Mechanisms for action prediction operate differently in observers with motor experience

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Recent theoretical and empirical work has suggested an important role for the motor system in generating predictions about the timing of external events. These predictions may play an important role in peoples' ability to engage in temporally coordinated joint action with other people. As many forms of joint action involve skilled actors, such as musicians and dancers, researchers have recently turned their attention to whether specific motor experience might enhance predictive abilities. We tested the hypothesis that motor experience with an observed action modulates prediction accuracy by comparing the performance of naïve and experienced observers on a task that required participants to predict the timing of particular critical points in a ongoing observed action. Crucially, we employed action and non-action stimuli with identical temporal dynamics, and we predicted that motor experience would enhance prediction accuracy specifically for actions and would have a reduced or negligible effect on enhancing prediction accuracy for non-action stimuli. Our results showed that motor experience did modulate prediction accuracy and this resulted in greater accuracy for predictions about action stimuli relative to non-action stimuli. No difference between conditions was observed for the naïve observers. This suggests that motor experience with a partners actions might enhance peoples' prediction accuracy and, therefore, their ability to engage in temporally coordinated joint action.

Keywords: Joint action, action prediction, perception–action

Introduction

Many types of joint action require two actors to coordinate their actions in time. For example, in joint actions such as ensemble music and dance performance, successful completion of the joint action might require the actions of two people to be precisely temporally aligned, or synchronized. If people were to observe and then react to the actions of their co-actors this would introduce disruptive delays. Instead, individuals must anticipate the actions of their co-actors so that they can plan actions early. Consequently, researchers have emphasized

the role of prediction in recent theoretical accounts of joint action coordination (Colling, Knoblich, & Sebanz, 2013; Colling & Williamson, 2014; Csibra, 2008; Knoblich, Butterfill, & Sebanz, 2011; Wilson & Knoblich, 2005). Furthermore, as many cases of joint action, such as music, dance, or sport performance, also involve cases of *expert* performance, researchers have also turned their attention to how these predictive processes might be modulated by motor experience (e.g., Aglioti, Cesari, Romani, & Urgesi, 2008; Sebanz & Shiffrar, 2009). It is the influence of motor experience on action prediction that is the primary concern of the present study.

Particularly useful for understanding how action prediction might be achieved within the context of joint action have been concepts borrowed from control theory (for an introduction to control theory, see Golnaraghi, 2010). Specifically, *inverse models* and *forward models* have proved theoretically useful. Inverse models perform an *inverse mapping* from an output or goal state to the sequence of control commands necessary to produce that output. And forward models perform a *forward mapping* from the control commands to the output. That is, they model the dynamics of the target system.

Inverse and forward models—together known as *internal models*—have a central role in theoretical accounts of action control (for example, see Wolpert, Miall, & Kawato, 1998). Inverse models act as controllers that transform a desired limb trajectory into the motor commands that would produce that trajectory. And forward models replicate the dynamics of the limb and can, therefore, be used to predict how the limb will respond to motor commands. Used together, internal models make it possible to plan actions without specifying the motor commands precisely at the outset (Wolpert & Kawato, 1998). Running the forward model *offline*—that is, without producing any actual motor output—can be used to internally simulate limb movements. Grush (1997, 2004) refers to this process as *emulation* and to the forward model as an *emulator*.

Predicting observed actions

Grush's (1997, 2004) ideas about emulation have been developed into an account of action prediction that has been termed the *emulator theory of action* prediction (Colling, Thompson, & Sutton, 2014; Colling & Williamson, 2014). While many formulations of this theory exist (see also Colling et al., 2013; Csibra, 2008; Keller, 2012; Wilson & Knoblich, 2005; Wolpert, Doya, & Kawato, 2003), the basic idea is that prediction of observed actions relies on the same internal mechanisms that support action production. It is claimed that, the observer's action control system acts as an emulator enabling the observed action to be internally simulated in real-time. These real-time simulations can then be used as the basis for anticipatory action planning. However, in order to internally simulate the observed action using an emulator, a motor command, which ordinarily drives the forward model during action production, is needed. One way to generate this motor command might be to formulate a conjecture of what action the observed agent is producing (Kilner, Friston, & Frith, 2007) or by visually analyzing the observed action (Csibra, 2008). Visual analysis can be performed with the inverse model to simulate the motor commands driving the observed action.

Prediction and motor experience. A key claim of the emulator theory of action prediction, at least as formulated by Wilson and Knoblich (2005) and Colling and colleagues (Colling et al., 2013; Colling & Williamson, 2014), is that the observed action is mapped onto the observer's body in a part-by-part, or isomorphic manner. That is, prediction occurs by internally simulating the action *as if the observer was performing it*. Because prediction is tied to the observer's own action repertoire, predictions should carry traces of the observers action repertoire.

One way to test this claim is to compare action prediction in experts and novices[1]. For example,

[1]Related to these studies are those that exam-

Aglioti et al. (2008) employed a basketball free throw prediction task to compare the performance of novice and expert basketball players. The general finding from these paradigms is that experts generate more accurate predictions than novices (Abernethy, 1990; Aglioti et al., 2008; Isaacs & Finch, 1983; Sebanz & Shiffrar, 2009).

Although studies comparing action prediction in experts and novices appear to demonstrate that predictive processes are enhanced by motor experience at least one concern can be raised. Specifically, the causal relationship between expertise and prediction is not clear. It may be the case that expertise causes superior predictive abilities; however, it is also possible that those who become experts do so because they already possess superior predictive abilities. To uncover the direction of causality it may be preferable to train people on an action rather than use experts. This approach was adopted by Casile and Giese (2006). However, this study only examined whether motor training led to enhanced performance on a visual action discrimination task, and it did not examine the question of action prediction.

In addition to concerns about the direction of causality, a second concern can also be raised about previous studies. In previous work by, for example, Aglioti et al. (2008), Sebanz and Shiffrar (2009), Ikegami and Ganesh (2014), Mulligan and Hodges (2013), and others[2], participants were asked to generate a prediction about the outcome of an action. For example, whether a basketball free-throw would be successful or not. While these tasks do test predictive mechanisms, it is not clear whether they test the same predictive mechanisms that underlie joint performance in music, dance, and sport. The predictive mechanisms that underlie joint action must have two features, neither of which are tested by these kinds of tasks. First, predictions must be generated rapidly and in real-time and, second, it must be possible to use the predictions as the basis for anticipatory action planning. This second concern is highlighted by recent work from Mann, Abernethy, and Farrow (2010). In their task, participants were required to generate a prediction about an action and then report their prediction in different ways. This could either be by verbal report or by producing the appropriate action in response to the prediction (in this case, performing the correct cricket shot in response to the predicted trajectory of a ball delivered by a bowler). The result showed that prediction accuracy was modulated by response modality, suggesting that predictions generated for verbal report and action planning might reside in different (sub)systems.

Temporal alignment tasks. One method to specifically probe the mechanisms that underlie prediction during joint action is to employ a temporal alignment task or tasks were observers are required to perform an action on the basis of their prediction, rather than make a decision. Performing an action on the basis of a prediction is indeed the response modality chosen by Cross, Stadler, Parkinson, Schütz-Bosbach, and Prinz (2013). In this study, participants were asked to generate a prediction about when a gymnast or a toy, which were moving across the screen, would reappear after moving behind an occluder. Participants were required to press a button at the point in time that they believed the person or object would reappear. The primary finding of this study was that repeated visual exposure to the stimuli resulted in more accurate predictions about when the gymnast or toy would reappear. Importantly, however, it is not clear whether the task employed in this study actually taps into action prediction mechanisms. In-

ine expertise-related changes in motor cortex activity during action observation tasks (e.g., see Calvo-Merino, Glaser, Grézes, Passingham, & Haggard, 2005; Calvo-Merino, Grézes, Glaser, Passingham, & Haggard, 2006). While the results of these studies are consistent with the emulator hypothesis, they do not provide a test of the theory because they do not involve prediction tasks.

[2]For neuroimaging studies that involve outcome prediction see, for example, Abreu et al. (2012) and Diersch et al. (2013).

deed, this task could instead be performed using mechanisms that allow people to judge the duration of intervals. As the gymnast or toy moves across the screen, accurate perception of how long it takes to move a fixed distance would allow the observer to accurately predict when it will reappear from behind the occulder.

A different task, which more accurately captures the demands of joint action, has been developed by Colling et al. (2014)[3]. In this temporal alignment task, participants viewed mannequins performing up-and-down arm movements while attempting to align a button press with the point when movement changed from upward to downward. Importantly, the spacing between the points of direction change was irregular thus preventing the observer from relying on interval timing mechanisms (see Colling et al., 2014, , Experiment 2–3). Mannequins were viewed under two conditions. In the *self* condition, participants viewed mannequins created from motion capture recordings of themselves producing the movements at an earlier time. In the *other* condition, participants viewed mannequins created from recordings of another person's movements. The results showed that people were significantly more accurate at aligning button press responses with the points of direction change when viewing recordings of their own actions. Importantly, these tasks require participants to not only generate predictions quickly and in real-time but also to plan and execute actions on the basis of these predictions. By employing a paradigm such as that developed by Colling et al. (2014), it should be possible to examine the influence of motor experience on prediction in tasks that more closely match the demands of joint action. That is, it may be possible to examine how motor experience influences peoples' ability to engage in temporally coordinated joint action.

How does motor experience modify action prediction?

While the studies cited above (e.g., Aglioti et al., 2008) suggest that motor experience enables more accurate predictions (at least for action outcome tasks), these studies do not answer the question of *how* the prediction process changes in order to achieve this. However, an extension of the emulator hypothesis, developed by Schubotz (2007), might suggest an answer. Based on results from fMRI (e.g., Schubotz & von Cramon, 2004) and lesion studies (e.g., Schubotz, Sakreida, Tittgemeyer, & von Cramon, 2004), which implicate premotor regions in sequence prediction, Schubotz (2007) suggests that motor simulation is a general purpose predictive mechanism for predicting not only human actions but all manner of external events. In the case of *reproducible events* (human actions) it is possible to internally simulate the observed action using the same mechanisms used to produced them, as claimed by the emulator theory (e.g., see Colling et al., 2013; Colling & Williamson, 2014; Wilson & Knoblich, 2005). In the terminology of Schubotz (2007, p. 213), observers may use their "motor memories to run a simulation of the observed movement". In the absence of these motor memories, Schubotz (2007) suggests that predictions might be generated by mapping the observed event onto an effector that best matches the general dynamics of the observed stimuli. This suggests that experienced and naïve observers might actually engage in *qualitatively different* types of action prediction, with experienced observers internally replicating the observed action *as it was performed* and naïve observers just replicating the stimulus dynamics with whatever effector does the best job.

This generic simulation might not only occur in the absence of motor experience. It might also occur when the observed stimuli cannot be easily mapped onto the observer's body. For example, when the action stimuli are impoverished so that it is not clear *how* the action is being produced—that is, when the observed actions are not amenable to visual analysis (Csibra, 2008)—it might not be clear which action, out of all possible actions, to

[3]See Keller, Knoblich, and Repp (2007) and Flach, Knoblich, and Prinz (2003) for similar tasks.

internally simulate. In this case, observers might again internally replicate the dynamics of the stimulus using whatever effector does the best job rather than replicating the action as it was produced.

Aims of the present study

The aim of the present study is to investigate *how* predictive processes change when observers have experience producing observed actions. Previous studies have reported that action prediction becomes more accurate when observers possess motor experience; however, it is not clear how the process changes to enable this. Furthermore, previous studies on action prediction have generally tended to focus on predicting action outcomes, with relatively few studies (e.g., Colling et al., 2014; Flach et al., 2003; Keller et al., 2007) employing the kind of tasks that replicate the temporal demands found in joint action.

Based on the work of Schubotz (2007), we suggest that generic simulation may occur in at least two situations. First, when the action stimulus is impoverished, so that it cannot easily be mapped on to the body in a part-by-part manner. Second, when the observer is viewing an action that they have little or no experience producing. Furthermore, these two factors should interact. That is, if an observer is engaged in generic, or approximate, simulation of the observed action, such as when they have no experience producing the action, then increasing stimulus detail by providing more information about how the action is produced should be of no benefit. Conversely, if the observer is engaged in a detailed part-by-part simulation then decreasing the stimulus detail, so that it is not clear how the action is being produced, should interfere with the predictive process.

To test this hypothesis, we examined the influence of motor experience on prediction using a temporal alignment paradigm similar to Colling et al. (2014). Two groups of participants, those with experience producing the observed action and naïve participants, viewed actions under two conditions. In the full information condition, the stimuli depicted the actions in full, including information about the limbs and joints used to produce the action. In the point information condition, participants were required to generate a prediction about the same dynamic information; however, the displays were impoverished so that they did not depict an action. We predict that naïve observers, who only engage an approximate predictive solution that replicates the dynamic information of the stimulus but without internally replicating the action itself, should not differ between the two conditions. In experienced observers, however, decreasing stimulus information should hamper the process of internal replication. This should result in a difference in prediction accuracy between stimulus conditions as a function of motor experience. Using this procedure has an advantage over simply comparing prediction accuracy for a single stimulus type (i.e., action stimuli only) because then it would not be possible to draw inferences about whether specific motor experience enhances prediction accuracy for specific actions or whether it simply improves prediction accuracy more generally.

Methods

Participants

There were 13 participants (11 females, mean age of 27.5 years) in the experienced group, and 12 participants (8 females, mean age of 20.1 years) in the naïve group. All participants were right-handed (Oldfield, 1971), and all procedures were approved by the Macquarie University Human Subjects Ethics committee.

Stimuli

To create the stimuli for the test session, five right-handed females (mean age of 24.8 years) performed a movement task while their movements were recorded with motion capture. The movement task involved tracing out wave and zigzag patterns as if drawing them on a blackboard (the

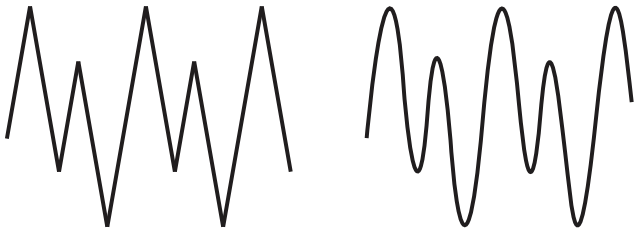

Figure 1. The zigzag (left) and wave (right) patterns used as stimuli during the movement task

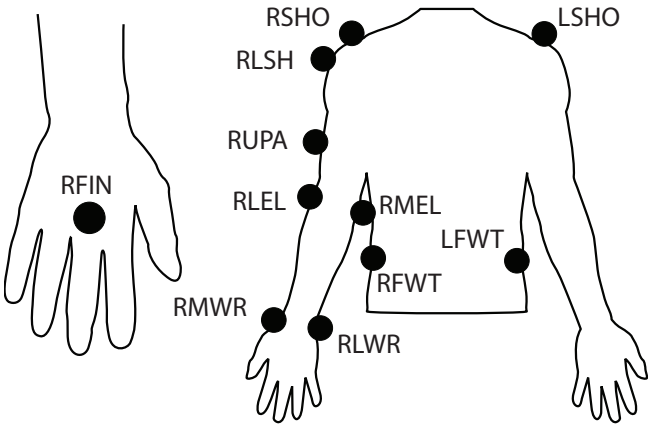

Figure 2. Marker positions for the 11 reflective markers used during the movement task.

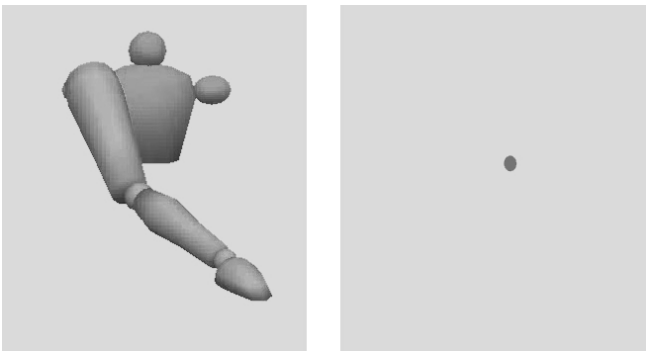

Figure 3. Example stimuli from the full information condition (left) and the point information condition (right).

patterns measured 0.584 m × 0.841 m; see Figure 1). Each pattern contained five peaks, alternating in height from large to small; however, they differed in the nature of the direction change at the apex of the peaks. The zigzag pattern contained an abrupt change while the wave pattern had a smooth direction change. We had no predictions about how pattern would influence performance and different patterns were only included to increase stimulus variability.

Movements were recorded using an 8-camera 3-D passive optical motion capture system (Vicon MX with 4 MX-F20 and 4 MX13+ cameras; 200 Hz sampling rate). To define the limb segments, and the position of the torso, markers were placed on the shoulders, the right elbow, wrist, waist, and the top of the right hand (See Figure 2). For the full information condition, the motion capture data was rendered as an animated character consisting of an upper torso, right arm and right hand. For the point information condition, only a single point tracking the movement of the RFIN marker was displayed (See Figure 3). Mannequins were preferred over point-light displays because they preserve occlusion.

Procedure

Participants in the experienced group undertook a movement session that was identical to the task employed during stimulus creation. Participants performed 3 blocks containing 5 repetitions of each pattern (in random order) with their eyes closed to limit visual experience. The movement session and the test session were on average separated by 16.69 days (7 to 28 days).

The task in the test session, which was conducted in a different lab to the movement task, was to press the response button when the hand of the mannequin, or the marker tracking the hand, reached the apex of each upward movement. That is, on each trial participants were required to press the button *five* times. They were instructed to synchronize the button-press with the display as accurately as possible and were told that this may require them to anticipate when the peak will occur. Each participant performed 4 blocks containing 40 unique stimuli (composed of 20 trials for the full information condition and 20 trials for the point information condition) with equal numbers

of wave and zigzag stimuli. Participants that did not undergo the movement session were given a brief verbal description of the movement task.

Results

To measure alignment accuracy, we calculated the absolute timing difference between the timing of the peak in the motion capture trajectory and the timing of the button presses performed by the participant. Only the last four button presses were analyzed because several stimuli contained missing frames leading up to the first peak. Absolute timing error was analyzed by means of a 2×2 mixed ANOVA with the factors stimulus condition (full information, point information) and group (experienced, naïve).

The results showed that there were no systematic differences in alignment accuracy between the experienced group (M = 126.42 ms, SD = 48.4) and the naïve group (M = 114.46 ms, SD = 33.22), $F_{1,23} = 0.510$, $p = 0.482$, $\eta^2_G = 0.022$. Furthermore there were no systematic differences in alignment accuracy between the point information condition (M = 113.43 ms, SD = 30.25) and the full information condition (M = 115.49 ms, SD = 36.38), $F_{1,23} = 1.867$, $p = 0.185$, $\eta^2_G = 0.001$. The condition means are shown in Figure 4.

However, our primary comparison of interest was whether the effect of stimulus condition was modulated by group. This is examined by the interaction in the ANOVA which compares the difference in alignment accuracy between the Point information condition and the Full information condition in the experienced group with this difference in the naïve group. The difference, which we term the *full information advantage*, was larger for the experienced group (M = −6.37 ms, SD = 7.9) than the naïve group (M = 2.06 ms, SD = 7.85), $F_{1,23} = 7.135$, $p = 0.014$, $\eta^2_G = 0.003$, Hedges' g = −1.03, 95% CI [−14.94; −1.9][4]. Supplementary t-tests confirmed that difference between the Full information condition and the Point information was signficant for the Motor experience group, $t_{12} = -2.907$, $p = .013$, Hedges' $g = -0.13$, M_Δ = −6.37 ms, 95% CI[−11.14; −1.59][5], but not for the Naïve group group, $t_{11} = 0.907$, $p = .384$, Hedges' $g = 0.06$, M_Δ = 2.06 ms 95% CI[−2.93; 7.05][6]. This interaction is shown in Figure 5.

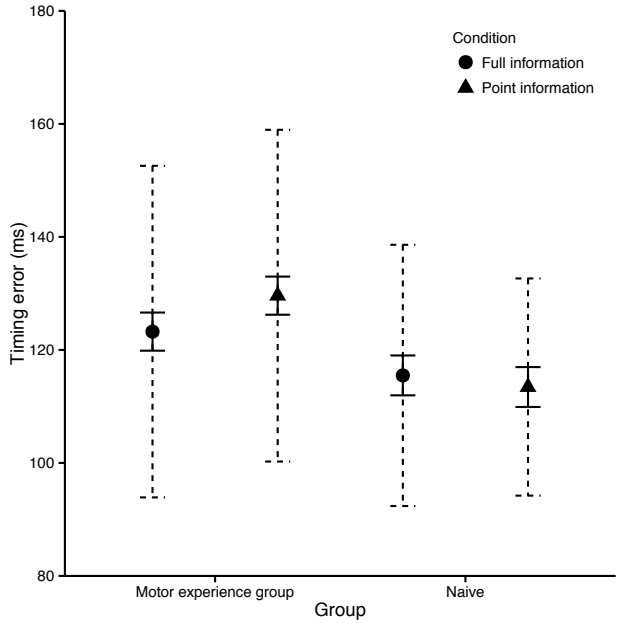

Figure 4. Plot of the condition means for the motor experience and naïve groups. Dashed error bars show the between-subjects 95% confidence interval while the solid error bars show the within-subjects 95% confidence intervals.

In order to determine the source of this interaction we conducted Bayesian t-tests to compare performance on each condition betweeen the two

[4]These results were confirmed with a Bayesian analysis that found moderate evidence for the interaction, JZS BF_{10} = 3.86. The posterior mean difference was −8.41 ms, 95% HDI [−15.5; −0.93].

[5]These results were confirmed with a Bayesian analysis that found moderate evidence for a difference between Full information and Point information JZS BF_{10} = 4.59, with a posterior mean difference of −6.17 ms, 95% HDI [−11.2; −1.15]

[6]These results were confirmed with a Bayesian analysis that found anecdotal evidence for the null hypothesis of no difference between Full information and Point information JZS BF_{10} = 0.51, with a posterior mean difference of 2.24 ms, 95% HDI [−3.3; 7.44]

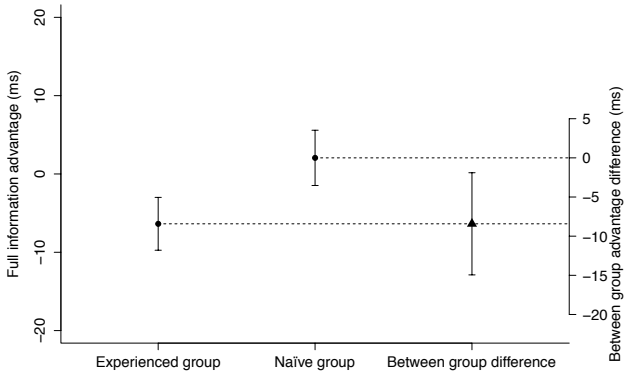

Figure 5. Plot of the interaction between stimulus information and group. Error bars show the 95% confidence interval.

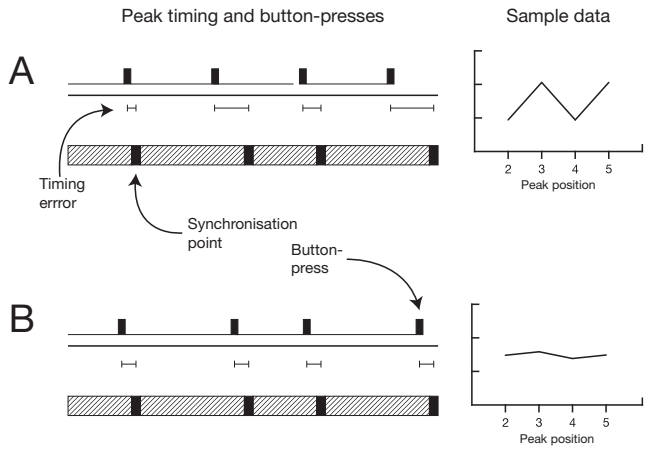

Figure 6. (A) Evenly spaced button-presses results in timing errors that vary as a function of peak number. (B) Button presses that vary according to peak position results in timing error that does not vary according to peak positions.

groups. For both the Point information condition, t_{23} = -0.99, p = .333 and the Full information condition, t_{23} = -0.45, p = .658, found no significant differences between groups [7]. There it is difficult to draw any conclusions about source of the interaction beyond that it results from a difference in the paired differences (between the two conditions) for the two groups. That is, that the paired differences are non-zero for the motor experience group but not signficantly different from zero for the naïve group.

Exploratory analysis of group differences

A further attempt was made to explore differences in task performance between the experienced and naïve group. To do this, we examined whether there were any differences in task performance related to whether participants primarily responded to the local aspects or the global aspects of the stimulus. If the stimuli, the duration of each upward movement alternated from long to short leading to local variations in the timing of the peaks. If participants based their responses on the global aspects of the stimulus—for example, average inter-peak interval—then the magnitude of the timing error would fluctuate from peak to peak. If, on the other hand, participants adjusted their responses according to the local variations in the stimulus then timing error should be relatively constant. (The logic of this analysis is shown in Figure 6). Therefore, we analyzed timing error as a function of peak position using two separate one-way ANOVAs. The analysis showed significant differences in timing errors between peaks for the naïve group, $F_{3,33}$ = 11.148, p = 0.005, ϵ = 0.369, η^2_G = 0.216, but not for the experienced group, $F_{3,36}$ = 2.745, p = 0.117, ϵ = 0.386, η^2_G = 0.036. This suggests that the participants in the experienced group responded to the local aspects of the stimuli while the naïve participants responded to global aspects. This data are shown in Figure 7.

Discussion

The primary aim of the present study was to investigate how the predictive mechanisms that underlie joint action coordination are altered by motor experience. Previous studies have shown that

[7]This was confirmed with a Bayesian analysis that found anecdotal evidence in support of no difference between the groups for the Point information condition (JZS BF_{10} = 0.63, 95% HDI [−52.43; 22.14]) and the full information condition (JZS BF_{10} = 0.49, 95% HDI [−46.22; 33.14])

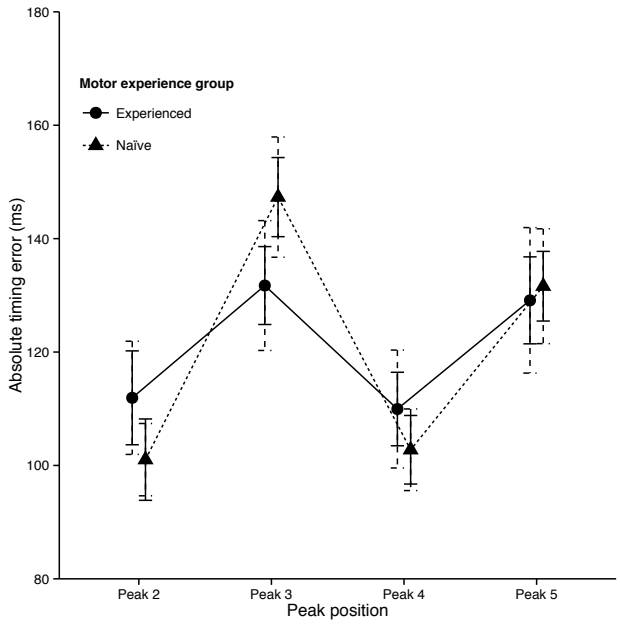

Figure 7. Timing error as a function of peak position for the experienced and naïve group. Dashed error bars show the between-subjects 95% confidence interval while the solid error bars show the within-subjects 95% confidence intervals. The results of the between-subject main effect are reported on page 7.

observers with motor experience are capable of generating more accurate predictions about observed actions (e.g., Aglioti et al., 2008; Sebanz & Shiffrar, 2009). However, these studies only show *that* predictive mechanisms are altered by motor experience but not *how* they are altered.

Based on work by Schubotz (2007), we hypothesized that motor experience may allow observers to engage in qualitatively different prediction. Specifically, observers with motor experience would be capable of reactivating "motor memories" from previous performances, which would enable them to internally simulate the same action that was being observed. Naïve observers, on the other hand, would only be able to engage in a generic simulation of the stimulus dynamics using the motor dynamics of the effector that most closely replicates the dynamics of the stimulus.

To test this hypothesis, we compared prediction accuracy for experienced and naïve participants under two stimulus conditions. In the full information condition, participants viewed stimuli that fully depicted the action being performed, including information about the limbs and joints used to produce the action. In the point information condition, participants viewed stimuli that did not depict an action but did replicate the stimulus dynamics shown in the full information condition. The logic of this manipulation is that if naïve observers are only engaged in generic simulation of the stimulus dynamics then adding additional information about how the action was performed should not enhance alignment accuracy, because the critical information—the stimulus dynamics—do not change between conditions. The experienced observers, however, are capable of internally stimulating the observed action as it was performed by reactivating "motor memories" from past performances. Therefore, the addition of information that specifies how the action was produced would allow them to internally simulate the correct action thereby enhancing prediction accuracy when this information is present relative to the condition where this information is absent.

The effect of stimulus condition

The results showed that overall there was no difference in alignment accuracy between the full information and the point information condition. This result may initially appear surprising. However, it is consistent with our prediction that stimulus information should only increase alignment accuracy in participants with motor experience. If half the participants showed increased alignment accuracy for the full information stimuli while the other did not then this would not result in a main effect of stimulus condition.

The effect of motor experience

The results also showed no main effect of motor experience on alignment accuracy. This finding is more difficult to reconcile with previous lit-

erature. For example, work by Aglioti et al. (2008) and Sebanz and Shiffrar (2009) has shown that motor experience facilitates more accurate predictions about observed actions. However, this finding is consistent with the hypothesis under examination. Our study was designed to examine whether motor experience results in observers engaging *qualitatively* different prediction mechanisms. This is agnostic to the question of whether these predictive mechanisms result in superior prediction. It may be the case that overall performance accuracy is no different. Furthermore, our data do give a clue to how this predictive process might be changed. In the present study, participants were asked to generate predictions about the ongoing dynamics of the stimulus in real-time. That is, for each stimulus, rather than generating one prediction they instead generated five predictions (one for each peak in the stimulus). It may be the case that naïve participants responded differently to the stimulus and that this resulted in some responses within a trial being better aligned than others with the overall mean alignment accuracy being no worse than that of the experienced participants.

To test this possibility we compared the intra-trial differences in alignment accuracy for the two groups. The results showed that for the naïve group, alignment accuracy differed significantly as a function of peak position. This was not the case for the experienced group. The data also show that for some peaks, naïve participants were able to align their responses to the stimulus more accurately than experienced participants while for other peaks they were not. This alternating pattern of better and poorer alignment, demonstrated by naïve participants, could result in trial means that are no different to the experienced group. This result could be produced naïve participants merely responding to the global dynamics of the stimulus instead of responding to the fine-grained timing variations in the stimulus, as seen in the experienced participants. This result is consistent with the notion that experienced observers generate predictions about observed actions by employing an internal model of that action that is acquired through motor experience. By mapping the observed action onto their internal model for that action they are better able to capture the fine-grained timing variations in the stimulus because their predictive model more completely captures the constraints specific to the effectors used to produce the action. If naïve observers do not internally simulate the observed action then this generic model may be less capable of capturing these fine-grained details while still being able to capture the global dynamics.

Motor experience modulates stimulus effects

We have hypothesized that motor experience would allow participants to engage in a qualitatively different process of action prediction compared with naïve participants. In particular, we hypothesized that experienced participants would be able to activate an internal representation of the observed action that had be laid down by earlier performance of the action while naïve participants would just engage general purpose predictive mechanisms that are not specific to the action. This difference in the nature of prediction between the two groups should result in differences in how the two groups respond under the two stimulus conditions. For the experienced group, the full information condition should allow observers to more accurately select the correct internal action representation that corresponds to the observed action and this should result in an enhancement in alignment accuracy relative to the case where this information is absent. In the naïve group, however, the observers do not activate an internal representation of the observed action and, therefore, the addition of information that helps select the appropriate internal action representation should be of no benefit. As hypothesized, we found that alignment accuracy was enhanced in response to the full information stimuli only for participants who had experience producing the observed action.

While previous studies have been able to demonstrate *that* motor experience changes pro-

cesses involved in action prediction by, for example, enhancing prediction accuracy (Aglioti et al., 2008), the results presented here go further to demonstrate *how* these predictive processes are changed. Specifically, these results are consistent with the idea that experienced and naïve participants engage in *qualitatively different types of prediction*. This distinction between internally replicating the action itself and merely simulating the stimulus dynamics with in the motor system is similar to the distinction between *emulation* and *simulation*, respectively, put forward by Grush (2004). By internally replicating the action itself, observers might not only generate more accurate predictions but may also generate predictions that more accurately replicate the fine-grained timing details of the observed action. These differences in fine-grained details may not appear in tests of gross performance, such as predicting binary action outcomes (e.g., Aglioti et al., 2008; Sebanz & Shiffrar, 2009).

Conclusions

Taken together, the results presented here suggest that observers with and without experience performing an action engage qualitatively different processes when asked to generate predictions about that observed action. Observers who have experience actually performing the observed action generate predictions by internally replicating the actual observed action, possibly through reactivating motor representations laid down by earlier performance. Observers without this experience, however, engage general purpose predictive mechanisms that do not necessarily replicate the actual action nor the fine-grained details of the observed action. Furthermore, when stimulus dynamics are held constant, only experienced observers are able to take advantage of action-related information (information about the limbs and joints used to produce the action) while this action-related information has no influence on the predictions generated by naïve observes. Thus, the findings of this study show not only *that* motor experience changes action prediction but also *how* motor experience changes the operation of these predictive processes.

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