Skill and Expertise in Joint Action

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Abstract

Many highly skilled actions require people to act together in order to achieve a common goal. From team sports, to orchestras, group dances, and high-risk joint actions such as surgery, joint actions are an integral feature of many domains of expertise. In this chapter we describe the coordination mechanisms that underpin skilled joint actions and we explore how these mechanisms reflect domain general principles of joint action performance that can apply not only to highly skilled actions but also to more everyday joint actions. These mechanisms allow individuals to facilitate coordination by making specific modulations to their own actions, by predicting others' actions, and by planning and monitoring joint rather than individual actions. Experts' superior ability to coordinate on skilled actions compared with novices is due to their ability to refine these domain-general mechanisms to task-specific problems. We draw on studies from cognitive psychology and cognitive neuroscience that show that coordination is a skill in its own right and highlight the role of visual and motor experience in the flexible use of these domain general mechanisms. Finally, we discuss the role of context in joint actions, focusing on how the same mechanisms can work very differently under competitive and cooperative contexts. We also outline some open questions relating to how experts such as players in competitive team sports manage to use such context-sensitive flexibility effectively in skilled joint actions.

Introduction

Developing an individual skill is a daunting undertaking. Take learning a musical instrument: when a person first picks up a guitar, she must learn the basic motor actions that will produce prescribed chords, how each string is supposed to sound and be tuned, and her own motoric constraints of what kinds of chords she can produce and the speed with which she can transition. Only then can she progress to adapting these to suit her own needs. Now imagine the guitarist wants to learn guitar so that she can play as part of a band, and this individual skill must transition to a joint skill where, in addition to learning the guitar she must also contend with the performance of her bandmates. Now, as well as producing her own music she must also anticipate and adapt to production features that are outside of her control.

This chapter focuses on two questions related to skilled joint action. The first question is what are the mechanisms that allow people to perform skilled joint actions. The second question is how context affects skilled joint action, such as whether coordination occurs in the course of a cooperative or competitive interaction. In addressing these questions, we draw on studies from a wide range of skilled joint actions, including music, sports, and dance, as well as on more basic coordination tasks designed to investigate fundamental mechanisms of coordination. While acquiring specific joint actions—like dancing tango or playing in a string quartet—may entail challenges that are unique to a specific domain, there are also general principles of skilled joint action performance. Such principles can not only be derived from studies on "experts" who have been trained to perform joint actions in particular domains; rather, any typical human being can to some extent be considered a joint action expert, given our life-long engagement in joint actions such as handshakes, object transfers, and conversations.

Mechanisms in Skilled Joint Action

When performing a joint action, coordinating with other individuals is vital. In this section we introduce and describe empirical evidence of coordination processes and mechanisms that expert actors can rely on to facilitate the performance of skilled joint actions: strategic action modulations, joint action planning and monitoring, and action prediction.

Strategies of action modulation

Making oneself predictable. Several studies have shown that when people are instructed to synchronise their actions with a partner, their actions become less variable than when they act alone (Vesper et al., 2016, 2011). In particular, by increasing the speed of their actions, interaction partners reduce their temporal variability. Furthermore, they may choose trajectories and velocities that are easy to predict. In a study of joint improvisation, Hart et al. (2014) asked participants to synchronise their actions in a simplified version of the mirror game, an exercise from improvisational theatre that requires two people to perform the same actions at the same time without knowing what their partner will do next. They found that experienced improvisers systematically modulated the velocity profile of their movements in order to achieve synchrony with their partner, considerably deviating from their way of moving individually. These adjustments were interpreted as attempts to make themselves more predictable for their partner, thereby facilitating coordination. On the one hand, the strategy of making one's actions less variable and more predictable appears to be very basic, as it can be found in simple coordination tasks that do not require specific training and has even been reported in macaque monkeys (Visco-Comandini et al., 2015). On the other hand, for specific skilled joint actions, such as joint improvisation in the mirror game, considerable training may be necessary in order to learn how to make one's actions more predictable.

Ancillary Movements. Head and instrument movements in musicians that are not directly linked to music production but are an integral part of musical performance are examples of ancillary movements (as opposed to instrumental movements that are necessary to produce a sound; Nusseck and Wanderley, 2009). For example, ancillary gestures are related to musical expression in clarinet players, as they use more frequent and variable ancillary movements when asked to play expressively than when asked to play inexpressively (Palmer et al., 2009; Wanderley, 2001; Wanderley et al., 2005). The question then is how and whether these gestures of musical expression occur differently in a context where music is produced as part of an ensemble; whether musicians maintain their own rhythm of gestures, whether they copy others' gestures, or whether they use ancillary gestures strategically to coordinate.

Coordination of ancillary movements in music production can serve to maximise predictability of different expert players in an ensemble, without necessarily sacrificing their expressivity. Glowinski et al. (2013) asked professional and student violinists to play five pieces of music on their own and as part of a quartet while they monitored players’ head movements using motion capture. They found that, while the violinists produced task-irrelevant head movements in all playing conditions, these movements were significantly more regular when they were playing as part of their ensemble compared with when they were playing a solo. Given that increasing regularity and decreasing variability can facilitate coordination (Vesper et al., 2016, 2011), this is to be expected. According to Palmer et al. (2009), who found that lower variability of movement related to lower ratings of expressivity in music production, we might also expect that these coordinative ensemble productions would be judged as less expressive. However, when Glowinski et al. showed videos of the performances to both non-expert and expert violinists, more regular head movements were not rated as any less expressive. Rather, observers could tell if the production was a solo or ensemble performance based on the violinists’ head movements – and this judgement accuracy was related to expertise: professional violinists found it easier than novices to tell whether head movements came from an ensemble performance.

Importantly, the collaborative function of ancillary movements can be used strategically to adapt to adverse conditions. If auditory feedback during joint music making is noisy or absent, pianists make efforts to adjust according to the available information (Goebl and Palmer, 2009). They try to compensate for reductions in auditory feedback through increased synchrony of postural swaying and other physical movements that can serve as visual signals to timing (ibid). This suggests that in adverse conditions players can establish a common understanding of timing using ancillary movements.

Controlling Entrainment. In physical terms, entrainment is the process by which oscillating systems assume the same period in time. In psychological terms it means much the same: entrainment of behaviour refers to the process by which two or more individuals producing regular patterns of behaviour fall into the same rhythm. For example, two people walking side by side along a quiet street will typically fall into a rhythm of footsteps, either in-phase (both left feet forwards at the same time) or anti-phase (one person’s left foot forward at the same time as the other person’s right foot). Entrainment is considered as an emergent, non-strategic phenomenon that is the result of strong automatic coupling between action and perception (Schmidt and Richardson, 2008).

Entrainment has been proposed as a key component of everyday skills such as turn-taking in speech (Cummins, 2009). There is also evidence that entrainment increases attention to an interaction, which can improve subsequent memory for features unrelated to the entrained behaviour (Macrae et al., 2008), and can increase participants' sense of social affiliation with the coupled entrainment partner (Hove and Risen, 2009). In the context of skilled joint action two questions arise: whether experts entrain differently from novices, and whether they differ in terms of their experience of the social and cognitive consequences of entrainment.

There is surprisingly little research that examines entrainment as an emergent property in experts. Interestingly, some instances of expert behaviour, such as running, require resistance to entrainment (Blikslager and de Poel, 2017; but cf. Varlet and Richardson, 2015). This is a particularly difficult task, as there is a natural tendency to fall into a rhythm with other people even when trying to maintain one's own unique rhythm. Participants entrain to another's rhythm if they are visually coupled despite having been told to maintain their own preferred rhythm and in light of different ecological constraints (Richardson et al., 2007b; Schmidt and O'Brien, 1997) and they maintain this entrained rhythm even when visual information about the other is removed (Oullier et al., 2008). However, there are instances of joint skilled behaviour, such as dancing or ensemble music playing, where one must avoid entraining to a partner's (or partners') rhythms in order to produce one's own part. As such, expert dancers or musicians should be better able to resist entrainment than the novices tested in these studies.

To test this experimentally, Sofanidis, Elliott, Wing and Hatzitaki (2014) asked expert Greek dancers – who are skilled at dancing to music in haptically connected groups of dancers – and novice dancers to close their eyes and sway their bodies according to a metronome they heard over headphones. Participants swayed while they either touched fingers with a partner next to them who was doing the same task, or they stood independently. Crucially, the two partners were always guided by different metronome speeds, such that while one would be tasked with swaying fast the other would sway slowly. They found that while novice dancers were likely to show interference from their partner's rhythm when they were touching each other, experts showed little interference from the partner and matched to the rhythm of the metronome. This shows that entrainment in expert joint action can be selectively inhibited. It suggests that one crucial aspect of expertise in joint action is the ability to strategically suppress otherwise automatically processed information from a partner or partners.

This can also be seen in contexts where synchronisation within a group is desired, but entrainment with other groups is not. Take the Congado, an Afro-Brazilian religious tradition where teams of musicians all play at the same time in the same place and all try to maintain a unique rhythm within their own group while not entraining to other groups around them. Resisting the natural tendency to synchronise with other groups is used to demonstrate the cohesive identity of one's own group, as well as one's own group's musical competence (Lucas et al., 2011).

More generally, strategically adapting to specific sources and resisting entrainment with others may constitute a hallmark of joint action expertise. To illustrate, consider team rowers who face a particular challenge when deciding how to use available environmental information. In a two-person row team, both rowers face the same way, which means that one rower has access to more visual information than the other as they can see their partner's movements. As such, one strategy the second rower might use would be to couple their actions to the rhythm and movement of the visually disadvantaged rower, taking into account their environmental constraints. However, a study of Olympic and World Championship rowers found that rather than focus on this feature, rowers who could see their partner instead coupled themselves to the invariant haptic signals from the boat, and the perception of water passing (Millar et al., 2013). That is, rather than couple themselves to the primary coordination target (their teammate) they instead coupled to the environmental features that they knew their target would use in order to improve coordination.

Finally, it should be noted that music novices are also able to adjust their coordination strategies to different contexts (Honisch et al., 2016). It remains to be seen how experts' ability to use these timing strategies directly compares with that of novices.

Action prediction

Joint actions rely not only on modulating one's own actions: it is important to be able to read and anticipate the actions of others. Expert action perception is therefore a crucial component of skilled joint action.

Expert tennis players, for example, are faster to respond to their opponents' strokes than are novices, and there is evidence that this is related, at least in part, to more effective visual search strategies (Williams et al., 2002). This relationship appears to be causal: when recreational players are trained to use the same visual search strategy that experts use, their tennis performance improves more than if they are instructed with a placebo strategy.

There has been a growing body of research aiming at identifying the underlying structure of expert advantage in action perception. Expert dancers are able to identify dance moves in an upright configuration even when these sequences have been reduced to point-light displays (the videos only show a series of white dots that correspond to landmarks at various joints on the body, while all other perceptual information is removed; Calvo-Merino et al., 2010). When the same dance moves are shown in an inverted configuration, experts perform as poorly as novices. This indicates that experts use a configural processing strategy to process the kinematic information in these low-information displays. Similar results with badminton players have shown that experts can pick up kinematic cues from point light displays even from only short segments of the action (Abernethy and Zawi, 2007) and that experts perform similarly to point-light displays as they do for full videos, indicating that these configural kinematic features are sufficient to explain the expert advantage in this particular task (Abernethy et al., 2008).

Perceptual and motor expertise are fundamentally linked. Action observation often recruits relevant motor systems (Cross et al., 2009), and motor experience plays a key role in perceptual expertise. Elite basketball players are better at predicting the success of observed free-throws than people with comparable visual experience such as their coaches or sports journalists, and this appears to be related to specific motor activation during action observation (Aglioti et al., 2008). In novices even short periods of blindfolded motor learning can enhance later perceptual judgements (Casile and Giese, 2006; Hecht et al., 2001).

This perceptual expertise in experts is also highly specific to the nature of actors' action repertoire. For example, expert cricketers are better than novices at predicting the direction of a bowled ball and moving to meet it, and they show this advantage even before the ball has left the bowler's hand. However, a study found that this expert advantage was significantly more prominent when experts made physical movements to intercept the ball, and this was even greater when they held a cricket bat in their hands. Although the visual information was the same, the context of holding a cricket bat improved experts' accuracy in anticipating the direction of an incoming bowl even when the only visual information came from the bowler's actions up until the point of ball release (Mann et al., 2010). Other studies have found that in long-term experts many of these neural responses are stronger for dancers' own school of dance compared with a different school (e.g. ballet vs. capoeira; Calvo-Merino et al., 2004). There is also some evidence that female experts are better than male experts at matching point-light upright dance sequences modelled by female dancers even when all models and observers come from the same school (Calvo-Merino et al., 2010). This could suggest that the specificity of this action simulation is greater even within established roles from the same school of dance.

The studies discussed above provide support for action simulation– that is, experts recruit both action perception and production mechanisms during action observation to simulate and anticipate the observed action, which allows for more efficient action understanding and prediction. In doing so, they rely on so-called internal forward models in the motor system that are used both for predicting the outcomes of one's own actions and the outcomes of others' actions (Wolpert et al., 2003). Accordingly, greater similarity between the system making the predictions and the system to be predicted improves prediction and ultimately coordination. In an experiment with skilled pianists, Keller, Knoblich and Repp (2007) asked participants to perform one half (that is, one hand's part) of a piece along with a pre-recording of the other half that either the participant themselves or one of the other participants had played. They found that participants achieved better temporal coordination when playing duets with their own recordings than with others' recordings. Furthermore, participants who were better at identifying their own idiosyncrasies from the recordings (see also Repp and Knoblich, 2004) showed a greater self-synchronisation advantage than those who could not recognise their own playing. A follow-up study by Loehr and Palmer (2011) found that this extended beyond playing duets with one's own recordings – the degree of a priori similarity between performers playing together affected their success of achieving temporal coordination. Such findings suggest that during duet or ensemble performances musicians internally simulate the actions of other musicians, and that similarity of personal idiosyncrasies can aid this simulation.

Skilled joint action performance may particularly benefit from predictions that are not only made by one interaction partner about the other, but by reciprocal, coupled predictions. This idea was put forward by Noy and colleagues based on findings from an experimental version of the mirror game (Noy et al., 2011). They found that expert performance was marked by stretches of time during which both interaction partners moved smoothly in synchrony without one of them leading and the other following. According to their model, engaging in this “co-confident” motion hinges on predictive internal models in the motor system that are coupled so that the output of one controller is the input for the other.

Joint action planning and monitoring

Planning. When planning a joint action, co-actors must consider the affordances and limitations of their co-actors, which allows for sophisticated coordination and distribution of tasks (Richardson et al., 2007a). Studies examining the mechanics of how people represent others’ affordances and limitations in a joint action task are limited, but evidence with transcranial magnetic stimulation (TMS) has shown that the size of motor evoked potentials (MEPs; a measure of motor excitability) to objects depend on how accessible the objects are to the participant: MEPs are stronger to objects that the participant can act upon than to those that are out of reach (Cardellicchio et al., 2011). Interestingly, enhanced MEPs can also be elicited when the object is out of participant’s reach if they are within reach of another agent (Cardellicchio et al., 2013), suggesting that participants spontaneously accommodate another’s affordances during object processing.

As well as accommodating the joint action partner’s affordances, one must also consider their action constraints. That is, it is not enough to consider whether a partner *can* act, but how costly their action would be relative to one’s own, and how that might affect the joint outcome. Experimental evidence shows that people do take the difficulty of another person’s task into account when they attempt to coordinate. Vesper, van der Wel, Knoblich and Sebanz (2013) instructed participants to make coordinated forward jumps – each participant had a different distance to jump forward onto a target plate, and their task was to land at the same time. While they could not see or hear their partner, participants knew how far their partner had to jump, as well as how far they themselves had to jump. They found that participants distributed the coordination effort according to the task difficulty, such that those with the easier task (a shorter distance to jump) made more adjustments to coordinate with the partner who had the more demanding task. Further evidence suggests that this asymmetry in adjustment is not just a result of a general slowing down on the part of the person with an easier task – in an experiment where participants had to move objects between two sites with an aim to landing at the end point at the same time, unobstructed participants adjusted their movement profiles if their partner had to move around an obstruction (Schmitz et al., 2017). These adjustments were not just a result of slowing down; these participants moved as though they were also moving around an obstacle, indicating that they were not just representing coarse information but specifically representing the nature of the obstacle.

Electrophysiological evidence shows that participants plan not only their own actions, but also include a task partner's actions in their planning. Kourtis, Knoblich and Sebanz (2013) studied this by providing participants with an instruction cue (a symbol representing the type of action they were about to perform) followed one second later by a 'go' or imperative stimulus that indicated that they should start to perform the action. This gave a 1,000ms window where participants had to plan the action they were about to perform, during which electroencephalography (EEG) was recorded on both participants. The cues either informed participants that they would perform an individual action – grasping an object, raising it off the table, then returning it to the starting position – a joint passing action – grasping the object and then passing it to the other person on the other side of the table – or a joint receiving action – taking the object as it was passed to them by their partner.

Kourtis et al. found that planning to perform the joint action reduced the magnitude of the right lateral-P3b component, a component that reacts strongly to information related to processing of group-relevant information. The fact that this component was smaller in the joint action conditions indicates that participants evaluated the instruction cue in terms of relevance for the group (themselves and their partner) rather than just to themselves. The right lateral P3b component is thought to arise in the temporoparietal junction (TPJ), an area of the brain associated with mentalising. This suggests that participants did not just represent what they had to do but also what their partner would have to do.

To investigate how similar the planning of one's own and another's actions is, a later EEG study compared unimanual actions (lifting a cup from a table), bimanual actions (lifting two cups and touching them together), and joint actions (two people lifting cups and touching them together, as people do when toasting) while EEG was recorded from one participant (Kourtis et al., 2014). They found that the contingent negative variation (CNV; a slow potential that reflects time-based motor preparation) was not only larger during joint action planning than during individual action, but just as large when planning a joint action as when planning a bimanual action. This suggests that participants planned their own action together with the other's action, much in the same way as planning a coordinated action with their two hands.

Behavioural evidence also shows that, even as novices, participants represent their partners' actions in an effort to achieve a joint goal. Piano novices were asked to perform simple melodies, either individually or as a duet (Loehr and Vesper, 2016). They then reproduced the melodies in a test block, either with or without accompaniment. If, during learning, participants approach a joint task with an individual mind-set – that is, a focus on producing their own melody regardless of what their partner does – then participants should perform best in the absence of any shared feedback as they can focus on their own melody without interference. However, if even novices represent the shared goal of the duet, then they should perform better when playing with an accompaniment and experiencing the full duet. Loehr and Vesper found that participants did indeed represent the joint goal, and that this was specific to when they played a duet with another person – the same results were not found for computer-generated accompaniments. This suggests that even from an early stage of proficiency, efficiently achieving joint goals relies on practicing and learning within a joint context, and that representing the other's task is a key feature of successful joint action.

However, to represent another's task in the same way as one's own is not always conducive to joint action. If two people are playing a duet, one player cannot allow their duet partner's melody to interfere with their own or the necessary complementarity of the two productions would be lost. Novembre, Ticini, Schütz-Bosbach, and Keller (2012) had musicians play the right hand part of a piano piece that they had learned to play bimanually, either alone or listening to another person play the left hand accompaniment. While they played, the experimenters applied TMS and measured MEPs in the left hand (the resting hand) to see if corticospinal excitability associated with action representations of the left hand part differed as a result of whether the musician played alone (an individual context where they have to inhibit the known left-hand part in order to produce the right-hand part) or as part of a duet (where someone else is playing the left-hand part and so the left hand becomes associated with the other person). They found stronger MEPs in the joint condition, when the left-hand accompaniment was associated with the other, than in the individual condition where it was associated with the self. Importantly, the same results were found in a control condition where the participants could not hear the other player but still believed that they were playing the accompaniment. In a self-relevant condition, where the participant is the only player, the un-played accompaniment must be inhibited to avoid interfering with the right-hand melody. However, participants do not appear to exert the same inhibition in a joint task where the action has been assigned to the partner.

Many of the tasks used in laboratory joint action studies are very simple motor tasks designed to examine specific mechanisms. But these are not necessarily comparable to highly skilled – and often highly idiosyncratic – expert behaviours. Our own base motor expertise in, for example, clinking glasses in a toast (Kourtis et al., 2014) allows us to make accurate predictions about a partner's movements without ever having toasted with a particular partner before. However, experts must often form much more specialised and temporally fine-grained predictions about their co-actors' movements in order to achieve optimal performance, such as musicians playing in an orchestra or football players anticipating each other's running paths. As such, it is necessary not only to know what another is going to do, but also *how* they are going to do it and what sort of idiosyncrasies characterise their playing style. Greater familiarity with a duet partner's part but no experience with actually playing with that partner leads to more asynchronies and poorer coordination, and these asynchronies are driven in part by each individual's own playing style (Ragert et al., 2013). Experts in domains such as music, therefore, must develop fine-grained action predictions and plans that are tailored to the individuals and context with which they perform those joint actions.

Monitoring. As a joint action requires the input of more than one individual to achieve a joint goal, it is not sufficient to represent what another *could* do. It is also necessary to monitor what that person *does*, particularly with regards to any errors made, so that one can adjust one's own behaviour or prepare for any costs incurred. Loehr et al. (2013) used EEG to study error monitoring in pianists playing a series of chords in a duet. On some trials, either the participant's or the partner's keyboard was programmed to play the wrong note resulting in an error that either affected the overall harmony of the combined chords (the joint outcome) or only affected the individual harmony (individual outcome). While they showed that feedback-related negativity (FRN; an ERP component that emerges early, around 200ms following an error) reflected a similar response to all errors regardless of who produced them, a later positive potential known as the P300 showed evidence of specific action monitoring with a stronger response to a partner's errors that affected the joint outcome than to errors that affected only the individual outcome. As such, while earlier, low-level monitoring of errors appears to monitor all errors equally, later processes then show sensitivity not only to the source (self vs. other) but to the significance of the error (affecting only one person's outcome vs. affecting the joint outcome).

There is evidence that participants represent others' errors in a similar way to their own. In reaction time studies, there is a well-established phenomenon where participants slow down on trials immediately following an error they made. During joint tasks, where participants are asked to perform different tasks simultaneously, participants also show post-error slowing in response to observed errors (De Bruijn et al., 2012; Schuch and Tipper, 2007). This adds to a series of studies that show similar results from neuroimaging, indicating that others' errors are also represented in a similar way to one's own at the neural level (Bates et al., 2005; de Bruijn and von Rhein, 2012; Kang et al., 2010; Picton et al., 2012).

Allowing others' errors to impact one's own performance can be costly in skilled joint action, as such monitoring makes demands of limited cognitive resources. However, evidence that participants are prone to post-error slowing suggests that monitoring others' errors encourages people to slow down and approach tasks more cautiously. This means that others' errors may serve as cues to or reminders of task difficulty. In addition to that, in contexts where the joint outcome is prioritised over the individual goal, such as in music, dance, or high-risk joint actions such as surgery, it would make sense for experts to treat any error as their own in order to be better able to adapt to and compensate for it.

Action Contexts: Cooperation vs. Competition

So far this chapter has discussed joint action largely from the perspective of it being an inherently cooperative endeavour. That is, individuals share a goal and coordinate their actions in time and space to achieve that goal together. While many accounts of joint action in philosophy (e.g., Bratman, 1992) and communication (e.g. Clark, 1996, see p.61) exclude competitive interactions from definitions of joint actions we believe it can be useful to include them: competition involves some of the same coordination mechanisms described so far, such as strategic modulations of action, resisting entrainment, action prediction, monitoring, and co-representation (Ruys and Aarts, 2010).

This is not to say that all of the processes involved in cooperation and competition are the same, however. For example, different action contexts lead to reliance on different aspects of perceptual information about others' actions. Streuber et al. (2011) invited participants to play either competitive (standard rules) or cooperative table tennis games (instructed to pass the ball back and forth as many times as possible) in a dark room with glowing markers attached to the players' bodies or paddles – creating a live impression of a point-light display. They found that being able to see the movements of one's own body improved participants' performance regardless of context. However, participants benefited in the cooperative condition if they could see the other's racket movements, whereas in the competitive condition they benefited if they could see the other's body movements. The authors interpret this as suggesting that action prediction (which relies on being able to see the opponent's body movements) is more important in competitive than cooperative actions. Given that predictability is a key feature of cooperative joint action, where efforts are taken to minimise any unexpected or unanticipated behaviours (Glover and Dixon, 2017; Issartel et al., 2017), the inverse must be true for competition in that a player must do their best to minimise predictability for an opponent, and the opponent is by extension driven to form predictions on the basis of subtle behavioural changes.

Knowing that an opponent is monitoring one's behaviour in order to predict future behaviour can be an advantage. An often-used competitive strategy is to disguise one's true intentions by deliberately providing misleading cues. Basketball players often feint when passing using gaze misdirection, and this kind of misleading gaze cue is difficult to inhibit, and so serves as a powerful deceptive cue. However, evidence also shows that experts are better able to resist these misleading gaze cues than are novice players, and that this is specific to participants' experience – basketball players are able to inhibit their response to misleading gaze cues following a previous basketball feint, but football players (who are skilled athletes but without the same domain-specific expertise) and non-athletes could not (Weigelt et al., 2016).

In addition to action prediction, other aspects of joint action differ between cooperation and competition. One example is error monitoring. While there is evidence that others' actions are treated in a similar way to one's own and that this can result in similar electrophysiological responses to errors (de Bruijn and von Rhein, 2012) and behavioural adjustments (De Bruijn et al., 2012; Schuch and Tipper, 2007), there is also evidence that treating others' errors as one's own is sensitive to the context of these errors. One's own error is typically a negative and potentially costly event, and in a cooperative context a partner's errors can be seen as also negative for the self. However, in a competitive context an opponent's errors can be a rewarding or positive event, as these create the opportunity for exploitation, and a growing body of research suggests that others' errors are represented differently at a neural level depending on whether they occur in a competitive or cooperative context (De Bruijn et al., 2009; Koban et al., 2010).

An outstanding question with regards to skilled joint action in competitive contexts is the role of teams. In the laboratory, many studies investigate competition and cooperation in isolation. This means that the role of the team, a crucial element of many competitive skilled actions, is often ignored. In sports such as football, rugby, or basketball, each player must strike up a balance within themselves in terms of communication and coordination. Given that skilled team players must cooperate with their own team (e.g. by making their actions more predictable) and compete with the opposing team (making themselves *less* predictable), how do they deal with these competing demands? Furthermore, there is the question of joint skill learning. While there is some limited research looking at how joint skills can be learned, there is little theoretical or empirical consideration of how competitive team players (e.g. football or rugby players) acquire this ability to balance cooperative and competitive motivations. This kind of cognitive juggling act that skilled players perform between the conflicting motivations of cooperation and competition offers a rich avenue for future research.

Conclusion

At first glance, skilled joint actions can appear to be largely by-products of skilled individual actions. In this view, skilled joint actions simply rely on developing an individual skill and then applying it to a joint context. However, true joint skill cannot be acquired individually. Good coordination with others is a skill in its own right, and one that is highly specific to particular action contexts. Skilled joint actors are not only good at producing task-relevant action features and adapting their behaviour to accommodate their interaction partners, but they can also use incidental or emergent behaviours strategically to communicate context and intention to other actors.

As well as showing expert advantage in action production, expertise also leads to benefits in action prediction and perception, and these are closely linked with motor expertise. That is, even with comparable visual experience, one cannot acquire the same expert advantage in action perception without motor experience.

With regards to action planning and error monitoring, there is little evidence for large qualitative differences between experts and novices. Indeed, novices are able to represent joint goals, plan joint actions, and monitor both their own and others' errors while also processing the source and significance of those errors. The key difference may not be in the mechanisms that experts use but in the resolution at which they apply them – creating much more temporally and spatially tuned predictions than novices that rely on an established interaction history.

The context of a particular action is a critical element of how skill emerges: cooperative and competitive actions make use of different action parameters and features. This applies not only to action production – where skilled actors must maximise predictability for co-operators while minimising predictability for competitors – but also action perception, where competitors' deceptive or misleading behaviours must be accurately identified and compensated for. The role of expertise in maintaining these conflicting motivations, and how this is acquired through learning and training, remains to be seen.

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