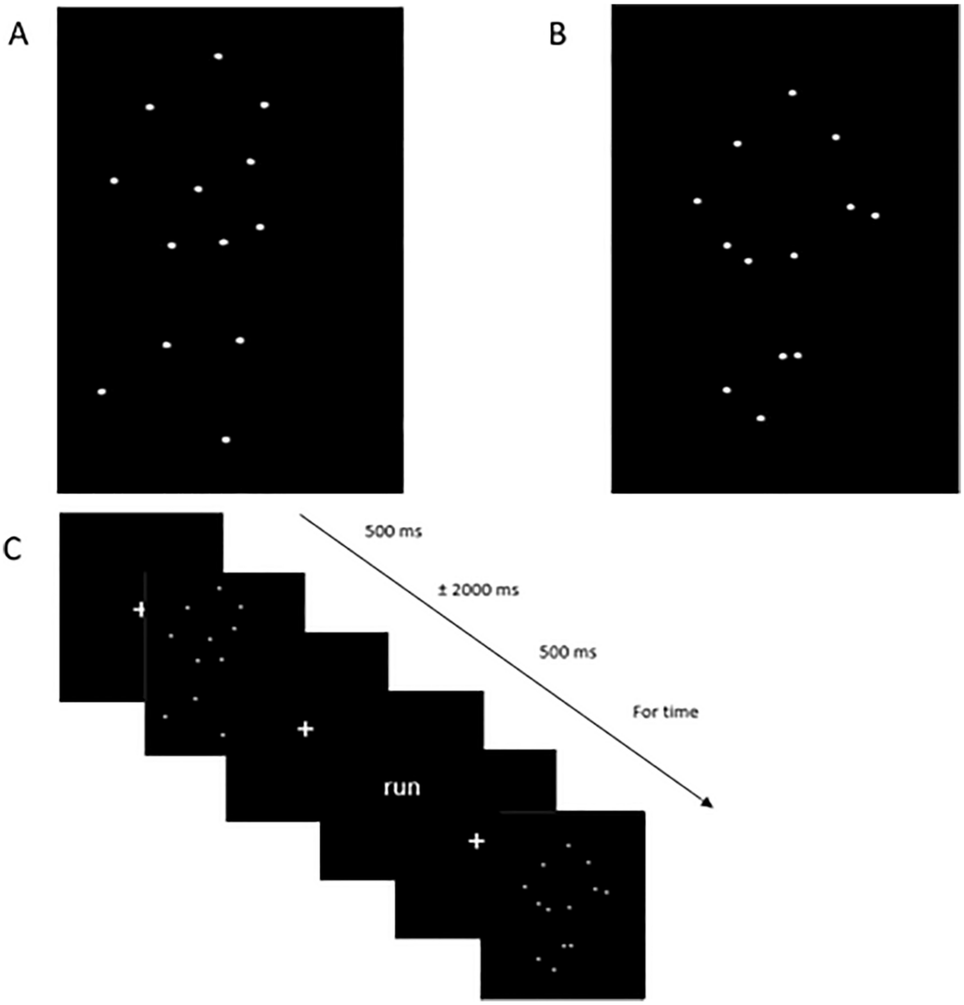

Fig. 1. Illustration (**A**) and (**B**) in the top row represent the PLDs of the running action by a man and woman, respectively. Illustration c represents the course of the procedure. This comprises successively one fixation cross (500 ms), one PLD (approximately 2000 ms, and their appearance in the male or female condition is randomized), a news fixation cross (500 ms), and finally one verb stimulus (where their congruence or not are randomized).

example, the verb "run" with the PLD "run") or an incongruent PLD (for example, the verb "run" with the PLD "jump"). Moreover, the PLD could represent either a man or a woman who performed the action. Finally, 120 trials were proposed to each participant: 60 trials with action verbs associated with 30 congruent PLDs (15 performed by a male, 15 performed by a female) and 30 incongruent PLDs (15 performed by a male, 15 performed by a female) and 60 trials with nonaction verbs associated with 30 PLDs performed by a male and 30 PLDs performed by a female. The experiment was programmed on E-Prime 3.0 software.

At the end of the experiment, participants performed a recognition task. The 30 PLDs associated with an action verb in the priming task were proposed with a new time to the participants, as the participants had to name the perceived action and attribute a gender (male or female). No time was given to make the task, but the experimenter encouraged the participants to be spontaneous.

Measure and analysis

In the priming task, the accuracy and the response time for correct answers were recorded for each trial. For the recognition task, we recorded the accuracy of the responses (about the name and the sex of the PLD) for each trial.

Statistics

For the priming task, accuracy and response times were averaged for each participant in each condition. For the response times, only the correct response less than 1500 ms was conserved (99% of the data). Then, repeated-measures ANOVAs were performed to assess the effect of congruency between the PLD and the verb and the gender matching between the PLD and the sex of the participant. As accuracy did not respect normality, Wilcoxon nonparametric tests were performed. The interaction was assessed by testing the effect of congruency on the difference between the mean accuracy for matching and mismatching gender conditions. In this first analysis, only the response for action verbs was conserved. Moreover, we investigated the Pearson's correlations existing between the rate of action recognition, the rate of sex recognition, the congruency effect (measured by the differences in response times between the incongruent and the congruent conditions), and the gender matching effect (measured by the differences in response times between miss matching and gender matching conditions). JASP free software, version 16.2, was used for each analysis, and we considered p<.05 to be significant. The effect sizes were given with eta squared (η^2) for the ANOVA, the Cohen's for the student test (d) and the rank biserial correlation (r) for the Wilcoxon tests. We also supplement the simple effect analysis of our variables with information from a Bayesian analysis of paired samples, using the Bayes Factor with neutral prior (BF_{10}) as an indicator. Where BF_{10} = 0-1: no evidence; BF_{10} = 1-3: anecdotal; BF_{10} = 3-10: moderate; BF_{10} = 10-30: strong evidence.

Results

Priming task accuracy

As illustrated in Figure2, the analyses showed a moderate effect of congruency (W30 = 118.50; p= 0.045; r= 0.54 or BF_{10}=3.251) with better accuracy for congruent (median =100%, IQR=3.5%) than incongruent (median=100%, IQR= 6.25) conditions. No difference was observed concerning gender matching (W30 = 56.5; p=0.55; r= − 0.16 or BF_{10}=0.253), and no interaction was present (W30 = 74.5; p=0.554 0.747; r= 0.096-0.16 or BF_{10}=0.341).

Time to response

As illustrated in Figure 3, our analyses revealed two significant effects. Firstly, we observed a large statistical effect of congruency (F (1,29) = 31.88 ; p<.001 ; η2 =.26) with faster response times for congruent conditions (M=611.95 ms, SD= 81.4 ms) than incongruent (M=656.3 ms, SD= 82.7 ms) conditions. Secondly, we obtained

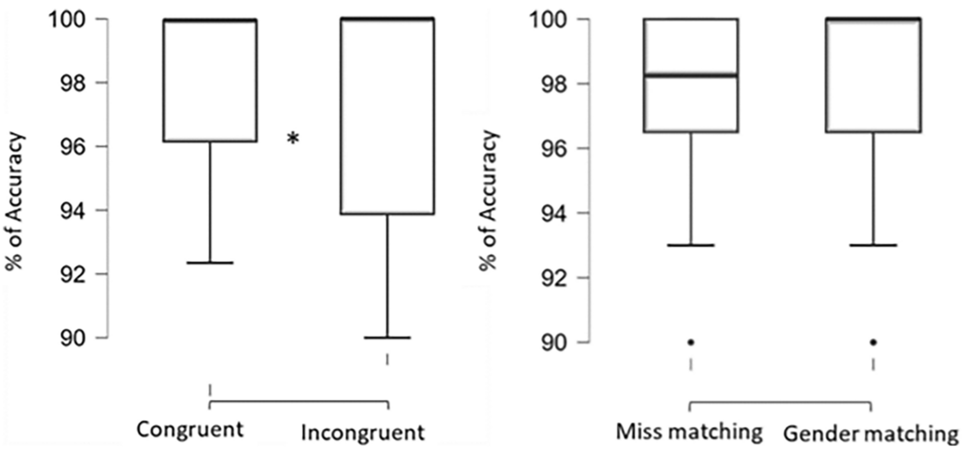

Fig. 2. Box plots representing the effect of congruency (**A**) and gender matching (**B**). * indicates a significant difference at p < .05.

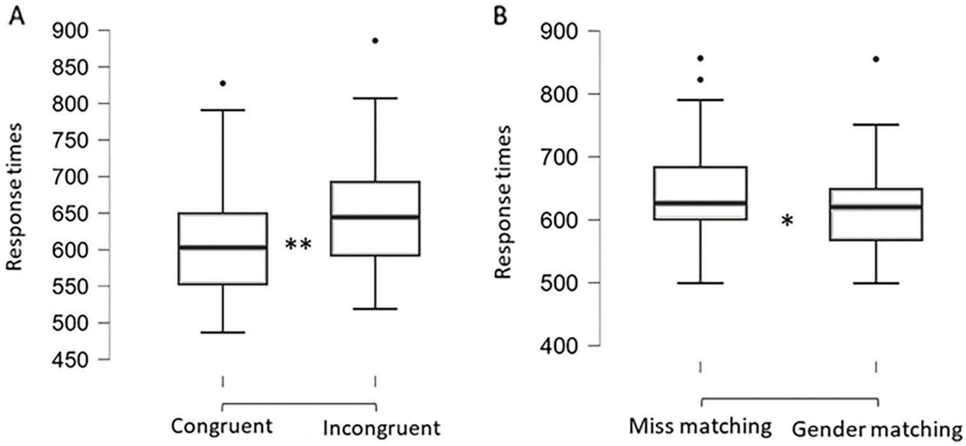

Fig. 3. Plot representing the effect of congruency and gender matching. Error bars indicate standard errors. * indicates a significant difference at p < 0.05. ** indicates a significant difference at p < 0.01.

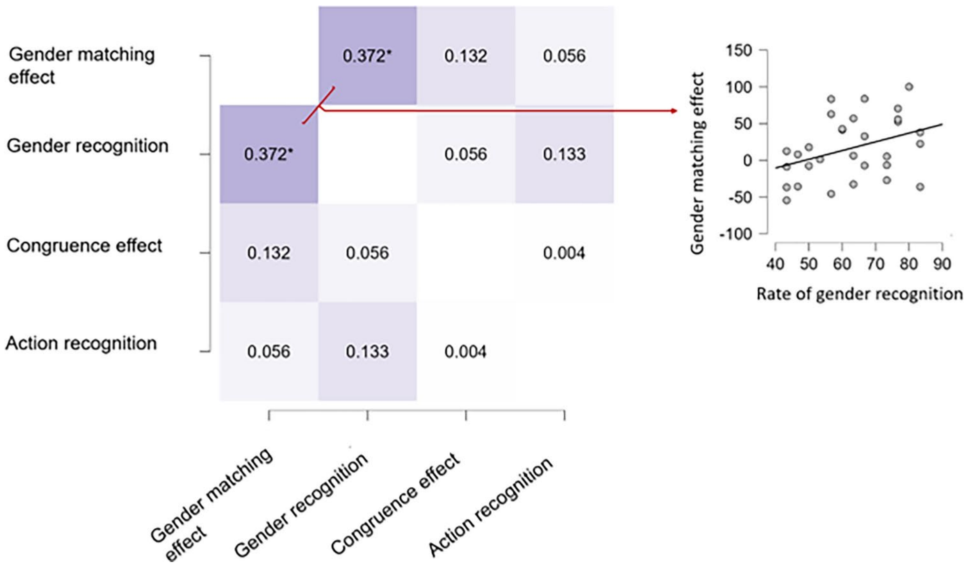

Fig. 4. Pearson's r headmaps and scatter plot for significant correlation. * indicates a significant difference at p < 0.05.

a moderate effect of gender matching (*F* (1,29) = 5.22 ; p=0.03 ; η2 = 0.04) with faster response times for gender matching (M=625.4 ms, SD= 78.4 ms) than for miss matching (M=642.8 ms, SD= 85.2 ms) conditions. However, we have no interaction between these two factors (*F* (1,29) = 0.41; p=0.52; η2 = 0.003). A Bayesian interpretation of our ANOVA results indicates a strong effect of congruence on RT differences (congruence: BF10=1781.385) compared to the null model, whereas the introduction of gender matching explains a low probability (gender matching: BF10=1.179). However, without considering the effectively non-existent interaction (BF10=0.779), accounting for both congruence and gender matching very strongly explains the differences in RT (BF10=2272.715).

PLD recognition
Concerning the recognition of action, we found a mean of 95.2% (SD= 4.4%) for action recognition and 62.7% (SD=13.25) for gender recognition. Interestingly, the mean recognition of gender is higher than the chance level with a large effect size of significance (t_{29} = 5.23; p <.001; d=0.95 or BF_{10} =3.136). The analysis of correlations (see Figure 4) revealed only a significant link between the matching gender effect and the rate of gender recognition (r=0.37; p=.040; or BF_{10} =3.136). No other correlation was significant (all r<0.14).

Short discussion
The aim of this first experiment was to investigate the role of motor repertory[24] on verb processing through a language judgement task. We operationalized this with gender matching (or not) between the participant and

the sex of the PLD used in prime. Concerning congruency, our findings confirmed the previous literature by showing that the observation of PLD affects the subsequent processing of action verbs with faster response times for congruent than incongruent conditions[39] and this effect was also sustained by better accuracy for congruent than incongruent conditions. This coordinates with the idea that PLD observation activates action representation, inducing facilitation in congruent conditions and/or inhibition in incongruent conditions[3]. Concerning the specific effect of motor repertories, the findings show no effect of gender matching on accuracy. This could be attributed to the fact that identification is relatively simple with only 3% of errors on average, which is not sufficient to observe differences. However, we obtain a significant effect in response times with faster response times for gender matching. As this effect of gender matching did not interact with the effect of congruency, it suggests that gender matching improves the temporal course of the activation of the action representation but not the quality of the activation. Actually, if the quality of the activation was impacted, we could envisage that it would have increased the activation of the action representation and thus influence the difference between the congruent and incongruent conditions with greater facilitation for congruent conditions and/or greater inhibition for incongruent conditions. This improvement in temporal course could be due to a better identification of the PLD related to the fact that the kinematics were more in correspondence with the motor repertory of the observer. This interpretation seems to be reasonable in the literature[25,26], but especially with the supplementary information provided by the result of the correlations. Actually, we found a positive significant correlation between the gender matching effect and the rate of sex recognition, suggesting that the difference between gender matching and miss matching conditions is accentuated when participants have a better identification of the sex of the perceived PLD. Finally, regarding the question of whether the motor repertory influences the link between action and language, our response is "yes" with an advantage in the response times to process action verbs. This suggests that motor repertory impacts the quickness of activation of the action representation during PLD observation. However, it should be noted that there is a limitation in this first experiment concerning the uncertainty regarding participants' familiarity with the kinematics used. Nevertheless, all actions employed in the study were common everyday actions (such as walking, sitting, drinking), making it unlikely that they were unfamiliar to the participant pool. Furthermore, the high level of recognition reported in the post-experiment questionnaires, where each kinematic was represented, supports the reasonable assumption of an acceptable level of familiarity.

Experiment 2

Methods

Participants

Using the same reasonning as for Experiment 1, 30 right-handed students (13 women and 17 men) aged 21.83 years (SD= 2.27) participated in Experiment 2. All declared no language disorder or visual (not corrected) disorder. All participants signed an informed written consent. The experimental paradigm of the study was approved by the Ethics Committee of Tours-Poitiers ("CER TP N°2022-01-02") and all methods were performed in accordance with the declaration of Helsinki.

Materials and procedure

As the methodology and procedure are the same as for Experiment 1, we will not go into detail. Indeed, the main modification here is that we no longer have gender matching as a dependent variable but attentional focus.

The motion capture used for this experiment was selected from the PLAViMOP database and adjusted with PLAViMoP software to obtain a strictly identical presentation of the action kinematics (see Fig. 5A, B). Each PLD contained thirteen white points on a black background. However, for the operationalization of attentional focus, we contrasted the members whom were most involved in the execution of the movement with those less involved. This was done by colouring the markers fluorescent green or white (more or less interesting, respectively). The aim was to attract the eyes of the participants. The kinematics chose differs from two actions of the first study, to take account the focus effect on more motor skills. For each of them, the PLD representing the female, or the male was chosen to represent the action depending on the level of recognition (the PLD with the best level of recognition was chosen in each case, see https://osf.io/rvsf8/?view_only=c425d1a775754cfd999fdb28991a2375).

Experimental design

Similar to Experiment 1, the participants were seated in front of a computer in a quiet and isolated room. The same procedure as for Experiment 1 was employed. They were asked to judge whether the verb presented after the cutscene was an action verb or not. For this, the participants responded with the AZERTY keyboard if the verb was an action verb or not (with the "a" and "p" key, respectively). After three training trials, the experiments began. Specifically, all participants observed and judged each condition. They were randomly presented with either the focused or unfocused PLD and the congruence or incongruence of the associated verb. 120 trials were proposed: 60 (30 focused and 30 unfocused) associated with action verbs and 60 (30 focused and 30 unfocused) associated with a non action verb. For the 60 actions associated with action verbs, 30 were congruent and 30 incongruent. Naturally, between each stimulus, a fixation cross (500 ms) appeared for refocusing the gaze on the centre of the screen (see Fig. 5C). After the experiment, the participants were invited to answer a questionnaire to check their level of recognition of the action.

Statistics

The same statistical analysis model of the first experiment was kept. A repeated ANOVA was performed to analyse the effect of verb congruence and attentional focus on response times, and Wilcoxon nonparametric tests were used for response accuracy. To assess the possible interaction for accuracy, we performed a Wilcoxon test on the differences between incongruent and congruent conditions in focused and unfocused conditions.

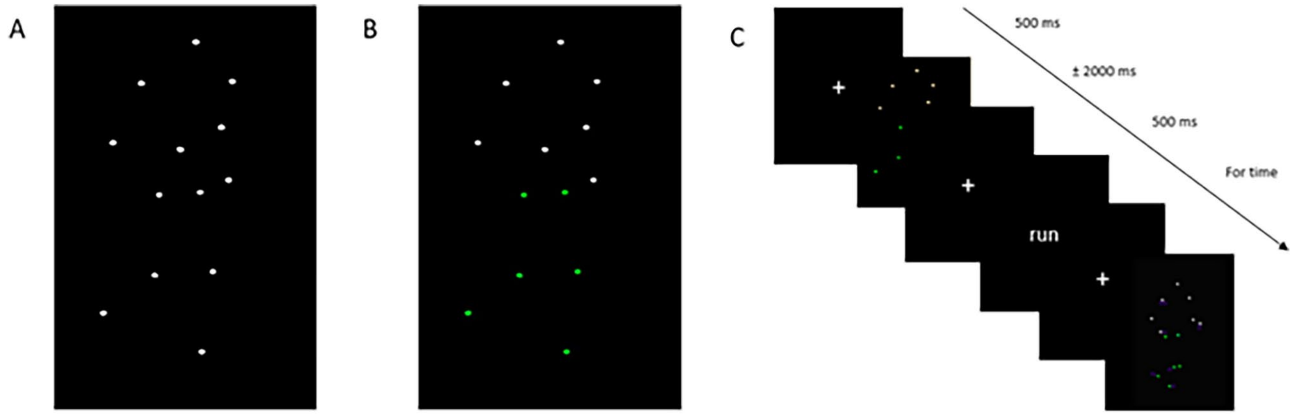

Fig. 5. Illustrations a and b in the top row represent the PLDs of the running action conventionally and focalized, respectively. Illustration c represents the course of the procedure. This comprises successively one fixation cross (500 ms), one PLD (approximately 2000 ms, and their appearance in the male or female condition is randomized), a news fixation cross (500 ms) and finally one verb stimulus (where their congruence or not are randomized).

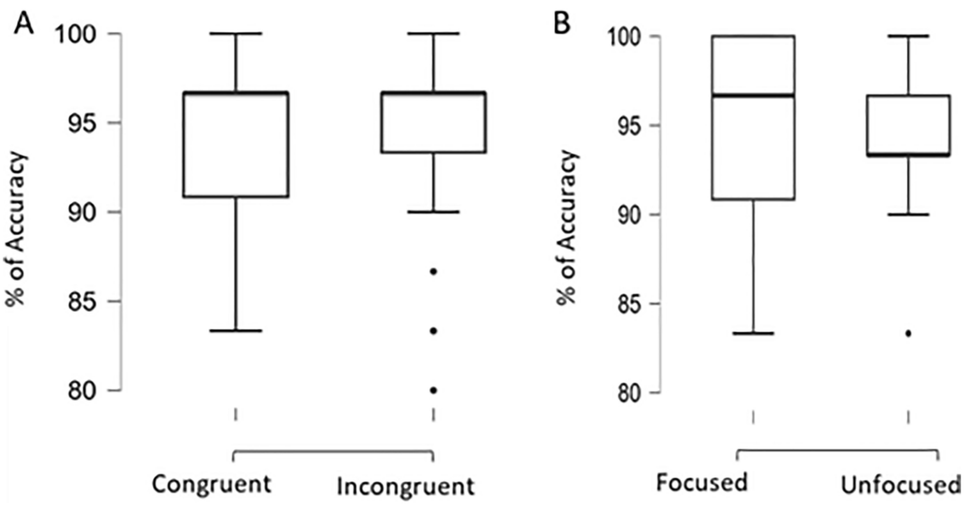

Fig. 6. Box plots representing the effect of congruency (**A**) and focalization (**B**).

Always keeping the significance level set at 0.05, the effect size presented by eta squared (η^2) for ANOVA and Biserial rank correlation (r) for Wilcoxon tests. As in Experiment 1, response times greater than 1500 ms were removed from the analysis (99% of the data were conserved). In contrast to the first study, we did not investigate the Pearson correlations between the recognition rate and the focus effect because the recognition was identical for focalized and nonfocalized PLDs and was very high for all participants.

Results

Priming task (accuracy and reaction time)

The analysis of accuracy (see Figure 6) showed no effect of congruence (W30=122.5; p=0.909 ; r=− 0.032, or BF_{10}=0.201), no effect of attentional focus (W30=142.5; p=0.841 ; r=− 0.50, or BF_{10}=0.196), and no interaction (W30=130; p=.93 ; r=0.028, or BF_{10}=0.2). In all conditions, the mean accuracy was between 73 and 100% (median congruent focused = 93.3%, IQR= 6.7%; median incongruent focused = 93.3%, IQR= 6.7%; median congruent unfocused = 93.3%, IQR= 11.7%) and median incongruent unfocused = 96.7%, IQR= 6.7%).

The analysis of response times (see Figure 7) showed a large effect of congruence (F (1,29) = 31.74; p <.001; η^2 = 0.29) with faster response times for congruent (mean=620.509 ms SD= 91.2 ms) than incongruent conditions (mean=664.4 ms SD= 96.9 ms). However, no effect of attentional focus (F (1,29) = 0.03; p =0.862; η^2 = 02.360×10^{-4}) and no interaction (F (1,29) = 0.99; p =0.328; η^2 = 0.007) appeared. A Bayesian interpretation of our ANOVA results will show that the congruence effect alone indeed accounts for the differences in RT (congruence: BF_{10}=3061.772) compared to the null model. Indeed, here, the effect of focus and its interaction with congruence do not seem to obtain evidence (BF_{10}=0.265 and BF10=0.354, respectively).

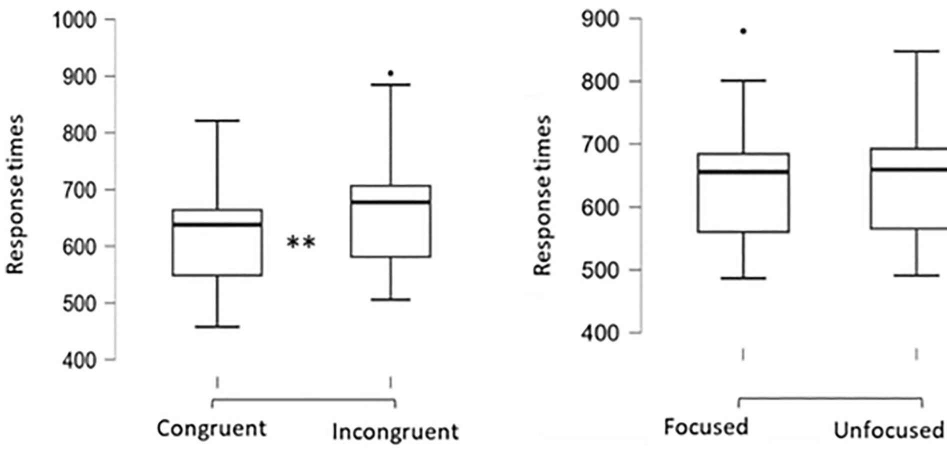

Fig. 7. Plot representing the effect of congruency and focalization. Error bars indicate standard errors. * indicates a significant difference at $p < 0.05$. ** indicates a significant difference at $p < 0.01$.

The rate of recognition of the action reached a maximum level with no difference (W=1; p=1; r=1, or BF_{10}=0.307) with or without focalization (mean=98.46, SD=3.13) (mean=98.20, SD=3.31). Therefore, the correlation between the level of recognition and possible effect was not relevant.

Short discussion
The aim of this second experiment was to investigate the role of somatotopy[14] in verb processing through a language judgment task. We operationalized this by manipulating attentional focus on the kinematics used in the prime. The results confirm the role of congruency in response times (RT), but not in accuracy (ACC). While an initial interpretation might suggest that the task did not effectively elicit the expected effects, the results on RT swiftly challenge this premature conclusion by demonstrating faster response times in congruent situations. Two alternative interpretations emerge as more plausible: Attentional focus may have attenuated the congruence effect on accuracy. The task itself may be relatively straightforward, resulting in a stronger congruence effect on response times. Additionally, it's possible that a participant pool more proficient than in the first study could have better categorized the verbs, influencing the observed effects.

Secondly, in this second experiment, there was no significant effect of attentional focus or interaction on response accuracy or response times. This would suggest that attentional focus does not affect the link between action observation and action verb processing for healthy subjects. This suggests that attentional focus on the main limb of actions could be automatic for us. This idea is consistent with the literature, both in the field of motor skills[44] or the AO that was acting on the points of interest. In the field of action-language links, Beauprez et Bidet-Ildei (2018)[39] showed that the modification of kinematics of the main limbs were required to perform the action, which negatively modulated the judgement of subsequent action verbs, whereas the modification of kinematics of the other limbs did not affect performance. This suggests that an attentional focus on the main limbs of action could be automatically used when humans perceive PLD. To our knowledge, no study has assessed this hypothesis in the literature, but it could be a good track for future research.

Synthesis of results and further analyses

Overall, our results confirm the presence of a link between action observation and action language processing, as evidenced by a positive congruency effect observed in both accuracy and response times in the first experiment, and in response times only in the second experiment[3]. The discrepancy in effects between the two experiments could potentially be attributed to task difficulty or participant characteristics. Regarding the specific effects of moderators, we found a positive effect of gender matching on response times, indicating faster processing of action verbs when the prime matched the observer's gender. However, we did not observe an effect of attentional focus on either accuracy or response times. This unexpected finding may be explained by participants automatically focusing on essential action components[39]. According to the model proposed by Proietti et al.[45], perceptual curiosity may drive eye exploration strategies to form recognition hypotheses, before switching to a strategy of controlling the invariant in the detected action. Building on this idea, we cautiously propose an explanatory hypothesis suggesting that assistance in tasks participants are already proficient in may not necessarily add value and could potentially be detrimental in an antagonistic task. To test this hypothesis, we proposed to analyze non-action word stimuli, which were initially included solely to facilitate task completion for participants but were not typically analyzed due to being processed with the non-dominant hand. However, we believe that analyzing these stimuli could be informative in assessing the hypothesis of deterioration in a priming antagonist task. Therefore, if our hypothesis is correct, we anticipate that gender matching and attentional focus could negatively impact performance for non-action verbs.

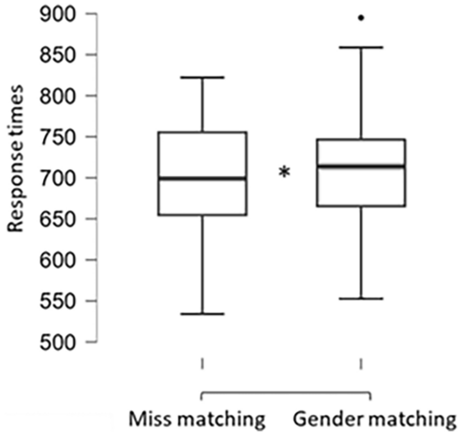

Fig. 8. Plot representing the effect of gender matching. Error bars indicate standard errors. * indicates a significant difference at p<.05

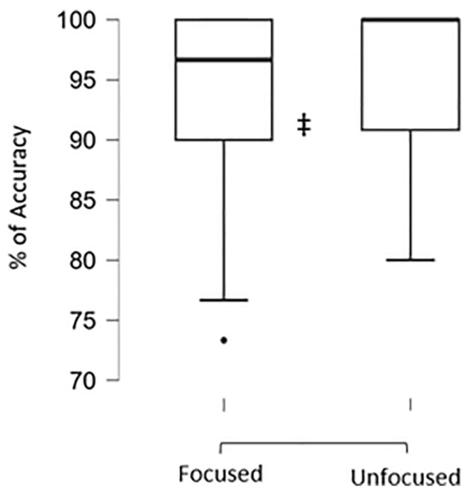

Fig. 9. Plot representing the effect of focalization. Error bars indicate standard errors. ‡ indicates a trend of difference at p=0.056

Non-action verbs sub-analysis of Study 1

Our subanalysis showed no effect of gender matching on accuracy for neutral verbs (W30 = 46; p =0.35 ; r=− 0.124 or (BF_{10}=0.319). However, there was a negative medium effect of Gender Matching on the response times for the judgement of the neutral verb (W30 = 331; p =0.021; r=0.42, or BF_{10}=5.12) with longer response times for matching gender (M =712.79 ms, SD =81.71) than miss-matching gender condition (M =698.41 ms, SD =73.46, see Figure 8).

Non-action verbs sub-analysis of Study 2

Our subanalysis showed no significant effect for the response time (W = 258; p =0.612; r=0.110, or BF_{10}=0.270) but, interestingly, an anecdotical tendency for accuracy (W = 121.5, p =0.056; r=0.421, or BF_{10}=2.22), giving the verb categorization better realized after the visualization of an unfocused PLD (M = 95%, SD = 7%) than after the visualization of a focused PLD (M = 93%, SD = 8%, see Figure 9).

Overall, the sub-analyses on non-action verbs align with the idea that assistance in tasks could be detrimental in antagonistic situations. In the first study, the analysis of neutral verbs supports the hypothesis of the role of gender matching in the quick reconstruction of actions, as inhibiting the reconstruction of a non-action verb is presumably more difficult when the representation is processed faster. Thus, we suggest that gender matching acts as a catalyst for action identification, leading to a faster activation of action representations. Using the ACT-IN memory model[35], gender matching may have facilitated the concept of action by activating a multimodal inter-trace engram in our memories, thereby facilitating the processing of action verbs while deteriorating the processing of non-action verbs.

Similarly, in the second study, our sub-analysis showed a trend difference between focused and unfocused point light display (PLD) conditions in accuracy for non-action verbs, which supports the idea that automatic focus in action situations can degrade the processing of non-action situations. This suggests that the variable of focalization could serve as a discriminator for selecting relevant information for extracting sensorimotor representations. Additionally, focalization is expected to enhance the quality of mental reconstruction of action, but this ability may be automatic in healthy individuals, explaining the absence of a difference between focused and unfocused conditions when assessing action verbs. Returning to the vocabulary of ACT-IN, the discriminative aspect of focusing could facilitate intra-trace activation, as proposed by the second postulate of Proietti et al.[45], where the specificity of what is observed seeks confirmation after identifying a class of probable movement/action.

General discussion

The present experiment aimed to assess whether attentional focus and motor repertory could affect the link between action observation and language. Our main results show that motor repertory improves the link with faster response times for action verbs, whereas attentional focus does not affect the link between action observation and action verb processing. Concerning the effect of motor repertory, our results are in accordance with the literature, which demonstrates that humans better recognize their own kinematics[24,25], and with the idea that observation of action that belongs to our own motor repertory increases the activation of the mirror neuron system[26]. Moreover, it offers strong evidence for the role of gender matching in action verb processing. As this effect is positively correlated with the ability to recognize the gender of the actor through this kinematic mechanism, it also suggests that it could be related to an explicit capacity to better recognize kinematics[25]. To reinforce this result, there is a significant trace of this effect, making non-action verb processing more difficult. Evidence for gender matching is not found on accuracy but on response time, suggesting that this factor plays a role in the reconstruction of mental representation and not on its quality. It is obvious that we can have a clear representation of the action of others even if it is not in concordance with our motor repertory. The representation will be reconstructed and interpreted by similarity with previous experiences to obtain a plausible answer[36]. In the case of gender matching, the reconstruction and interpretation are faster, which is why this factor can be considered a catalyst of the reconstruction of the mental representation.

Concerning the role of attentional focus, the results are less concludable. Indeed, our absence of effect could be due 1) to an absence of detection of the differences between focused and unfocused PLD and/or 2) to an automatic focalization on the main limbs of the actions even if they are not coloured**.** As our findings do not show any difference between the recognition of focused and unfocused PLD, the first hypothesis could be plausible. However, the tendency observed in accuracy for non-action verb processing is more in favour of the second. It seems that humans can differ between focused and unfocused PLDs because we observed a tendency to be less performant in accuracy when non-action verbs were presented after a focused than an unfocused PLD. The validity of this hypothesis of a focusing effect, although not necessarily automatic, could notably justify the attenuation of the classical congruence effect, which was not found in accuracy (for the analysis of action verbs), more accurately than the simple justification of a pool of the most proficient participants. In the theory of visual processing**,** Giese and Poggio (2003)[46] argue that visual perception is based on two parallel processes: form pathway and motion. Moreover, they evoked one type of neuron, the "snapshot detectors", which have the ability to learn spatial and temporal invariances in the form pathway. This element is one key recognition of movement because in the motion pathway, the analysis of movement is only permitted by one temporal order of image processing. However, the authors assume that PLDs mostly use the motion pathway to search for invariances between perception and previous learning of a specific action. For the results that occupy this discussion, the factor of attentional focus could play a role as a discriminator for fixing the relevant element in the perception to compare with the invariants. Even if these elements should be tested in the future, they suggest that attentional focus could intervene in the quality of sensorimotor representation activation. It is important to consider the limitation that this study suffers from, which is not knowing precisely where the participants look. Future research could benefit from the concentration of visual angle location, by means of eye trackers, and whether focusing modifies the gaze on kinematics and if so what type of focusing, specifically.

For looping with the models of the link between action-language, this paper further supports the models proposing a link between action and language by emphasizing the importance of motor repertoire, moderated by gender matching, in the processing of action verbs. Similar to findings from Pulvermüller's team[4] and Rizzolatti's team[7,8], the alignment of motor repertoires between the observer and priming kinematics suggests stronger activity in a common network shaped by experience-induced plasticity. This aligns with the expectations of models proposed by Bidet-Ildei et al. (2020)[3] or Barsalou (2008)[23], where priming kinematics effectively anchor the processing of semantics downstream. Specifically, our findings on gender matching are also in accordance with previous studies indicating that motor experience plays a crucial role in the link between action observation and action verb processing[47], and suggest that gender matching could enhance the re-enactment of actions by integrating sensorimotor and semantic abilities. Regarding the role of attentional focus, we tentatively suggest, given the fragility of the results, that focusing may be useful for discriminating elements necessary for understanding an action within the realm of perception. In the context of language, this may shape the systematic enactment of these invariants in our representations.

Finally, from an applied perspective, our findings offer insights into strengthening the impact of action observation on language rehabilitation through gender matching. The potential effectiveness of attentional focus warrants further investigation with patients, as the absence of effects in healthy participants, suggests an automaticity of attentional focus in healthy individuals. However, this does not rule out the possibility of a potential effect in patients, where automaticity may be compromised and this should be studied in further studies.

Conclusion

In summary, the current paper strengthens the literature arguing for a link between action observation and language. Moreover, it demonstrates for the first time that motor repertory can affect the link between action observation and action verb processing. As some studies have already shown that language disorders can be improved by action observation[20,48], this study provides some perspective to reinforce the impact of action observation on language rehabilitation through gender matching.

Data availability

The data that support the findings of this study will be openly available in OSF at https://osf.io/rvsf8/?view_only=c425d1a775754cfd999fdb28991a2375

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Author contributions

All authors contributed to the design of the study (stimuli were produced with AD), interpreted the data and approved the final version of the manuscript for submission. MV. carried out the data collection, under the supervision of C.B.I. Data analysis was carried out by V.F and C.B.I and VF drafted the first version of the manuscript. V.F. and C.B.I. designed and performed the research; M.V. contributed to the performed research; A.D. constructed the stimuli of motion capture; V. F and C.B.I. analysed the data; V. F and C.B. I wrote the edited versions of the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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