The Role of Action Planning and Control within Joint Action

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Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Psychology

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Declaration of Authorship

I, Afshin Aheadi, hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Signed: ______________________________

Date: _______________________________

Abstract

Past work on joint action has shown that the performance of joint action improves when individuals within a pair behave using a predictable strategy. The present study sought to examine the effects of manipulating task demands on joint action planning strategies and online control. Participant pairs performed a joint task in which a Passer passed an object to a Receiver, who had to place it in a target area in a pre-determined orientation.

Seven experiments varied the demands, constraints, and roles involved in each participants' task. Experiment 1, which served as a control for the following experiments, examined the basic action planning formation amongst two individuals. Experiment 2 and 3 applied an artificial impairment in a predictable and unpredictable manner, respectively, to one of the participants to examine its effect on strategy formation relative to action planning and control. In Experiment 4 the effects of gaze cue was examined, whilst Experiment 5 increased task difficulty through the insertion of an added precision task. Experiment 6 examined the role of imitation and adopting a partner's role during joint cooperation by swapping roles during the object passing task. Experiment 7 increased movement complexity through the application of a cube that could be rotated in 3 dimensions.

Overall, it was observed that Passers were inclined to rotate the object prior to handing it to the Receiver, thereby accommodating the latter's affordances. When task demands were varied within a session, Passer's adopted highly consistent strategies across conditions. When roles were reversed halfway through the session, participants generally behaved as their partner had in the first block. Taken in sum,

these results suggest that planning a joint action is influenced by a partner’s task and the overall action goal, with predictability being an important component of strategy formation.

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The Extent of my Personal Contribution

In accordance with the requirements of the University of London, the extent of my personal contribution to the work in this thesis is specified as follows.

I was offered the Royal Holloway College Research Scholarship. My supervisor was Dr. Scott Glover and my advisor was Dr. John Wann. I made major contributions in the design, data collection and data analysis of all the experimental work reported in the present thesis.

This thesis is entirely my own original work and no other person should be held accountable for its contents.

Afshin Aheadi

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1. Joint Action

Introduction

The study of joint action has received extensive interest and become increasingly popular over the years (e.g. Gonzalez, Studenka, Glazebrook & Lyons, 2011; Harrison & Richardson, 2009; Huber, Knoll, Brandt & Glasauer, 2009; Kourtis, Sebanz & Knoblich, 2010; Obhi & Sebanz, 2011; Reed, Peshkin, Hartmann, Grabowecky, Patton & Vishton, 2006; Tsai, Sebanz & Knoblich, 2011; Vesper, van der Wel, Knoblich, & Sebanz, 2011). Joint action refers to the ability of a number of agents executing mutually dependent actions to achieve a common a goal. Examples of joint action include day to day activities, such as lifting heavy objects, dancing together or performing a musical duet. In order for two agents to successfully complete a joint task, they not only have to process the relevant visuospatial cues used to plan and control their own actions in space and time, but also similar cues that provide information about the movements of their partner, and social cues as to the partner's mental states and goals, and incorporate all of these within their own action planning (Knoblich & Jordan, 2003).

Recent work in the area of joint action has expanded greatly (Chartrand & Bargh, 1999; Georgiou, Becchio, Glover & Castiello, 2007; Glover & Dixon, 2012; Knoblich & Flach, 2001, 2003; Knoblich & Jordan, 2003; Sebanz, Knoblich & Prinz, 2003, 2005). Advances in theory and technology make this an enterprising endeavour, and the need for work that can help synthesise knowledge in areas as diverse as social cognition and motor control is an important motivator for the present work.

Although much has been learned from recent studies, little research has been conducted on pre-movement planning and online control (Glover, 2004) or the end-state comfort effect (Gonzalez et al., 2011; Rosenbaum, Marchak, Barnes, Vaughan, Slotta & Jorgensen, 1990; Weigelt, Kunde & Prinz, 2006) in joint action, despite these being two fundamental principles of motor control (Jeannerod, 1988; Rosenbaum, 1991). Before a movement is initialised, the relatively slow process of action planning incorporates a broad array of perceptual and cognitive information in order to select and start an appropriate motor programme. Predictability of a partner's movement and action provides an important foundation to the planning strategy within joint action. Being predictable enables participants to precisely plan their actions in accordance to the observed behaviour of their partner, thus decreasing any spatiotemporal variability that could potentially lead to erroneous movements and result in the application of online control. It is during movement execution that fast online control processes are applied to minimise any spatial error of the movement through the use of perceptual feedback. Furthermore, most previous studies have focused on indirect interactions such as button pressing tasks wherein the actors do not physically interact in space (Sebanz et al., 2003; 2005) with only few examining direct manual interactions between participants (Gonzalez et al., 2011; Knoblich & Sebanz, 2008).

The present study investigated these issues and more by using a joint passing and placing task that varied the task constraints using mechanical perturbations, increasing precision tasks, role swapping and more complex rotations of the object. The aim of the thesis was to examine the application of action planning and control within a joint action. Action planning and control would presumably function in a similar manner as that observed in single individual studies, however the demands on each system would be multiplied by the need to integrate one's own actions with those of a co-actor. During planning, this requires incorporating additional levels of information, such as the need to represent the partner's physical capabilities in terms of optimal strategies and action possibilities. During online control, on the other hand, in addition to correcting for any spatial error in one's own movement plan, there is the further need to adjust quickly to the spatiotemporal characteristics of a partner's actions. This will by nature vary to at least some extent over subsequent executions of the same general movement, thus predictability is considered to play a vital role within joint action. As compared to interacting with an inanimate target, planning and controlling an action with a cooperating partner poses significant additional challenges to the motor system. Understanding how the motor system deals with these challenges in planning and controlling action is the focus of the present study in addition to examining how a partner's end-state comfort and varying task requirements would affect the strategic planning and online control of joint actions.

This chapter will begin by discussing past work on joint actions. Ensuing sections will cover the planning/control distinction and end-state comfort effect, and how these might be applied to joint actions. The chapter will conclude with a detailed overview of the present studies.

Joint action

A number of principles of joint action have been uncovered to date, which the present thesis classifies under four main headings: 1) Action representations; 2) Joint strategy formation; 3) Unconscious synchronisation; 4) Temporal synchronisation; and 5) Spatial coordination. Whereas many of these principles have been generalised from studies of individuals acting alone (such as temporal synchronisation and spatial coordination), others are novel and unique to actions involving multiple participants, including joint strategy formation.

1) Action Representation

It has long been known that the mind is able to distinguish between the self and the other, and to represent actions (e.g., Decety, Perani, Jeannerod, Bettinardi, Tadary, Woods, Mazziotta & Fazio, 1994; Jeannerod, 1988; Knoblich & Sebanz, 2006; Kourtis et al., 2010; Sebanz et al. 2003; 2005). Under normal circumstances, each of us is generally aware of when we are the agent of an action versus when another person is carrying it out. A recent addition to this area of study is the assertion that humans can also form joint action representations.

Joint Representations

Sebanz et al. (2003) provided initial evidence for joint representations in action. They compared performance of individuals and pairs across three different conditions involving stimulus-response compatibility (the "Simon Effect" - e.g., Dutta & Proctor, 1992; Heyes & Ray, 2004; Whitaker, 1982). They asked participants to observe a coloured ring on an index finger that was either pointing to the left or the right, and participants had to respond with either a left or right button press for either colour, while ignoring the irrelevant spatial information.

In the two-choice condition, a single individual had to respond to both colours (red and green) with a left or right button press. A standard spatial compatibility effect was observed, whereby participants were influenced by the irrelevant spatial information and were faster when the irrelevant spatial information corresponded to the location of the response. Conversely, responses were slower when the irrelevant spatial information was spatially incompatible with the response. In the joint go/nogo condition, the task was distributed amongst two individuals and each participant was responsible for either the left or right button press. Similar findings were observed in this condition. Participants were affected by the irrelevant spatial stimulus although they were asked to ignore it. In the individual go/nogo condition, a single individual was responsible for only one colour by responding with a single button press, whilst nobody else was responding to the second colour. Surprisingly no spatial compatibility effect was found in this condition.

If no spatial compatibility effect was observed in the individual go/nogo scenario, then why was a spatial compatibility effect observed in the joint go-nogo condition? The results seem to suggest that people form a representation of their partner's task and actions which affect their own actions. Individuals involuntarily integrate the task of a cooperating partner within their own action planning and consider them as an extended version of themselves.

Sebanz et al. (2005) extended the above study by assigning the two participants different task requirements. Just as in Sebanz et al. (2003), two individuals worked alongside each other. However in this case they had to respond to different features of the same stimuli. One person was responsible for the colour, whilst the other only responded to the direction of the stimuli. Interestingly participants had slower reaction times on trials that created task conflicts, in which a stimulus required a response from both participants at the same time, thus people form a shared task representation even when the task requirements varied from that of their own. Performances on both the colour and direction task were influenced by their cooperating partner's task leading to a hindrance in self-performance.

A shortcoming of the Simon task is that is cannot identify whether the interference (delay in reaction time) occurred as a result of action or task co-representation. Atmaca, Sebanz & Knoblich (2011) introduced a variation of Sebanz et al. (2003) study using the Eriksen flanker task. The Eriksen flanker task involves a central target letter stimulus that is surrounded by distracter letters that are identical to the target letter (compatible trials) or surrounded by opposite response targets (incompatible trials). For example, participants had to press a left key when the central target was H or K, and press a right key when the target was C or S.
Like Sebanz's (2003) study, their study also included three conditions: an individual binary choice condition, a joint single response go/nogo task and an individual condition. The results showed that when participants performed the task in the joint go/nogo task, their reaction times were much slower when the target letters were surrounded by target letters that required a response from their partner (incompatible trials) in comparison to compatible or neutral flankers. Furthermore, this flanker effect was much larger in the joint condition than the individual go/ nogo condition implying that the delay in reaction time may have occurred as a result of interference of the partner's task.

Wenke, Atmaca, Hollander, Liepelt, Baess & Prinz (2011) performed a variation of this task using colours instead of letters and obtained further supporting evidence that demonstrated a joint interference effect; when the target was flanked by the agent's own colours (intra-individual condition), their response was generally faster than when the target was flanked by their partner's colour (inter-individual condition). A possible explanation for this effect is that participants assigned the allocated colours with their own movement (task), whereas the other two colours were associated with the partner's task. However, simultaneously this implies that despite ignoring their partner’s task, participants involuntarily represented their partner’s task within their own action system, affecting their own performance.

Further concrete support for the notion of people forming a shared task representation and representing their partner’s action within their own action planning and execution comes from event related potentials (ERP) performed by Sebanz, Knoblich, Prinz and Wascher (2006). They measured the ERPs of individuals who performed the same spatial compatibility task either together with another participant or alone. As in the Sebanz et al. (2003) study, in the joint group condition each participant had to respond to one of the two assigned colours with either a left or right button press. In the second condition, only one person had to respond to their assigned colour with a single button press whilst the other partner merely sat beside them. The ERP’s were compared for the two conditions and Sebanz et al. (2006) observed a larger amount of activation in a specific electrophysiological component, the no-go P300, which specified strong inhibition. The no-go P300 amplitude was higher for the joint task condition as opposed to the single task condition, as a spatial compatibility effect was observed causing more interference during irrelevant spatially compatible trials. There was more inhibition when participants performed the same task with a partner, as opposed to performing the task alone. Thus the representation of the actions of others need to be suppressed when cooperating with a partner on a similar task. This further supports the notion that individuals consider a partner’s action and may even incorporate this within their own action planning even when asked to ignore other people’s tasks.

All of these studies suggest that we form a representation of our partner’s task and utilise this to plan our own actions. People plan their actions with their partner in mind, even when asked to ignore their partner’s task. An important question to consider is how does one share another person's task representation during joint action? One way might be through the integration of neural mechanisms for action representation and those used in self-other representation.

Self-Other Representations

Distinguishing between the self and the other in a joint action is invaluable. An actor can only plan and control their own movements, and it is their partner who they must represent, understand, and react to. Evidence for mechanisms used to apply this distinction is strong, and there is much to offer regarding how it affects individual behaviour.

Studies have shown that individuals are better able to recognise their own movements, handwriting, clapping and piano performances than that of others (Flach, Knoblich & Prinz, 2004; Gre`zes, Frith, & Passingham, 2004; Knoblich & Prinz, 2001; Loula, Prasad, Harber, & Shiffrar, 2005; Repp, 1987; Repp & Knoblich, 2004). Even under conditions when the piano performances were edited and altered in terms of tempo and loudness to make it less recognisable, individuals were still able to recognise their own performance (Repp & Knoblich, 2004).

Furthermore, it has been observed that activation of an action representation is higher when the observed action is similar to the way the observer would carry out the action. For example, Keller, Knoblich & Repp (2007) discovered that pianists played better when performing with themselves. Skilled pianists had to play and record assigned parts of a play and were then asked to play in duet with a slightly altered version of their own recording or that of others. The results showed that the pianists were not only able to recognise their own performance above chance level, but were much better at synchronising with their own performance.

Keller et al. (2007) explained this result as a consequence of individuals being able to distinguish self-generated actions from others by means of accessing their own action knowledge. Actions are internally simulated and the activation of action representation is determined by the extent of variance between the perceived and the executed action. And as actions are imagined as soon as an action is observed, they are more strongly simulated when self-generated or performed by others very similar to one self (Calvo-Merino, Glaser, Grezes, Passingham & Haggard, 2005; Knoblich & Flach, 2001). Functional magnetic resonance imaging (fMRI) studies have shown that there is strong activity in the premotor cortex, parietal areas and the superior temporal sulcus during action observations in humans (Grafton, Arbib, Fadiga & Rizzolatti, 1996). However is action observation tuned to a person's acquired motor repertoire? If this is the case, then we would expect stronger activation in those areas when people observe movements they are extremely familiar with.

Expert ballet and capoeira dancers watched videos of either ballet or capoeira movements, whilst non-expert dancers were used as a control group (Calvo-Merino et al., 2005). It was hypothesised that expert dancers would show stronger activation when observing the dance styles they were experienced with, whereas the non-experts would have shown similar activation for both kinds of dance movements. The results showed strong bilateral activation in the premotor cortex, intraparietal sulcus and superior temporal sulcus analogous to the expertise effect. When expert ballet dancers watched ballet movements, they demonstrated stronger activation than observing capoeira movements and vice-versa.

The non-expert dancers, on the other hand, showed a similar neural response to both dance movements. This suggests that although these movements are simulated by our own action system, particular brain activity occurs when viewing actions that we are familiar with. Thus action observation involves internal reproduction of the observed movement, as if we were to carry out the movement ourselves. Therefore, if we observe others perform similar movements to us, our brain is more likely to simulate those actions within our own action system, which can lead us to imitating the behaviours of others and alternatively lead us to establishing a greater liking for them (Chartrand & Bargh, 1999). For that reason it could be suggested that action observation is tuned to a person's acquired motor repertoire. Given that we have more motor expertise with human actions than robotic arms, this may also explain why previous studies have observed stronger mirror activation to the sight of human actions (Tai, Scherfler, Brooks, Sawamoto & Castiello, 2004).

Neural Bases for Joint Action Representation

Studies have shown that the brain is uniquely developed for the perception and representation of others' actions. Area F5, the ventral pre-motor cortex, of the macaque monkey contains neurons that are responsible for the imitation of certain movements, known as 'mirror neurons'. These neurons have been found to discharge when the monkey executed an action as well as when the monkey observed the same movement being performed by another monkey or the experimenter. Hence, these neurons 'mirror' the observed actions performed by another person (Di Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992; Murata, Fadiga, Fogassi, Gallese, Raos & Rizzolatti, 1997; Rizzolatti, Fadiga, Fogassi & Gallese, 1996).

Rizzolatti et al. (1996) presented monkeys with a tray of food; on some trials, the monkey would grasp a piece of the food from the tray or observe either the experimenter or another monkey grasp a piece of the food instead. Rizzolatti et al. (1996) discovered that the mirror neurons discharged both when the monkey executed a motor act and when it observed another individual (a human being or another monkey) perform the same motor act. However, these neurons did not discharge in response to the presentation of the food tray alone. Furthermore, these neurons did not discharge when the monkey observed the same action being mimicked in the absence of the target object. Therefore, these mirror neurons only discharged when the observed agent was interacting with the object. The properties of mirror neurons indicate that they represent a mechanism that maps observed actions onto the same action system needed to facilitate the same action. However, it had been noticed that the mirror neurons in the macaque's brain only fired when the observed action was goal-oriented. This shows that the observed action acts as a primer onto the agent's motor system that executes the relevant action. These neurons play a vital role for action planning as well as learning through observation (Gallese, Fadiga, Fogassi & Rizzolatti, 1996).

The mirror neuron system has also been found to exist in humans. Brain imaging studies have shown that neurons with similar properties to the mirror neurons have been found in the premotor cortex, superior temporal sulcus (STS) and the posterior parietal cortex. Buccino, Binkofski, Fink, Fadiga, Fogassi, Gallese, Seitz, Zilles, Rizzolatti & Freund (2001) observed an overlap between the different regions being involved during goal-oriented action observation as well as goal-oriented action execution. They found that action execution activated different segments of the premotor cortex and these segments were also active when the participant observed that same action being performed by another.

As the mirror neuron system fires when a person observes somebody else perform an action in addition to executing the same action, it allows us to establish the observed person's intention and automatically enables us to prepare for an appropriate response. Thus the mirror neuron system has a crucial role for understanding other people's intentions and actions in terms of cooperative behaviour, as it allows us to plan an action prior to execution by understanding our partner's goals. An action representation system is vital to social species, as it allows one to not only interpret the actions and intentions of others, but it also allows one to predict a response and respond accordingly (Annett, 1996; Meltzoff, 1999).

Activation of the mirror neuron system seems to be solely receptive to actions carried out by a biological agent. Tai et al. (2004) scanned volunteers using Positron Emission Tomography (PET) while having a human or a robot perform actions in the scanner room in front of the subjects. The experiment consisted of two conditions; one involved the experimenter grasping a cylinder three times in a row, with variability in the movement, whilst the other condition involved an artificial arm grasping the same object in a pre-programmed motion three times in a row. The results showed that the mirror neuron system was activated for the observation of the human arm movement but not for the robotic arm. This suggests that activation of the mirror neuron system is reliant on the observation of biological movement.

However, it could also be argued that the results could have arisen due to the variability in the human movement and lack of thereof in the pre-programmed robotic arm movements. Gazzola, Rizzolatti, Wicker and Keysers (2007) measured activity of the mirror neuron system during human and robotic hand performance using fMRI. Participants were shown still pictures and movies of robots and human agents performing actions. The results showed that the observation of both the simple and complex movements involving the robot and the human agent resulted in the activation of the temporal, parietal and frontal areas, classically thought to not only contain the mirror neuron system, but also being involved in the motor execution of similar actions. Nevertheless, when participants observed robots perform the same single actions repeatedly, they found no activation of the mirror neuron system, implying that repetitiveness of actions leads to habituation. Activation of the mirror neuron system decreases when there is a lack of variability in movement, as demonstrated by the robotic arm. Similar findings were reported by Hamilton and Grafton (2006).

It has also been found that these neurons expand to regions outside the pre-motor cortex. Mukamel, Ekstrom, Kaplan, Iacoboni and Fried (2010) recorded neuronal cell activity of the mirror neuron system in the motor region as well as the regions implicated in vision and memory in patients suffering from intractable epilepsy. Patients either observed various actions on a computer screen or were presented with words. In the observation phase, they observed the various actions being executed. In the performance phase, they had to execute the actions of the visually presented words, whilst in the control condition they read the same words as in the performance phase, however they did not execute them.

As previous studies have shown, the neurons fired both when the patient observed and executed an action. However, activity of the mirror neuron system was recorded in the medial frontal cortex, which is responsible for movement selection, and medial temporal cortex, accountable for memory, which has previously not been identified. The findings suggest that the mirror neuron system is not limited to the frontal and parietal areas of the brain, but that these extend to further regions of the brain. Moreover, activity in the mirror neuron system increased when participants were required to execute an action, whereas activity decreased when they observed the action. The researchers suggested that the difference in activity occurred as a result to distinguish the actions as either being executed or observed. One of the reasons why activity was less during observation could be due to the reason that activity needed to be inhibited from being executed, as had been observed by Sebanz et al. (2006).

Kourtis et al. (2010) recorded electroencephalograms (EEG) during a three way interaction to examine anticipatory motor activation within the mirror neuron system. The task involved two agents to directly interact with one another, whilst the third person was considered as a ‘loner’. The object, which was placed in the centre of the table, had to be lifted and either returned to its original position or passed to and received from another cooperating participant. The results indicated that anticipatory motor activation was strongly activated and more pronounced when a person was considered as an interactive partner. Simulation of a partner’s action is involuntarily considered and taking into account during a movement.

Finally, the medial frontal gyrus has shown a higher rate of activity when healthy people had to attribute a mental state to others, whereas individuals suffering from autism show a lower activity in this part of the brain. This may explain why people with autism are unable to infer other people’s mental states (Blakemore & Decety, 2001). These shared representations can influence an individual’s choice of action planning and may hinder them in efficiently performing their own part of a joint action task.

Overall, the mirror neuron system predominantly found in the premotor cortex, the STS and PPC allows us to understand people’s actions through discharge during an observed or executed action (Gallese et al., 1996; Rizzolatti et al., 1996).

Other brain areas involved in movement selection, motor execution, action goals and intentions as well as memory are also important for understanding interpersonal action coordination. Although the precise neural underpinnings of joint action are not fully understood, its implementation undoubtedly requires integrating processing from among different brain regions.

2) *Joint Action Strategy Formation*

An important reason why co-representation might be useful in joint action is that it allows for the formation and implementation of effective joint strategies. Knoblich and Jordan (2003) investigated the ability of dyads to perform a joint coordination task. Participants were required to track a horizontally-moving target either alone or in cooperation with a partner. Initially, performance of dyads was inferior to that of individuals. However, with practise the dyads' performance improved and became comparable to that of individuals' performance. Knoblich and Jordan (2003) claimed that, when cooperating with others, we initially assume that others move in the same way as we do and subsequently we adjust our own movement to that of others.

Predictability as a Joint Action Strategy

Vesper et al. (2011) demonstrated that being predictable is a valuable planning strategy for temporal coordination in the absence of continuous feedback. This allows partners to plan a more accurate movement. Participants were asked to act synchronously and coordinate their responses to discrete visual events. The task involved the formation of pre-movement action planning, however the short, ballistic movements required of the participants did not enable them to obtain sufficient visual feedback of their partner's movement to successfully control their movement online. It was hypothesised that if participants used predictability as a factor to compensate for their lack of visual feedback, then participants would adopt a consistent strategy throughout the task in the joint condition in comparison to the individual task, where more variation would be observed.

Vesper et al. (2011) compared participants' individual and joint performance on the Simon task. Reminiscent of Sebanz et al. (2003, 2005), participants performed the task alone in the individual condition or simultaneously with another individual in the joint condition. In the corresponding mapping group, the target required either a congruent or incongruent response from both actors (same key press for the target). However, in the non-corresponding mapping group, the responses varied for each participant; one participant would have a congruent response, whereas the other would have an incongruent response (different key press for the target). The non-corresponding task posed more of a challenge on the participants' coordination.

The results showed that reaction times were less variable in the joint condition in comparison to the individual condition. Furthermore, correlations showed that the reduced variance in movement was used to lessen asynchrony and plan a more accurate movement. This implies that participants used predictability as a strategy to better coordinate and synchronise their movements with those of their partners.

3) *Unconscious Synchronisation*

An element of behaviour that may contribute to joint social action is unintentional synchronisation where people often imitate the behaviour of that of a partner at an unconscious level. The synchronisation of an action allows individuals to form a stronger social bond with a partner and facilitate social liking. One of the main forms of this kind of joint action occurs in the form of unconscious mimicry.

Mimicry

Chartrand and Bargh (1999) used the term 'chameleon effect' to refer to unintentional changes in a person's behaviour that copy the behaviour of a cooperating partner. Perceiving others carrying out a certain type of behaviour immediately primes us to change our own behaviour and take on the behaviour of others.

Bargh, Chen and Burrows (1996) primed words that were linked to a 'rude' personality trait, a 'polite' trait or neither, whereby no words linked to personality traits were employed in the control condition. Participants were unaware that the experiment was conducted as a measure of their behaviour; instead they were thought to believe that they had participated in a language test. It was believed that participants that were exposed to perceiving either kind of behaviour traits were likely to imitate them. After being exposed to those rude or polite words, they were then placed in a situation where their behaviour was put to the test.

The results showed that 38% of those in the control condition, that were exposed to neither personality trait, intervened a conversation, compared to a staggering 67% of participants that were primed to the rude trait, whilst only 16% of participants of the 'polite' trait condition interrupted the ongoing conversation. This shows that participants were likely to adopt their primed personality traits and imitate those characteristics associated with that trait. Although this study has provided evidence that perception facilitates action, it can be argued that the perception of the primed words did not necessarily prime a behaviour associated with the primed personality traits.

Chartrand and Bargh (1999) accounted this flaw when conducting their experiment on the effects of perception on action. The first experiment focused on unintentional mimicry that would occur between strangers. Participants were paired with a confederate (C1), with whom they interacted for about 10mins. After interaction with C1, they were then paired with another confederate (C2). During their interaction with the confederates, both of the confederates would take on different habits, either by rubbing their face or by shaking their foot. If C1 was rubbing their face, C2 would shake their foot and vice versa. At the same time, the confederate would either be smiling or putting on a neutral face; if C1 was smiling, then C2 would be adapting a neutral facial expression and vice versa.

The results indicated that people had a tendency to mimic the behaviours of their partners. They rubbed their face when the confederate rubbed their face, they increased their foot shaking when the confederate shook their foot. Participants were likely to imitate their partner's behaviour even when the opposing confederate did not smile or make eye contact. Thus a chameleon effect was observed across the two different conditions involving different confederates. What is fascinating about this study is that the interaction did not even require an action goal. It suggests that perceiving a motor movement is mapped onto our own action system, and that our brain simulates the action and imagines as if it is carrying out the movement (Jeannerod, 1994). But why does the brain map actions onto our own action system? What implications does this have?

One way of explaining this is that matching behaviours is related to building a better relationship amongst individuals and facilitates better interaction, which was observed in the second part of Chartrand and Bargh's (1999) experiment. Participants interacted with a confederate for 15 minutes, who either imitated their behaviour or engaged in a neutral interaction. Following the interaction, the participants were asked to complete a questionnaire about their interactive partner as to how much they liked the confederate and how smoothly they perceived the interaction. The results demonstrated that there was an effect of mimicry on liking; participants rated the confederate more favourably and reported smoother interaction when their behaviour was being mimicked. It shows that mimicking facilitates liking between people and better interaction, as we expect the other person to be more like us and we are able to work best with people who function in the same way as we do (Knoblich & Jordan, 2003). This may be especially important to individuals who have to perform tasks in synchrony.

4) Temporal Synchronisation

Temporal synchronisation is a critical element of successful action execution in individuals, for example in the domain of bimanual coordination (Yamanishi, Kawato & Suzuki, 1980). Inasmuch as a bimanual action is akin to a joint action in which both actors are of one mind, it bears briefly describing some of the main findings in this area before describing how these have been shown to generalise to joint action.

Bimanual Coordination

When performing bimanual tasks, such as clapping, holding a book or moving our hands whilst running, both effectors seem to be coupled with one another in terms of time, space and posture to either imitate the actions of each other (in-phase) or to move in opposing directions (anti-phase). The motor system seems to prefer coordinated movement types that are symmetrically congruent (Otte & van Mier, 2006; Summers, Todd & Kim, 1993; Yamanishi et al, 1980).

According to Bernstein (1967) the motor system prefers to apply synergetic movement to reduce the many degrees of freedom of the joints. Congruent tasks, particularly in-phase tasks, require the control of a fewer number of kinematic degrees of freedom, hence it seems easier for the motor system to accomplish, whilst incongruent tasks involve the activation of a larger number of joint and muscle groups resulting in a greater number of degrees of freedom.

Joint Timing Coordination

Fine and Amazeen (2011) examined unimanual, bimanual and interpersonal coordination amongst two individuals applying the notion of Fitts' law (1954) using a rhythmic tapping task. Participants had to move their finger from one target to another target as fast as possible with degrees of variations in the target sizes and distances. Fine and Amazeen (2011) noticed a coordination pattern evolving during the bimanual trials. When the index of difficulty varied across the conditions for the two different hands in the bimanual condition, participants would obtain a similar movement time for both hands irrespective of the variation in level of difficulty. A similar finding was observed when two participants performed the task collectively using one hand, suggesting that synchronization is not only limited to intrapersonal coordination, but can also be extended to interpersonal coordination.

Similar patterns of synchronous movement have also been observed within two individuals working alongside each other (Georgiou et al., 2007; Harrison & Richardson, 2009; Richardson, Mash, Isenhower, Goodman & Schmidt, 2007;

Schmidt, Carello, & Turvey, 1990; Schmidt & Turvey, 1994). Harrison & Richardson (2009) asked pairs of participants that were physically connected through a foam appendage, at a particular distance behind or in front of each other, or not connected at all to walk or jog at their own comfortable pace. The results demonstrated that participants coordinated their pattern of movement with that of their partner in either condition, however this coupling was stronger and resembled that of a horse trot when participants had full vision of each others' movement in addition to being mechanically linked. Not only does the motor system prefer coordinated limb action within oneself, but the findings imply that the limbs of two individuals temporarily couple together unintentionally to become a single element.

Temporal coupling of two limbs seems to be present even in the absence of a mechanical connection and in the mere presence of a partner. Richardson et al. (2007) observed pairs of participants swinging on rocking chairs and found that participants rocked their chair at the same frequency as their partner despite being instructed to rock at their own preferred tempo. Having full vision of a partner's movement influences one's own choice of movement pattern.

5) Spatial Coordination

In contrast to studies of joint temporal coordination, examinations of spatial coordination have been comparatively rare. This likely is a consequence of the technical challenges posed by the recording of the spatial components of movement, and to the fact that many investigators in joint action come from a background of cognitive psychology rather than motor control. As alluded to earlier, spatial coordination is a feature mainly of joint actions that involve a direct physical interaction between partners, such as passing an object.

Georgiou et al. (2007) examined the action patterns of dyads in a coordinated object placing task. Participants either performed in a cooperative condition, where each person had to collaborate with their partner to perform the task of forming a tower, or in a competitive condition, where each had to compete to place their object in the centre of the table first. The results showed that the kinematics of peak acceleration and peak velocity for the individuals in the cooperative task were highly correlated with one another. This pattern was not observed for the competitive condition, which suggests that during cooperation individuals closely coordinate their movements to achieve an optimal result.

Huber et al. (2009) examined the effects of physically handing over a cube to a partner. The findings showed that although the task involved no action goal, partners became more efficient in passing the object; a decrease in reaction time was observed throughout the trials. Furthermore, all participants preferred handing over the object at a consistent height and distance, thus opting to choose a more predictable movement, thereby reducing variations within the online component of action planning. This implies that action planning and control are not only considered prior to physically interacting with a partner but anticipating a partner's action seems very crucial within the role of joint action.

6) *Summary of Joint Action Studies*

Past work on joint action has revealed a number of interesting findings. The action representation system is vital to the role of joint action, as it allows one to not only interpret the actions and intentions of others, but it also allows one to predict a response and react accordingly. One needs to be able to distinguish their own actions with that of others in order to form a mutual understanding of the joint task and implement an effective joint strategy formation. Predictability is a valuable factor for the development of a temporal coordination amongst joint performance to enhance coordination and synchronisation. Not only do individuals prefer to be more predictable in their actions, they are also influenced by mimicry of their partner's actions, as this facilitates a better relationship amongst pairs and results in the development of unintentional temporal and spatial coupling between individuals. Overall, participants are influenced by the actions of their partner and consider this within their own action planning when interacting alongside another person. Despite this corpus of work, there are two important principles of action that have yet to be investigated in detail in joint action, planning versus control and the end-state comfort effect.

Planning versus Control

The planning and control dichotomy was first proposed by Woodworth (1899), who introduced the model of limb control. The model put forward the idea of goal directed aiming movements to consist of two phases, the 'initial adjustment phase' and the 'current control phase'. The first phase is responsible for transporting the limb to a target and the latter phase controls errors and noise within the movement to accurately transport the limb to the target. This model has provided a feasible framework for goal directed aiming movement and has gained extensive interest over the years giving rise to alternative and updated theories such as Glover's planning-control model to explain action execution.

Glover (2004) put forward the idea that visual representations are divided into planning and control. The combination of the two systems is able to account for movement execution, even though the two systems differ systematically from each other. Glover, Wall and Smith (2012) examined the neural bases of the postulated planning and control systems using an fMRI study. They found that action planning activated the premotor cortex, basal ganglia, anterior cingulate, superior parietal occipital cortex, and middle intraparietal sulcus whilst online control activated regions of the sensorimotor cortex, the cerebellum, the supramarginal gyrus, and the superior parietal lobe. The findings demonstrated evidence for the existence of two independent systems responsible for movement planning and control, and specifically that distinct parts of the parietal lobe are involved in each stage of action.

Action Planning

Planning involves a visual representation of the planned movement and occurs prior to movement execution. During planning, movements are considered in relation to action goals heavily relying on cognitive processes that provide us with vital stored knowledge about objects of interest. In order to successfully plan a movement, a person needs to consider a number of important factors. First of all, one needs to consider the spatial and non-spatial characteristics prior to forming an interaction with an object of interest. The spatial characteristics refer to the size, shape, orientation and position of the object and allows one to determine how far the object is in relation to one‘s own body position and the kind of grasp needed to interact with the object. Determining the visual characteristics enables us to identify the object. However to productively interact with the object, the object needs to be further evaluated in terms of its non-spatial properties, such as the texture, fragility and weight of the object. These, among other things, non-spatial characteristics cannot be determined solely through the use of vision, but rely on a combination of current visual information and stored object knowledge. The next important factor is the goal of the action in relation to one's own goal and the overall goal (considering another person's actions and intentions). All this information is combined with memory of past events, which helps facilitate low-visual non-spatial characteristics. Thus planning is subject to conscious awareness and considers a wide array of factors including action goal and target characteristics in order to initiate an appropriate motor program for an anticipated action (Glover, 2004).

Evidence that action goals are incorporated within an action planning comes from a study carried out by Marteniuk, MacKenzie, Jeannerod, Athenes and Dugas (1987). Marteniuk et al. (1987) asked participants to grasp a disc and either place it in a tight slot or toss it in a large container. The findings demonstrated that movement times were longer followed by a longer deceleration phase for the precision task, where the disc had to be placed in the tight slot, in comparison to the condition where the disc had to be thrown in to the bucket. The deceleration phase signifies the time between peak velocity and time when contact is made with the object. This increased timeframe enables one to practically apply the second phase of the model, the online-control phase, to overcome any erroneous movement and enhance movement control.

Action Control

The control system monitors and adjusts motor programs in flight that often occur as a result of unplanned changes in the spatial characteristics of a target or noise in the motor program. Unlike the planning system, the control phase is not influenced by internal cognitive processes and thus requires no conscious awareness. It solely relies on updated visual and proprioceptive feedback of the limb and the target (Day & Lyon, 2000; Goodale, Pelisson & Prablanc, 1986; Pisella, Grea, Tilikete, Vighetto, Desmurget, Rode, Boisson & Rossetti, 2000). Simultaneously this poses a limitation for the system, as the control system will be hindered if access to updated visual information is not readily available.

A fine example of the application of online-control is prominent in Fitt's Law (1954). The speed and accuracy of a task are commonly related; increasing the speed of a task results in decreasing the accuracy and vice versa, thereby requiring the need of a superior control phase. Thus, precision tasks lead to increased movement times as a result of a longer deceleration phase and a greater emphasis of control being applied in situations requiring more care and accuracy. Perturbation studies provide a profound insight into the relationship of action planning and action control.

Perturbation Studies

The planning and online control distinction is prominent in perturbation studies, where planned movements are susceptible to the introduction of a physical or mechanical perturbation resulting in the application of online control. Most perturbation studies involve participants to perform a series of reach and grasp movements that change position or size corresponding to movement onset.

Many studies have demonstrated that when the position of a target was perturbed during movement, the trajectory of the hand was altered to the position of the new target. Goodale et al. (1986) observed that corrections to the hand trajectory occurred despite the fact that subjects were unaware that the target location had changed. Furthermore, when the time between target onset and displacement was very short, and the target displacement corresponded to hand movement onset, online corrections would occur automatically with no significant effect on reaction times or movement times (Day & Lyon, 2000; Komilis, Pelisson & Prablanc, 1993);

movement times increased somewhat by up to 80ms and reaction times were delayed by 40ms in the perturbed conditions.

Paulignan, MacKenzie, Marteniuk & Jeannerod (1990) obtained similar findings. When participants reached for a cylinder that changed its position, corrections in the transport phase of the movement were observed, leading to an increase in movement time of an average of 100ms. The sudden changes to the object location allowed participants to make relatively quick online adjustments to move their hand from the initial target location to the new location during their ongoing movement. This illustrates that the online system is fast at detecting errors and adjusts these automatically without conscious awareness, as subjects were not even aware of the perturbation.

In another series of experiments, Paulignan, Jeannerod, MacKenzie and Marteniuk (1991a) perturbed the spatial element of reaching and grasping by altering the target object size. In the unperturbed control condition, the grasp aperture changed with the object size; the maximum grip aperture was smaller for the small object and this occurred earlier in the movement than for the large object. However, when the object unexpectedly changed from the small to the larger size (S-L), subject‘s movement times were slowed down by 175ms on average whilst an increase of 85ms was recorded when the object changed from the large size to a smaller size (L-S). Although movement time was affected to a lesser extent for the L-S than the S-L perturbation, the increased movement times occurred as a result of an increment in the low velocity phase towards the end of the transport phase. It could be proposed that the difference in movement time may have been due to the implementation of applying an extended grasp aperture, which takes more time and effort as opposed to decreasing one’s original aperture. The findings further imply that the online system is fast at accounting for changes, even when this involves perturbation to the size of the target.

Pisella et al. (2000) also perturbed the location of a target during movement onset and instructed subjects to either correct their movement or stop when they noticed the object shift. The results showed that participants were always making fast corrective movements even in the condition when they were told not to do so. This implies that the motor system is naturally attracted to the target and the online control system operates automatically, which allows the arm to quickly correct its trajectory without any conscious awareness. Castiello, Bennett and Chambers (1998) extended Paulignan et al's (1991a) study by applying perturbation to the size and the location of the object simultaneously. Subjects had to grasp an illuminated cylinder that unexpectedly changed in diameter in correspondence to movement onset. These cylinders, that were either small or large, appeared either to the left or the right of the central cylinder. Movement times were increased by up to 250ms and online corrections were visible after 400ms into the movement. These perturbations, that involved disruption in target size and location, delayed movement more than double step grasping that involved perturbation on one particular aspect. The results showed that it took participants longer to make the appropriate adjustments, implying that movement times for action control is significantly delayed when the perturbation involves more than one aspect.

On the whole, planning and control are two temporally overlapping systems that ensure a smooth and accurate execution of a goal directed movement. Prior to a movement being executed, the motor system uses cognitive and visual information available to ‘plan’ a movement according to the goal of the overall task, whilst ‘control’ occurs during flight to reduce any errors in the movement using spatial information.

The End-State Comfort Effect

Research on individual action has shown that participants plan their actions according to their selection of grip postures that provide optimal end state comfort. Thus action goals can also be represented in terms of comfort (Weigelt et al., 2006). Rosenbaum, Loukopoulos, Meulenbroek, Vaughan and Engelbrecht (1995) postulated the ‘posture-based movement planning’ model, which suggests that motor movements are planned in relation to the end-state of the movement. For example, it is easier to rotate an object that is held between the thumb and index finger forwards by 90° resulting with the thumb pointing upwards positioned on top of the object. This results in putting minimal strain on the wrist. On the contrary, tilting the object backwards by 90°, with the thumb pointing downwards placed at the bottom of the target, results in a more uncomfortable final position putting more strain on their wrist. Rosenbaum termed this ‘the end-state comfort effect’ and demonstrated this idea with an inverted glass; when people reach for an inverted glass to pour water in, they generally use an initial awkward grasp (with their thumbs pointing down) and end up in a more comfortable final state of action with their thumbs pointing up.

Rosenbaum et al. (1990) presented a similar concept within an experimental setup; participants had to reach out for a horizontally placed dowel with a black or white end and place one of the marked ends vertically on a target disk. The results showed that all the participants grasped the dowel with an underhand grip and ended the movement with a comfortable end-state along with their thumb pointing upwards. This shows that people prefer to maximize the comfort of their final posture at the expense of initial discomfort, which is considered prior to movement initiation as part of their action planning.

Weigelt et al. (2006) applied the concept of Rosenbaum et al. (1990) end state comfort effect in a bimanual object manipulation where participants simultaneously reached out for two bars that had to be placed with their ends adjusted in various manners on the table. The question of interest was whether participants preferred to select similar grasping styles for both the bars that would result in different final postures, or whether identical end state postures would be favoured over the employment of selecting different initial grasping styles. The results showed that participants preferred to select different initial grips, even if it put discomfort on the wrists, only to end up with a more comfortable end posture for the two hands. This implies that the notion of ending up in a more comfortable end state posture is more significant than the two limbs performing a congruent task; affecting the overall planning for a movement.

Gonzalez et al. (2011) extended the concept of end-state comfort effect and applied it within a joint action scenario where members of a pair had to pass a tool to their cooperating partner. They examined whether dyads considered the end state comfort of their partner within their own action planning by applying an initial awkward grasping posture to help maximise the efficiency of their partner or whether participants aimed to minimise their own movement cost leading to an awkward end state posture for their partner. The results showed that the ‘Passer’ offered the object to the ‘Receiver’ in a manner so as to allow the latter to adopt a comfortable final posture. Thus, the Passer planned their movement using a representation of the Receiver’s affordances, demonstrating that the concept of end-state comfort can also be applied to joint actions.

The Present Thesis

The primary goal of the current thesis was to examine if an agent adjusts their own action in accordance with their partner's affordances. The question of interest was whether the extent of an agent's cooperation would be modulated by the difficulty of their own task or that of their interactive partner.

The secondary goal of the present thesis concerned the overall strategy formation employed by each participant in relation to the effects of manipulating the tasks. Strategy formation is a form of planning that determines, on a gross level, how an agent is going to perform a particular action. It is valuable to determine the extent to which pairs choose a single, consistent strategy, or vary their strategy depending on task demands. The former has the advantage of making each participant more predictable to their partner, while the latter can be more optimal in terms of effort. While it may be beneficial in terms of joint action to apply a consistent and single strategy throughout the task, it is worth mentioning that applying a consistent strategy may be suboptimal when conditions change. When task demands are fluid, employing two (or more) separate strategies may be more appropriate. Yet applying two or more different strategies for completing a task requires greater cognitive effort and at least an implicit understanding among actors that the strategy will change depending on conditions.

In each experiment, apart from Experiment 7, a rectangular shaped object had to be passed from one participant (the Passer) to the other (the Receiver), who then had to place it in a target area. In Experiment 7, this rectangular object was replaced by a cube. On some trials, the object had to be rotated between the time the Passer initiated the movement and when it was placed down again by the Receiver. Unlike Gonzalez et al. (2011) who used common tools, we here used a neutral object to avoid any implicit demands associated with how a tool is used. Critically, the task instructions did not specify to what extent either the Passer or Receiver should rotate the object on those trials in which rotation was required. However, in the basic version of the task, if the Passer did not rotate the object prior to handing it to the Receiver, the end result would be an awkward and uncomfortable end-state posture for the Receiver. Movement kinematics was measured and recorded using a Polhemus FASTRAK system. This device uses electromagnetic currents to track the position of its sensors in relation to its stationary transmitter. The sensors, which were attached to the participants' thumb and index finger, enable us to measure movements in different directions (X, Y, Z), as well as the degree of rotation of their movements. This set up allowed us to measure the degree to which the Passer accommodated the Receiver's end-state comfort by comparing the change in rotation of the Passer's hand at the start of each trial to that at the time the object was passed, recorded as ROTA. A change in rotation would indicate that the Passers planned their action with their partner in mind, as task instructions did not specify to what extent either the Passer or Receiver should rotate the object on those trials in which rotation was required. If the Passer did not rotate the object prior to handing it to the Receiver, the end result would be the Receiver's thumb interfering with their final placing movement. In other words the Receiver's end-state comfort depended on the actions of the Passer prior to handing off the object: the more the Passer rotated prior to hand off, the more comfortable the Receiver's final posture. This set up allowed us to measure the degree to which the Passer accommodated the Receiver's end-state comfort by recording the extent to which the Passer's hand rotated prior to handing off the object to the Receiver. Based on previous research, it was hypothesised that the Passers would plan their movements in accordance to their partner's affordances, thereby rotating the object on trials that required rotation, especially when task demands increased for the Receiver and made it more difficult for the Receiver to complete the task alone. A correlation was established for ROTA across conditions within individuals. Large positive correlations on these measures would suggest that participants adopted a consistent strategy across conditions, whereas a lack of such effects would indicate that participants adopted flexible strategies. Seeing that predictability is an important factor when interacting with a partner, it was predicted that participants would generally adopt a consistent strategy formation and therefore it was expected to observe large positive correlation for ROTA.

An outstanding question in joint action research is the extent to which task demands may vary before participants will apply different strategies. To measure this aspect of planning, performance of individual pairs across conditions were correlated in terms of the time taken to pass an object from the Passer to the Receiver (TTP). Again, large positive correlations on these measures would suggest that participants adopted a consistent strategy across conditions and pre-planned their movement prior to movement execution.

Experiment 1 served as a control and provided baseline data. To measure the extent to which various manipulations affected online control, Experiments 2 and 3 increased the difficulty of the task through the application of magnetic stimulation to the Passer's bicep on a random (Experiment 2) or a blocked (Experiment 3) set of trials. Experiments 4 and 5 further varied the difficulty of the task by examining the effects of eye gaze and whether gaze direction served as a cue to a person's intention (Experiment 4) whilst the latter experiment (Experiment 5) imposed constraints of having to pass the object through a small frame. Experiment 6 examined the effects of role reversal on strategy formation; here the Passer and the Receiver swapped roles halfway through the session. The final experiment (Experiment 7) examined complex movements through the application of a cube that could be rotated along 3 dimensions. Although planning and control are two systems that differ in a number of ways, they are utilised in combination for the role of action execution. In a joint object passing task, people not only have to plan their movements with regards to the overall aim of the task by selecting an appropriate motor programme, but also with regard to what they anticipate their partner's actions. They each have to adjust their movements in flight based on how their expectations of their partner's action differ from what they anticipated, as well as any outside forces (i.e. mechanical perturbation) that act to disrupt their or their partner's movement. The factor of online control is important inasmuch as it provides a ready index of the relative difficulty of the various conditions, and accordingly the implicit demand for the use of a flexible strategy. Thus, to precisely index task difficulty, we measured the number of re-accelerations occurring in each participant's movement following the time of peak velocity. These re-accelerations are recognised as reflecting the number of online adjustments made during an action (Meyer, Abrams, Kornblum, Wright & Smith, 1988) referred to as OA-Pass and OA-Rec, which are known to correlate positively with task difficulty. It was thus predicted that online adjustments in both the Passer and the Receiver would increase with the demands of the task; increasing difficulty levels would result in an increase in these variables. An increase in OA-Pass would be indicative of an increase movement complexity resulting in the need to control for erroneous movements within flight, whereas an increase in OA-Rec reflects the Receiver's need to adjust to the vicissitudes of the Passer's movements.

2. Effects of varying target orientation on planning and control during physical joint action

Synopsis

The aim of this chapter was to investigate joint motor actions between two people during an object passing task. In the current experiment, the first person (the Passer) was required to pass a wooden rectangular target object to person two (the Receiver), who then had to place the object in a set target location. The experiment required the object to be rotated on some trials prior to the object being set in its final target area; however no instructions were given to specify who had to rotate the object. This experiment aimed to establish whether the Passer would adjust their movements based on the affordances of the Receiver.

The Passer had an easier task in comparison to the Receiver, as they only had to pass the object, thus they could plan their movement prior to initiation. The Receiver's actions were dependent on the Passer's choice of action. As a result, the Receiver could not plan their movement in advance and thus relied profoundly on action control. The Passer had the choice of adhering to their own objective or alternatively consider their partner's action and incorporate this within their own action planning. If the Passer would represent the Receiver's end-state comfort and was willing to adapt their movements to take this into account, they would be inclined to rotate the object prior to passing. However, if the Passer is unable to represent the Receiver's task, or unwilling to adapt their movements, then the Passer would not be rotating the object.

Based on previous research on end-state comfort effect and joint action (Glover & Dixon, 2012; Gonzalez et al., 2011; Sebanz et al, 2003; 2005; 2006) it was hypothesised that the Passer would adjust their movements in relation to the Receiver's affordances. The results showed that the Passer rotated the object prior to passing it to the Receiver on conditions that involved rotation. Although it was not required of the Passer to rotate the object, the results indicate that the Passer anticipated the Receiver's task and considered this within their own action planning, therefore the Passer's choice of movement was influenced by the final target position, particularly the Receiver's end-state comfort.

Introduction

Glover and Dixon (2012) examined the ability to represent another's action affordances in a joint motor task. Pairs of participants sat opposite each other and an object composed of a large and a small end was placed on the table between them. The first participant (the Passer) had to grasp the object by one end and pass it on to the second participant (the Receiver), who had to grasp the object by the other end and place it down in a particular orientation. The nature of the task was such that the Passer determined the grasp to be used by the Receiver, and the empirical question was whether the Passer would adjust their grasp so as to increase the overall comfort of the Receiver. The results showed that the Passer's grasp posture was modulated by the Receiver's task. The Passer was more likely to pick up the object so as to increase the overall comfort of the Receiver. A similar result occurred if the task was only simulated through motor imagery and not actually physically carried out. This study not only supports the view that individuals consider their partner's action within their own action planning when directly interacting with another individual, but also presents evidence that these representations influence an individual's choice of postures.

The current experiment used an object passing task to examine coordination between cooperating partners in terms of action planning and control, which has rarely been studied within joint action. Since none of the past studies on joint action have examined planning and control amongst people interacting with one another, the present study provides an innovative aspect to joint action. The main question of interest concerned the trials in which the object had to be rotated between the start and end of the movement. The aim of this experiment was to establish whether pairs of participants would adjust their movements based on the affordances of their partner. This first experiment was mainly conducted to establish a baseline for the comparison with Experiments 2 through 7, which examined the effects of various manipulations on the difficulty of task.

Experiment 1

The empirical question was whether the Passer would adjust their movements based on the affordances of the Receiver and therefore rotate the object before handing it to the Receiver. There are two possible main outcomes. First and foremost, if the Passer can represent the Receiver's task and is willing to adapt their movements accordingly, they will rotate the object on trials requiring rotation prior to passing it to the Receiver. The alternative outcome is if the Passer is either unable to represent the Receiver's task or is unwilling to adapt their movements to their partner, the Passer will not rotate the object.

Based on previous research (Glover & Dixon, 2012; Gonzalez et al., 2011; Sebanz et al, 2003, 2005, 2006), it was hypothesised that the Passer would rotate the object on conditions required rotations to achieve an overall efficient movement. This hypothesis is based on the postulate that people plan their movement prior to action execution, thus the Passer will consistently rotate the object for all the experimental trials requiring forwards and backwards rotation to accommodate the Receiver's affordances, reflected in an effect of orientation condition on ROTA. Participants will apply this consistent strategy throughout the experiment to be more predictable towards their partner and thus enabling the Receiver to be less reliant on online control. Furthermore, with the Passer rotating the object, the Receiver would be less likely to have to employ an uncomfortable end-state posture. The alternative hypothesis predicted that the Passer will not rotate the object prior to passing it to the Receiver on conditions requiring rotations and thus there should be no effect of orientation condition on ROTA.

Due to the nature of the experiment, being a simple object passing task, it was expected not to observe any significant effect for time to pass (TTP) and online adjustments in the orientation condition. TTP is indicative of action planning as well as online control and if we expect participants to plan their movements ahead of motor execution, we would expect TTP to be similar across the different orientation conditions. Alternatively, the null hypothesis would predict that if participants do not pre-plan their movements, then an effect of TTP should be observed, with longer times for the conditions requiring rotations. Also, as this object passing task is fairly straightforward and involves no mechanical perturbation of any form, it is expected for the number of online adjustments (OA) to be similar for both the Passer and the Receiver across conditions. Thus it was predicted that there would be no effect of orientation condition on OA-Pass and OA-Rec. Alternatively, if rotation condition requires more online adjustments, effects of rotation condition on OA-Pass and/ or OA-Rec will be observed.

Method

Participants

Eleven pairs of participants took part in Experiment 1. All were healthy, right handed individuals with normal or corrected vision, and all were naïve as to the exact purpose of the study. All participants received course credit and provided their informed consent prior to participating.

Stimuli and Apparatus

Pairs of participants were seated opposite each other along the width of a flat wooden table (90 cm x 55 cm x 60 cm in height). The table was marked in three positions: 1) the starting location of the target object, which was a 7 cm x 2 cm rectangle drawn in pencil on the tabletop, centred 6.2 cm from the edge of the table closest to the Passer, and approximately 45 cm from their midline; 2) the starting location of the Receiver's hand, which was centred 3.8 cm from the edge of the table closest to the Receiver, and approximately 40 cm from their midline; and 3) the final target location of the target object, which was a 7.1cm x 2.4 cm rectangle drawn in pencil on the tabletop, centred 28 cm to the left and 14 cm forward of the starting position of the Receiver. The target object was a wooden rectangular block (7 x 2 x 2 cm). Each elongated side was white, yellow, red or blue; for the purpose of this study, the white side was not used. The two ends of the block were also painted white. Every trial started with the target object being placed in front of the Passer with the blue side facing upwards. On some trials the object had to be rotated 90° forwards, 90° backwards or not at all (0°) based on the chosen colour. The yellow colour required +90° rotation, the red colour required -90° rotation whilst the blue condition entailed no rotation.

Prior to commencing the experiment, recording markers from the Polhemus Fastrak system were attached to the nail of the right thumb of the Passer, and the nail of the right thumb and the nail of the index finger of the Receiver. The Polhemus is an electromagnetic tracking system that enables us to accurately calculate the location and orientation of the markers as they move through space. It consists of a main transmitter and receivers, also known as the sensors. The transmitter is made up of electromagnetic coils within a plastic box that discharges a magnetic field. The sensors, which are connected to the electric unit, consist of electromagnetic coils that detect the magnetic fields discharged by the transmitter. These sensors are attached to the participants' fingers and communicate with the transmitter to establish their position in space; it provides us with instantaneous x, y, z positions of each marker as well as the markers' angle of rotation, which were recorded onto a computer and stored for analysis off-line. The Polhemus records a single marker at 120 Hz, and thus alternating recordings were taken from the three markers every 8.33 msec. The near to zero latency makes it an ideal and effective technique to capture motion data and is a useful method for measuring kinematics. The reason why only three markers were used is due to the fact that the Passer always had a constant grasping position prior to passing the object. Their grasp movement did not vary over the trials, thus one marker was sufficient for the Passer (Wing & Fraser, 1983). However recording from the Receiver required the use of two markers since they had to open their fingers to grasp the object from the Passer. Each trial started with the Receiver's hand in a pre-set initial position using a precision grip with their thumb and index finger firmly held together and placed on the table.

Data Analysis

A custom analysis program first filtered the data using a single-pass Gaussian filter, and then interpolated data points such that data was obtained for every 10 msec of recording time. Movement onset for each participant was determined as the first time after the beginning of the recording at which the velocity of the thumb exceeded 5 cm/sec. Each participant's movement was considered complete when the distance between the markers on their respective thumbs was at its minimum, which by definition represented the point at which the object was handed off.

The main variable of interest was the degree to which each participant rotated their hand between trial onset and the passing of the object. This aspect of joint action planning was indexed as the difference in rotation (ROTA) of the marker on the thumb of the Passer between the beginning and end of their respective movements. Another aspect of action planning in conjunction of online control is time to pass (TTP), which provides us with valuable insights into the difficulty of the diverse conditions. Time to pass was measured as the time between the sounding of the tone to begin each trial and when the distance between the markers on the thumb of the two participants was at its minimum, which by definition represented the time at which the object was handed off. Figure 2.1 shows a diagrammatic timeline of trials. This aspect of action planning and online control provides an important indication of index of task difficulty on the demand of the employment of a flexible strategy. Another defined indication of online control was the number of smaller peak accelerations that occurred after the peak velocity and prior to the pass off point for both participants indicative of the number of online adjustments (OA-Pass and OA-Rec) made during the movement. Movements made after the passing of the object were not measured. Mean values for the number of online adjustments were computed for each participant for each orientation condition (0°, +90°, and -90°). Data were then entered into a repeated measure ANOVA with three levels of orientation as the independent variable and participants as a random variable. Greenhouse Geisser corrections were applied where appropriate.

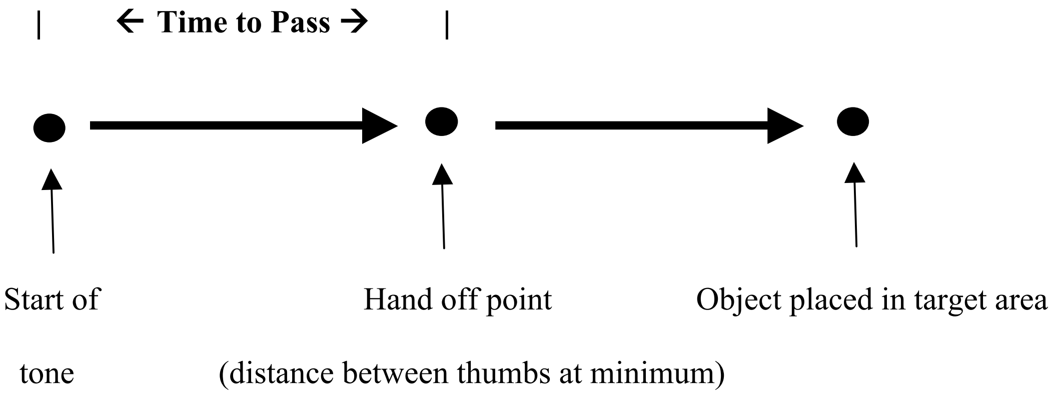

Figure 2.1: Diagrammatic timeline of trial. All of the dependent measures (ROTA, TTP, OA-Pass and OA-Rec) were obtained between the sounding of the tone and the time of hand off.

Procedure

Participants began each trial sitting opposite each other, with the Passer holding the object with a firm grip using their right thumb and index finger. The target object was placed in front of the Passer with the blue side always facing upwards before the start of the trial, whilst the yellow side was facing the Passer and the red side was facing the Receiver. The grasp was constrained so that the Passer held onto the right side of the object from their perspective (see Figure 2.2). The receiver rested their right hand in their own starting location with the thumb and index fingertip closed together.

Prior to the beginning of each trial, the Experimenter stated the colour that needed to be facing up in the final target area. Following this, the Experimenter pressed a key which simultaneously began the kinematic recording and caused a tone to be initiated by the computer. At the tone, the Passer had to lift the object and hand it off to the Receiver who then had to place it down in the target area with the appropriate colour facing upwards. The blue condition entailed no rotation (0°), whereas the yellow and red condition required +90° and -90° rotation, from the Passer's point of view, respectively. The task instructions required participants to complete each trial as quickly and accurately as possible. Participants were only allowed to use their right thumb and index finger to grasp the object. Trials in which participants used more than the two permitted fingers or in which the object was dropped or otherwise not placed correctly within the target area were excluded from the study. Each session consisted of 20 randomly ordered repetitions of each of the three target orientation (0°, +90°, -90°) conditions, for a total of 60 trials.

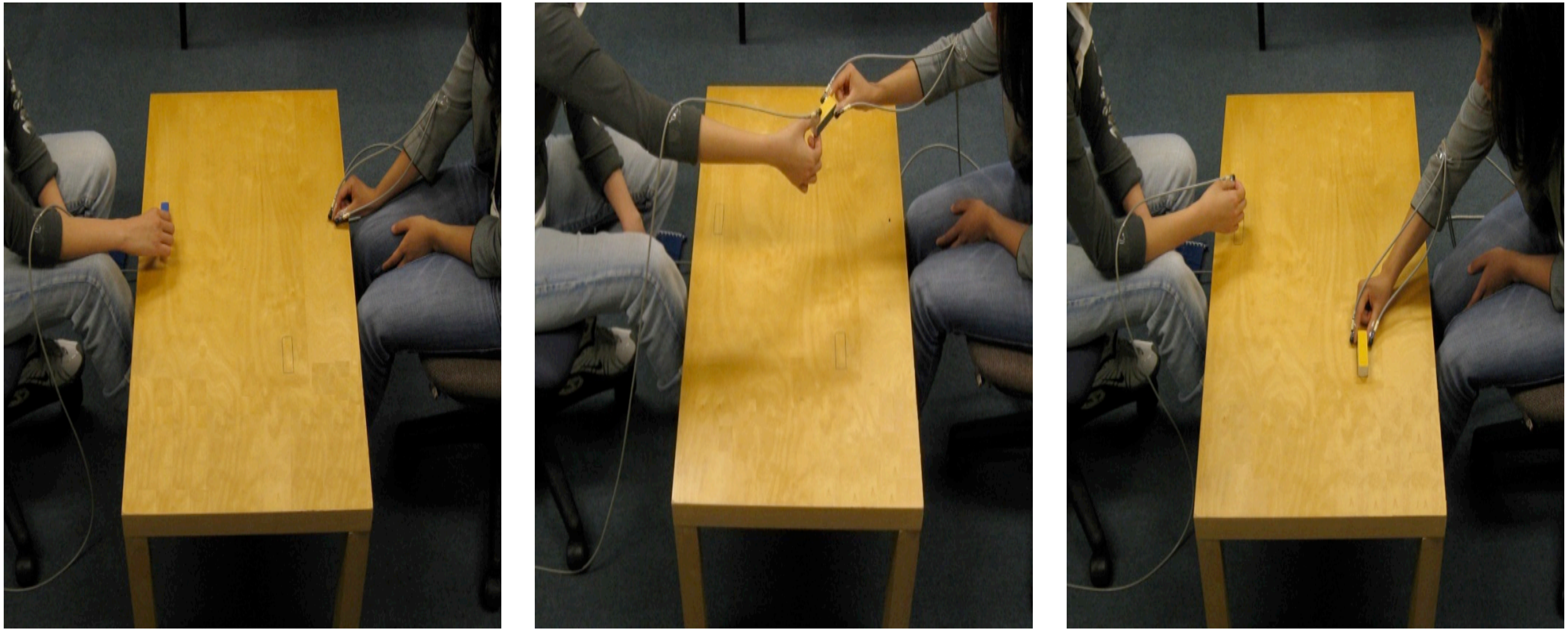

Figure 2.2: The experimental setup. Each trial began with the Passer (left) holding the object and the Receiver (right) sitting with their hand resting on the table. On the go signal, the Passer handed the object off to the Receiver. The Receiver then had to place it down in the target area with the appropriate side facing up. In this example, the +90° forward orientation (yellow) is being demonstrated.

Results

Kinematic data for the first six experiments are summarised in Appendix A. A total of 28 trials (M = 4.2%, SD = 4.04%) from all participants were discarded because the task was not completed successfully. Fig. 2.3 shows average rotation for the Passer (ROTA) as a function of orientation. Consistent with our hypothesis that the Passer would accommodate the Receiver's affordances by rotating the object prior to handing it off, there was an overall effect of orientation on ROTA (F [1.03, 10.26] = 8.470, $p < .05$).

On the other hand, no effect of orientation was observed on time to pass (TTP) (F [2, 20] = 1.91), p > .05 (0.174) or the number of online adjustments for either the Passer (OA-Pass) (F [2, 20] = 0.667, p > .05) or the Receiver (OA-Rec) (F [2, 20] = 0.135, p > .05).

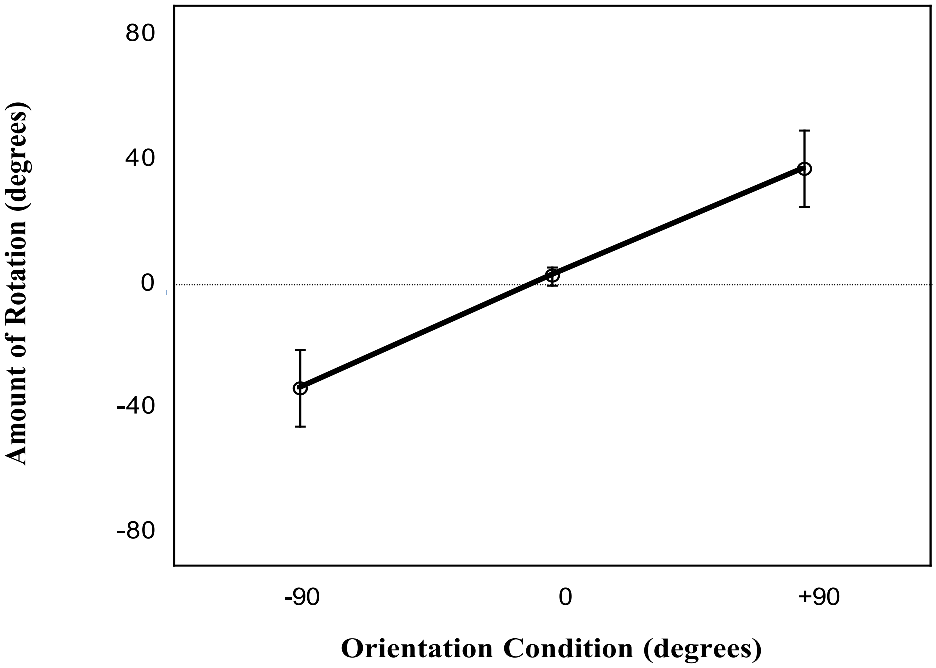

Figure 2.3. Mean degree of rotation of the Passer's hand prior to hand off (ROTA) as a function of orientation condition. Error bars represent standard errors of the mean.

Discussion

The main result of Experiment 1 supported the hypothesis that the Passer would accommodate the affordances of the Receiver by rotating the object in the appropriate direction prior to handing it off. There was a strong effect of orientation on ROTA. When participants were instructed to place the object with either the +90° forwards or -90° backwards orientation, the Passer accommodated the end-state comfort of the Receiver by generally rotating the object in the appropriate direction prior to passing it off. The results demonstrated that the Passer was able to form a representation of the Receiver's task in order to allow the latter to complete the task using a more comfortable posture. Participants are aware of their partner's task and actions and incorporate this within their own action planning (Glover & Dixon, 2012; Sebanz et al., 2003). As predicted, there was no effect of rotation condition on any of the indices of online control, including TTP, OA-Pass and OA-Rec.

When working with a partner, we seem to plan our movements based on the affordances of our partner and the overall action goal (Glover & Dixon, 2012; Sebanz et al, 2003; 2006). A possible explanation as to why the Passer represented the Receiver's affordances and considered this within their own action planning could be due to the increased work load the Receiver has had, as their task involved several procedures. First they had to meet the Passer's hand in a particular area in mid-air where they then had to grasp the object, which required a greater precision on the Receiver's part than for the Passer. The factors involved in reaching/grasping and placing the object can be divided into several different phases. They started off with the reaction phase at the beginning of the trial; this represents the time when they initially heard the tone. This phase was consequently followed by the acceleration phase, where they rapidly moved their hand at an increased speed to meet the Passer’s hand in midair. As soon as the two hands become closer in midair, the Receiver had to reduce their speed to successfully grasp the object from the Passer, which constituted the deceleration phase. Once the object had been grasped from the Passer, the Receiver had to decide whether the object required further rotation. Since the Receiver had to place the target object in the set target area, it required them to make more precise and detailed movement to complete their task. On the contrary, the Passer’s movement only required the single action of moving the object towards the Receiver. Furthermore, the Passer was holding the target in the beginning, thus they became the leader in this relationship, which made them accountable for the decision making. As they got to decide how to pass the object and where to hand it off, it put more constraints on the Receiver, who had to adjust to the Passer’s choices. The results demonstrated that the Passer was able to represent the task of the Receiver, and used this representation to modify their action so as to accommodate the task of the Receiver. This allowed the Receiver to complete the task using a comfortable posture.

Overall, Experiment 1 allowed us to establish that in the basic passing and placing task, the Passer was disposed to rotate the object prior to passing it to the Receiver on those trials in which rotation was required. In the following experiments we examined the degree to which this pattern would hold when the Passer’s task was made more difficult, either by inducing a mechanical perturbation of the Passer’s moving arm, removing of eye gaze, increasing the precision requirements of the passing component of the task, role swapping and the addition of more complex rotations involving a cube.

3. Effects of unpredictable perturbation on planning and control in joint action

Synopsis

After establishing a baseline performance in Experiment 1, an external mechanical perturbation to the Passer's bicep was introduced on randomly selected trials in Experiment 2 to examine strategy formation within the concept of planning and action execution in joint action. Perturbation studies, which have primarily been carried out on single person studies, have provided important insights into the processes involved in the online control of actions.

Pulses of magnetic stimulation were administered to the right bicep of the Passer, which resulted in a series of involuntary flexions of their elbow by approximately 8cm per pulse. This perturbation occurred on randomly selected trials that could not be anticipated by either participant. The aim of this perturbation was to increase difficulty of the Passer's task and examine the immediate, online response of both participants as well as to examine their overall strategic adjustment to the presence of perturbation trials. Due to the unpredictable ordering of the perturbation trials, it was hypothesised that participants would apply a consistent strategy throughout the experiment. Furthermore, the perturbation trials would result in the application of increased online compensatory strategies associated with uncertainty resulting in increased online adjustments and TTP. The application of a consistent strategy would enable participants to be more predictable towards their partner, allowing both to plan their movements prior to execution.

The results showed that participants applied a single, consistent strategy throughout the experiment, regardless of the condition. The Passer rotated their hand prior to pass off and this was independent of perturbation. Impairment in one member of the pair also led to more online adjustments in both participants, indicating an increased difficulty in task execution, as well as a decreased time to pass the object. These results suggest that the benefits of being predictable to one's partner can apply even when the difficulty of one participant's task is increased considerably. It can be postulated that a partner's task requirements are not only incorporated in one's own actions, but that actors are able to adapt their movement to an externally induced impairment in their partner.

Introduction

Experiment 1 gave us a brief insight to the role of cooperative behaviour and established that two people indeed share their work load by considering their partner's task within their own action system to complete an overall goal efficiently. It was posited that the Receiver had an increased work load, thus the Passer decided to take on some of the Receiver's task. Although this presumably affected the Passer's comfort, nevertheless it allowed them to successfully achieve the task quicker. The results were in line with previous studies on joint action (Glover & Dixon, 2012, Sebanz et al. 2003). However, the current experiment was interested in how the introduction of perturbation to one person's bicep would affect people's cooperation in terms of planning and controlling their movement. The aim of the current experiment was to apply a perturbation to make the Passer's movement harder to control and the Receiver's task more difficult in predicting their partner's trajectory. This will cause a potential problem for both of them, as this may affect their planned movement and require greater use of online control.

Movements have been shown to be planned prior to their initiation based on an analysis of target features and their relation to the effectors (Glover, 2004). However, this pre-planned action does not consider any unanticipated circumstances that could disrupt the movement. The control system accounts for any errors that occur during the execution and adjusts the motor program quickly based on visual and proprioceptive feedback of the target (Glover, 2004). This control system is evident in many perturbation studies, where movements cannot be anticipated for and thus require the use of online correction in flight (Day & Lyon, 2000; Pisella et al., 2000).

The motor system is naturally attracted to the target, which allows the arm to quickly correct its trajectory without any conscious awareness. Previous perturbation studies have shown that goal directed movements were unconsciously adjusted in flight based on proprioceptive information provided by the effectors and visual feedback of the new target location (Komilis et al., 1993). Furthermore, corrections occurred rapidly and early on in the movement (Paulignan et al., 1991a, Paulignan, MacKenzie, Marteniuk & Jeannerod, 1991b). Whilst planned movements are constructed with a conscious influence, online corrections are involuntarily and do not rely on conscious influence (Castiello, Bennett and Stelmach, 1993; Castiello et al., 1998; Prablanc & Martin, 1992).

Previous studies on perturbation have involved single persons, however the current thesis is novel as it is not only examining how one person responds to a perturbation, but how two people account for an unanticipated perturbation within a joint action, and particularly how it affects their joint action strategy formation. The repetitive magnetic stimulations applied to the Passer's bicep resulted in a series of involuntary flexions of the elbow joint. These stimulations occurred on a random 30% of trials. Past research on unpredictable perturbations has shown that participants would adjust and correct their movement trajectory in relation to the 'new' location or size of the object (Castiello et al., 1998; Goodale et al., 1986; Paulignan et al., 1990; 1991a, b; Pisella et al., 2000). It was expected that when perturbation would occur in an unpredictable manner, participants would adjust their movements resulting in the greater application of online control. Furthermore, as the perturbation occurred on randomly selected trials, participants could not anticipate the perturbation. Thus it was predicted that the Passer would minimally rotate the object and apply a single consistent strategy throughout the experiment irrespective of the perturbations.

Experiment 2

Experiment 1 showed that the Passer used a representation of the Receiver's action to complete the passing task. Experiment 2 sought to examine the aspects of action planning and execution on joint action through the application of a mechanical perturbation applied to the Passer. Here, as in most previous perturbation studies (Georgopolous, Kalaska & Massey, 1981; Pauligan et al., 1991a, b; van Sonderen, van der Gon & Gielen, 1988) the stimulation was given on randomly selected trials. As such, this approach allowed us to examine the immediate, online response of both participants to an unexpected perturbation, as well as to examine their overall strategic adjustment to the presence of perturbation trials.

Due to the perturbations occurring on random trials, neither the Passer nor the Receiver could anticipate the stimulations and thus two possible outcomes could be envisioned. First, it might be that the participants adopt a *flexible strategy.* This strategy would have the benefit of allowing the actors to optimize their performance across both perturbed and control trials. To do this, participants could wait to see if a given trial was a perturbation trial, and if so, adjust their strategy so as to accommodate the difficulties the perturbation caused in the Passer's ability to control their movement. This could be done most directly by having the Passer rotate the object less in the perturbation trials, leaving more of the task to the Receiver and decreasing the latter's end-state comfort. On this analysis, we would expect an effect of the perturbation on ROTA, with the values being closer to zero in the perturbation condition than in the control condition. Further, there would be little to expect a correlation between ROTA or TTP on those trials with stimulation versus those without.

Second, it might be that participants would choose a *consistent strategy* that served to make them more predictable to their partner (Vesper et al. 2011). This strategy would likely still account for the increase in difficulty for the Passer in the perturbation trials by having the Passer rotate less, but to be predictable they would also rotate less in the control trials. On this hypothesis, although the effects of orientation condition on ROTA should be moderated relative to Experiment 1, there should be no interaction between orientation and perturbation conditions. Further, if a consistent strategy were employed regardless of condition, there should be a large positive correlation for ROTA and time to pass between trials with and without stimulation. That is, the Passers should tend to rotate the same amount and attempt to move at a similar speed whether or not the trial is a perturbation trial, making them more predictable to their partner. Given that the trials in which a perturbation was applied could not be predicted by either participant, the latter hypothesis was favoured.

It was also hypothesised that the presence of perturbation would result in an increased number of online adjustments in the Passer (OA-Pass) and the Receiver (OA-Rec). Whereas the physical effects of the stimulation itself could contribute to an increase in OA-Pass by causing involuntary movements, any increase in OA-Rec in the perturbation condition would strictly reflect their need to adjust to the vicissitudes of the Passer's movements. Alternatively, if greater online control was not required during the perturbed movement, then the null hypothesis predicted that no difference in online adjustments for the control and stimulation trials would exist. It was also expected that TTP would be longer on the perturbed trials as these would result in an increased number of online adjustments due to the stimulation interfering with the initial planned action. If stimulation, on the other hand, did not increase task difficulty for the Passer, then TTP should not differ between the perturbed and non-perturbed conditions.

Method

Participants

Ten pairs of participants took part in Experiment 2. All were healthy, right handed individuals with normal or corrected vision, and all were naïve as to the exact purpose of the study. In each pair, the Passer was assigned to receive muscular stimulation from a Magstim^{TM} Transcranial Magnetic Stimulation (TMS) machine – this participant was screened for safety prior to running the study. The other member of the pair did not receive any muscular stimulation. All participants provided their informed consent prior to participating and received course credit.

Stimuli and Apparatus

Stimuli and apparatus were the same as in Experiment 1, except that a TMS machine (Magstim, Ltd), was employed on some of the trials. Stimulation was applied to the skin over the right bicep of the Passer at a rate of 10 Hz for one second (10 pulses total), on randomly determined trials. Stimulation began coincident with the sounding of the tone to begin the movement.

Data Analysis

Analysis was as in Experiment 1, except that perturbation was entered as a second independent variable along with orientation condition. Thus the data were analysed using a repeated measures 3 (orientation condition) x 2 (perturbation) ANOVA, with participants as a random variable.

Further, we measured the Pearson's correlation between each Passer's rotation in the perturbation and control trials (r_ROTA). To avoid spurious results, we used as a measure of rotation the difference between the +90° and -90° orientation conditions for each participant. Thus the difference in rotation in the perturbation condition was correlated to that in the control condition across participants, and the results showed how consistently the Passer applied their strategy. We also measured the Pearson's correlation between the time to pass in the perturbation and control trials (r_TTP) to index further this degree of consistency across conditions. For both r_ROTA and r_TTP a Kolgorov-Smirnov test was run to ensure normality. Here and in the ensuing experiments, where normality was violated, the results of the K-S test are reported and the data are instead analysed using a Spearman's correlation.

Procedure

Prior to commencing testing, the Passer was screened for safety regarding magnetic stimulation using the same guidelines as applied to transcranial magnetic stimulation (Wasserman, 1998). Once their suitability was determined, the motor threshold (i.e., the minimum amount of stimulation required to elicit a visible muscle response) for their right biceps was determined by single pulse stimulation. For the experimental trials, repetitive pulses set to 200% of the motor threshold were applied. This resulted in a flexion of the elbow of approximately 8 cm at rest.

The trial procedure was identical to that used in Experiment 1, except that on each trial, the experimenter held the stimulation coil pressed firmly against the Passer's right bicep and maintained the coil in this position throughout the entire trial. The Passer received randomly-determined magnetic stimulation to their right bicep on 30% of the trials (18 total, six per colour); the remaining 70% (42 total, 14 per orientation) were control trials.

Results

A total of 39 trials (M = 6.5%, SD = 2.41%) from all participants were excluded from the final analysis because the task was not completed successfully. Fig. 3.1 shows mean ROTA as a function of orientation condition in the perturbation and control condition. There was an overall effect of orientation condition on ROTA (F [1.07, 9.67] = 9.78, $p < .05$), but no interaction between orientation condition and perturbation (F [2, 18] = 0.176, $p > .05$). This result supported the hypothesis that a single consistent strategy would be employed across perturbation conditions.

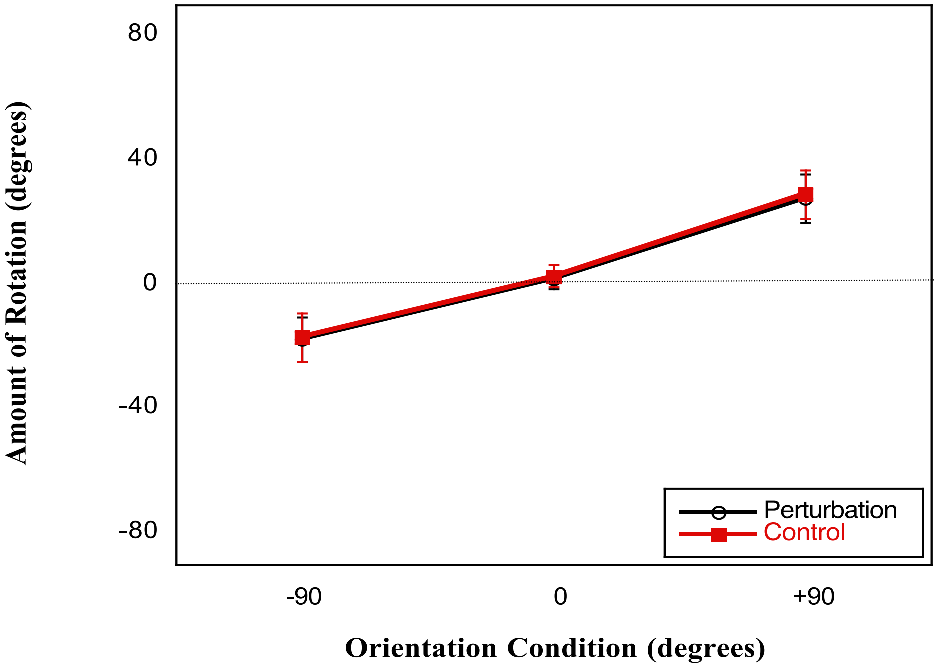

Figure 3.1. Mean degree of ROTA as a function of orientation condition in the perturbation and control conditions. Error bars represent standard errors of the mean.

Also consistent with this view was the large positive correlations found between perturbation and control conditions for r_ROTA, $r = .99$, $p < .001$ (Figure 3.2, left panel); Passers who rotated more or less in the perturbation condition also rotated more or less in the control condition. There was also a large correlation between time to pass (r_TTP) in the perturbation and control conditions, $r = 0.79$, $p < .01$, suggesting that participant pairs who were faster in the perturbation condition were also faster in the control condition (Figure 3.2, right panel).

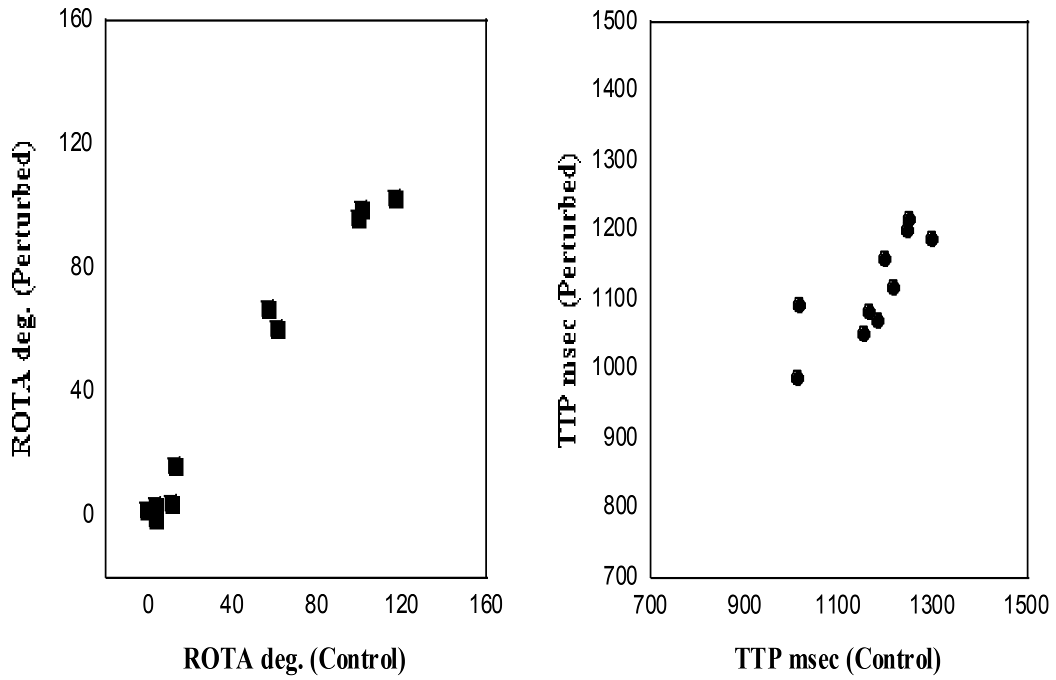

Figure 3.2. Comparison of mean ROTA (left) and TTP (right) of individual pairs between the control (x-axis) and perturbation (y-axis) conditions. ROTA in the correlation analysis was measured as the difference between ROTA in the +90° and -90° conditions.

Whilst no significant effect of orientation condition on OA-Pass (F [1.07, 9.67] = 0.99, p > .05), OA-Rec (F [2, 18] = 0.215, p >.05) and TTP (F [2, 18] = 3.10, p > .05) was observed, perturbation, on the other hand, had a significant effect on both OA-Pass (F [1, 9] = 33.54, *p* < .001) and OA-Rec (F [1, 9] = 29.64, p < .001). The number of online adjustments was larger for the perturbation trials than control trials, suggesting that the perturbation increased the demands on the online control system (Figure 3.3). Disruption of the movement through magnetic stimulation also had an effect on time to pass (TTP) (F [1, 9] = 8.99, *p* < .05) with TTP being significantly longer in the control condition than in the perturbation condition.

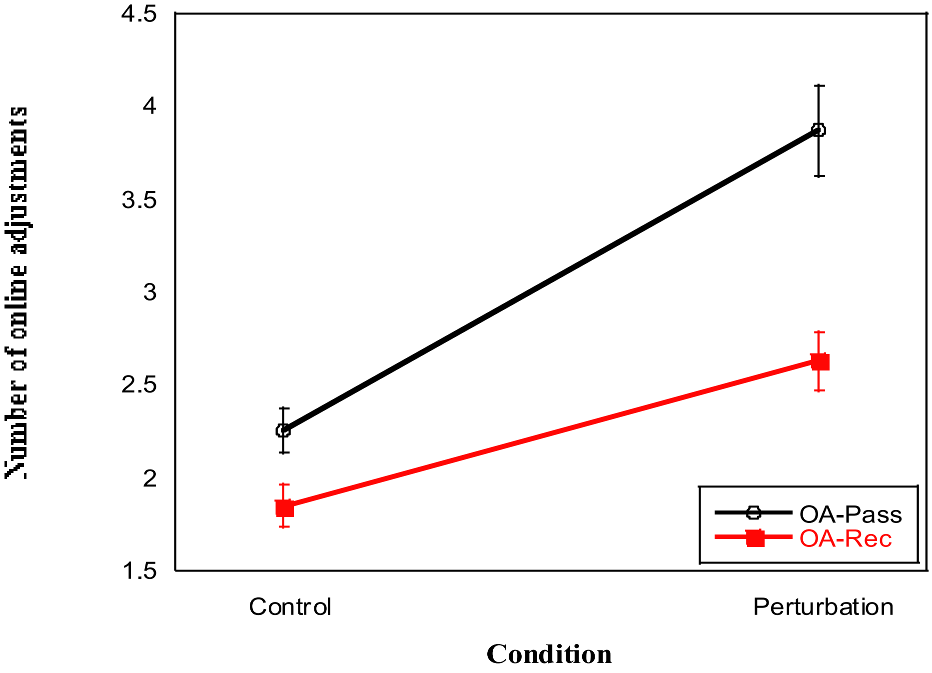

Figure 3.3. Mean number of online adjustments for the Passer (OA-Pass) and Receiver (OA-Rec) in the control and perturbation condition. Error bars represent standard errors of the mean.

Discussion

The main results of Experiment 2 showed that there was a strong effect of orientation on ROTA. Even when the Passer had their movement perturbed through magnetic stimulation on some trials, they nevertheless utilised a single, consistent strategy in rotating the object. In contrast, there was no evidence that Passers adopted a flexible rotation strategy based on the presence or absence of the perturbation. Rather, the Passers rotated the same amount whether or not a perturbation was applied and the time they took to pass was highly correlated across the perturbation and control conditions. It would appear from this that the benefits of being predictable to one's partner can apply even when the difficulty of one participant's task varies considerably.

On the other hand, perturbation did *not* affect ROTA relative to the control condition. This is also in line with our hypothesis, since participants were not aware of the timing of the stimulation and thus could not anticipate the perturbation. This suggests that at a movement planning level at least, participant pairs had already determined the general strategy they would adopt prior to each trial beginning. The stimulation did not affect how the Passers carried out their role and they continued to rotate the object in the orientation condition irrespective of whether perturbations were applied.

Evidence that the perturbation affected behaviour was manifest in at least two ways: For one, there was a clear effect of the perturbation on the number of online adjustments made by both participants. Both OA-Pass and OA-Rec were larger in the perturbation condition. The increase in OA-Pass is perhaps not surprising, as the Passer received stimulation to their bicep and thus experienced involuntary contractions. However, the increase in OA-Rec can only be attributed to an increased difficulty in predicting the Passer's movement path resulting in the need for more online adjustments by the Receiver. This result itself cannot be explained by the participants taking longer to make the movements, or being more careful when the perturbations arose, because the total time to pass was in fact lower in the perturbation than control condition. It was expected that the application of the stimulation would have slowed participants' ability to move and react to the task. However the fact that the TTP in the perturbation trials decreased indicates that the stimulation resulted in a startle effect. The inability to expect and anticipate the randomised stimulation caused the Passer to experience a 'jolt' every time they received the stimulation, thus making the Passer pass the object quicker and speeding up their overall movements. The only plausible explanation for the stimulation effect on OA-Pass and OA-Rec is thus that the perturbation resulted in an increase in workload for the online control system, just as has been shown in perturbation studies involving individuals (Bock & Jungling, 1999; Castiello et al., 1998; Paulignan et al., 1991a, b).

For another, Passers generally rotated the object less than had the Passers in Experiment 1. This suggests that participants adjusted to the possibility of a perturbation by adopting a compromise strategy in which the task of rotating the object was shared more equally. This likely was done in order to compensate for the extra difficulty faced by the Passer in the perturbation trials, which was in line with the stated hypothesis.

Although the results suggest that actors in a joint task are inclined to adopt a predictable strategy even under conditions that differed considerably, a potential limitation of this finding relates to the randomised ordering of the perturbation trials. Specifically, as participants could not anticipate on which trials a perturbation would occur, it would be impossible for them to plan a movement prior to a trial which could take the presence or absence of the perturbation into account. Further, because the online control system is adapted towards making relatively small adjustments (Goodale et al., 1986), and gross postural adjustments are costly to make in flight (Paulignan et al., 1991a) the adoption of the single, compromise strategy may in fact be optimal in terms of overall effort. Experiment 3 sought to examine this issue further by blocking the trials in which the perturbation occurred, making the presence or the absence of a perturbation on an upcoming trial known in advance to the participants.

4. Effects of predictable perturbation on planning and control in joint action

Synopsis

The aim of the present chapter was to investigate the effects of a predictable artificial impairment on the coordination of two cooperating partners. This kind of perturbation resembles interactions with people suffering from chronic motor impairments, such as Parkinson's or Huntington's disease wherein people have a lack of control over their movement.

In the previous chapter, the introduction of unpredictable stimulation applied to the Passer led to the application of a consistent strategy. If perturbation was to occur in a predictable manner, it would be predicted for participants to be employing flexible strategies consistent with the demands of the task across the two different blocks. The Passer would be expected to rotate the object more on the blocks of trials where no perturbation is applied, than on the trials involving perturbation. The results showed that irrespective of condition, both participants employed a single general strategy throughout the experiment. A possible explanation for this is that both the Passer and the Receiver were aware of the two conditions and knowing that the Passer would be hindered throughout the perturbed condition, both participants decided to adopt a general strategy of having the Receiver do the rotating regardless of the condition. This strategy not only allowed them to be more predictable towards their partner but also shows that when people cooperate with a partner suffering from a chronic motor impairment, they compensate for their lack of cooperation through division of labour.

Introduction

Damage to the central nervous system, particularly the basal ganglia and the cerebellum can lead to trembling and involuntary shaking, which impairs motor functioning. Parkinson's Disease (PD) and Huntington's Disease (HD) are two of the many disorders that chronically impair people's motor abilities. All of these diseases involve a lack of motor control, which results in tremor and involuntary movements, and causes great difficulty in performing fine hand and finger movements vital for reaching and grasping (Wenzelburger, Raethjen, Loffler, Stolze, Illert & Deuschl , 2000).

Previous studies have demonstrated that patients suffering from chronic motor impairments will have different kinematic patterns for reaching and grasping objects (Alberts, Saling, Adler & Stelmach, 2000; Bonfiglioli, De Berti, Nichelli, Nicoletti & Castiello, 1998; Castiello, 1999; Schettino, Adamovich, Henig, Tunik, Sage and Poizner, 2005; Weiss, Stelmach & Hefter, 1997). Bonfiglioli et al. (1998) demonstrated that patients suffering from HD had longer movement times for fast reaching conditions relative to PD and healthy subjects, who performed comparable. Furthermore, the time to peak acceleration was shorter for HD patients followed by a longer deceleration time in comparison to both PD and Control subjects. Similarly, elderly people exhibit a longer deceleration phase in comparison to younger people, who show a symmetrical shape for both acceleration and deceleration. The increased deceleration phase allows individuals to account for errors and adjust these within the transport phase in their movement (Cooke, Brown & Cunningham, 1989).

Whereas previous research has focused on PD and HD patients reaching and grasping perturbed objects, the current experiment is novel in examining physical interaction in people with consistent perturbed movements. In particular, how will an impairment resulting in involuntary movements and trembling, closely resembling that of a chronic motor impairment, affect the kinematics and coordination of a healthy cooperating partner? Specifically, what compensatory strategies will be employed by the participants during this predictable impairment? The anticipation of an upcoming perturbation could be an important motivator to adopt a flexible strategy.

The previous chapter revealed that unpredictable stimulation applied to the Passer's bicep resulted in the formation of a general compensatory strategy employed by both participants. Given that in this experiment stimulation is predictable, participants would be able to plan an upcoming action with knowledge of whether or not a perturbation would occur. It was predicted that the Passers would adopt a flexible strategy based on the demands of each condition. Receiving magnetic stimulation continuously throughout a single block will hinder the Passer and thus it was predicted that the Passer would rotate large amounts on the control trials, but less on the perturbation trials.

Experiment 3

Although Experiment 2 provided valuable insights into how participants respond to the possibility of a random motor impairment occurring in the Passer, it could not answer what would happen if participants knew in advance whether or not the movement would be perturbed. Providing foreknowledge of the conditions of an upcoming action could plausibly provide a valuable incentive for participants to adopt a flexible strategy. In the present experiment, a mechanical perturbation identical to that used in Experiment 2 was applied. However, here perturbation and control trials were blocked. Specifically, for half the participant pairs, all of the first block of trials involved stimulation of the Passer's bicep, and the second block were control trials; the converse was true for the remaining half of the participant pairs. As such, participants always knew in advance which type of trial they would be undergoing.

The primary goal of this experiment was to examine the effects of a predictable perturbation on joint action planning, in particular with regards to strategy formation. The secondary goal was to confirm the effects of perturbation on online parameters. Considering that participants would be able to plan an upcoming action in full knowledge of whether or not the Passer would be subject to a perturbation, it was predicted that the Passers would now adopt a flexible strategy that adapted to the different demands of each condition. Based on the results of Experiments 1 and 2, it was predicted that the Passer would be more inclined to rotate the object in the unperturbed condition and less in the perturbed trials; thus an interaction between perturbation and orientation condition on ROTA should be observed. The alternative hypothesis was that participants would apply a consistent strategy based on the demands of the task and the effect of orientation condition on ROTA would be consistent across perturbation conditions. Further, if a flexible strategy were employed, there would be no reason to expect a correlation to exist between perturbation and control conditions for r_ ROTA or r_TTP. In contrast, if participants adopted a consistent strategy across conditions, the pattern of effects should closely resemble those of Experiment 2: there should be no interaction between perturbation and orientation conditions for ROTA, and large positive correlations should exist across conditions for r_ROTA and r_TTP.

Regardless of the strategy adopted, as online control occurs during movement execution there should be no benefit of having foreknowledge of trial type on the requirement to adjust to the perturbation in flight. It was thus predicted that similar effects of the perturbation on online adjustments would be observed as in Experiment 2. Both OA-Pass and OA-Rec should be larger in the perturbation condition than in the control condition. Conversely, if the perturbation did not increase task difficulty, there ought to be no difference in OA-Pass and OA-Rec between the perturbed and non-perturbed trials.

In contrast to the results of Experiment 2, it was also predicted that TTP would be longer during the perturbation trials due to the predictable nature of the stimulation. This would enable participants to anticipate the ‘jolts’ and thus plan a longer movement to compensate for the perturbation. An increase in TTP would enable them to obtain more control over their movement. If this did not happen, then the alternative hypothesis would suggest to obtain no difference in TTP for either experimental condition.

Method

Participants

Eight pairs of participants took part in Experiment 3. All were healthy, right handed individuals with normal or corrected vision, and all were naïve as to the exact purpose of the study. As in Experiment 2, one was assigned to receive muscular stimulation from the TMS machine – this participant was screened for safety prior to running the study. The other participant did not receive any muscular stimulation. All participants received course credit and provided their informed consent prior to participating.

Stimuli and Apparatus

Stimuli and apparatus were the same as in Experiment 2.

Data Analysis

Analysis was carried out on kinematic data as in Experiment 2, except that order (stimulation first vs. stimulation second) was included as a between-subjects variable. The data were analysed using a mixed design 2 (order) x 3 (orientation condition) x 2 (perturbation) ANOVA, with participants as a random variable.

Procedure

The procedure was identical to that of Experiment 2, except that pairs of participants were exposed to one block of stimulation trials (30 trials, or 10 per orientation condition) and one block of control trials (30 trials, 10 per orientation condition), with order of blocks counterbalanced across participant pairs.

Results

A total of 38 trials (M = 7.92%, SD = 7.55%) from all participant pairs were excluded from the final analysis because the task was not completed successfully. Fig. 4.1 shows mean ROTA as a function of orientation in the perturbation and control conditions. There was no effect of orientation condition on ROTA (F [1.04, 6.24] = 2.27, $p > .05$). Contrary to the stated prediction that participants would adopt a flexible strategy given foreknowledge of trial condition, there was no interaction between perturbation and orientation for ROTA (F [2, 12] = 1.14, p > .05).

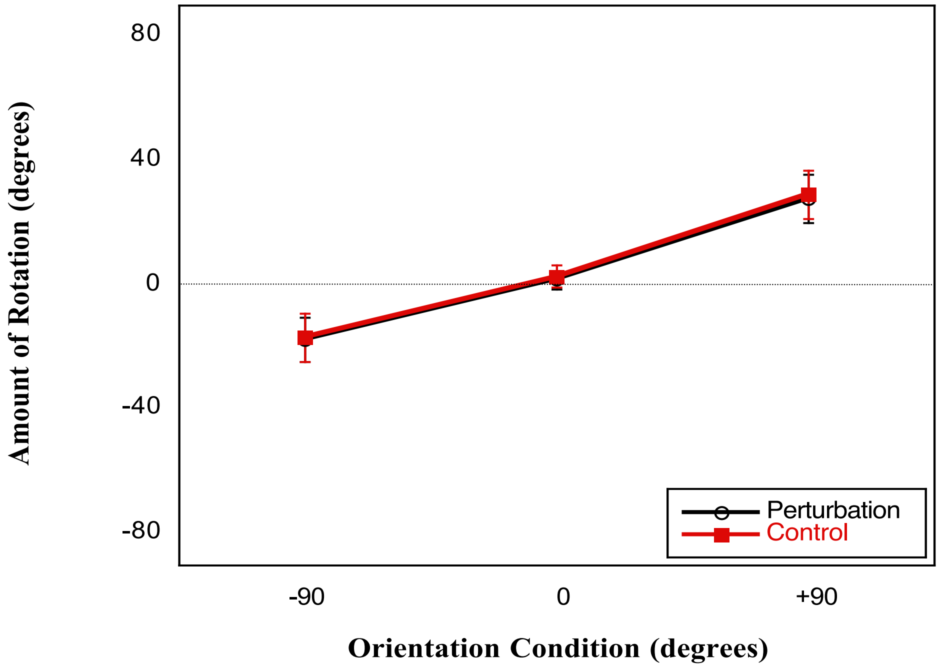

Figure 4.1. Mean degree of ROTA as a function of orientation condition in the perturbation and control conditions. Error bars represent standard errors of the mean

Also inconsistent with our predictions, a large positive correlation existed between the perturbation and control conditions for r_ROTA, $r = 0.92$, $p < .01$, showing that Passers who rotated more on the perturbation trials had a strong tendency to rotate more on the control trials (Figure 4.2, left). Further, a large positive correlation was found between perturbation and control conditions for the r_TTP data, $r = 0.89$, $p < .01$, indicating that pairs who took longer to pass the object on the perturbation trials also took longer on the control trials (Figure 4.2, right).

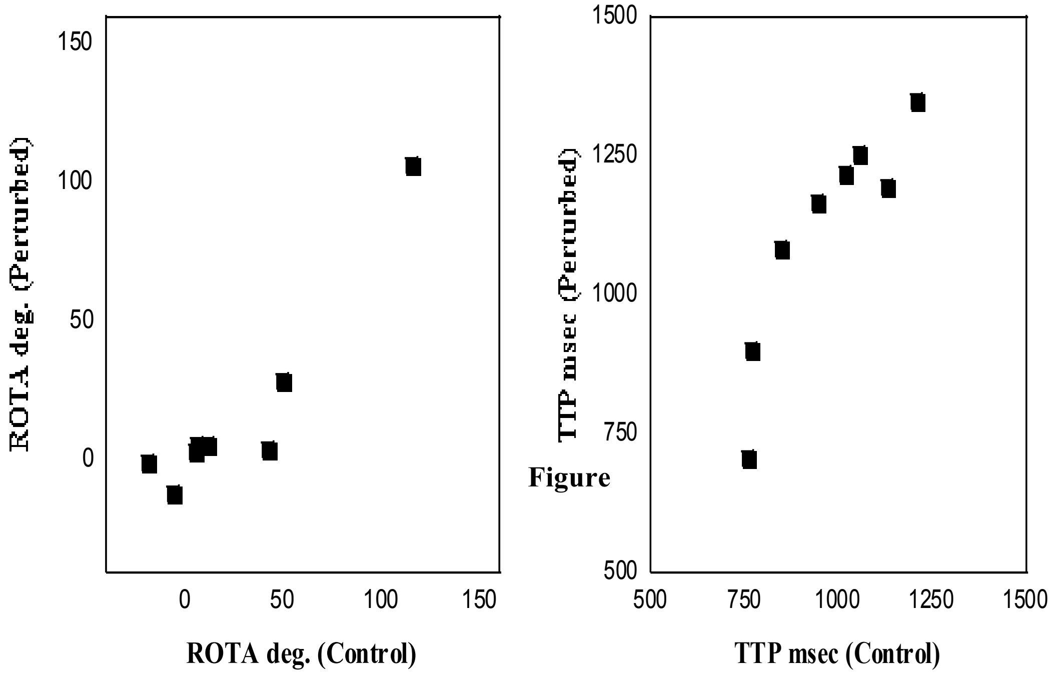

Figure 4.2. Comparison of mean ROTA (left) and TTP (right) of individual pairs between the control (x-axis) and perturbation (y-axis) conditions.

As predicted, there was also an effect of perturbation on OA-Pass (F [1, 6] = 45.14, p < .01) and OA-Rec (F [1, 6] = 36.22, p < .01) with an increased number observed in the perturbation condition relative to the control condition (see Figure 4.3). This implies that the perturbed trials put an increased burden on the online control system for both participants. In contrast to Experiment 2, time to pass (TTP) was longer in the perturbation condition than in the control condition (F [1,6] = 23.54, p < .01). Order did not affect or interact with any other variables.

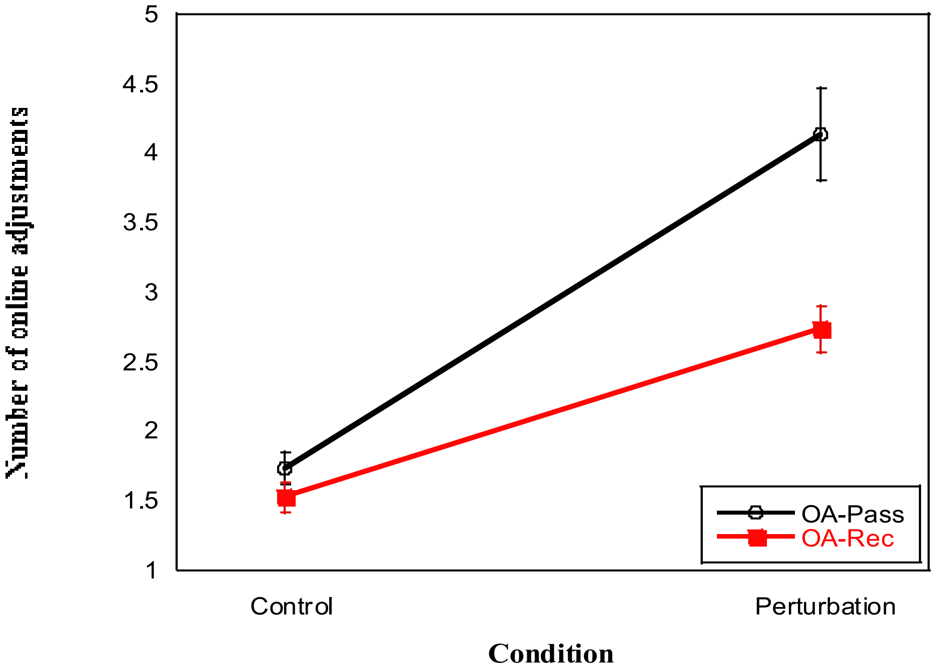

Figure 4.3. Mean number of online adjustments for the Passer (OA-Pass) and Receiver (OA-Rec) in the control and perturbation condition. Error bars represent standard errors of the mean.

Discussion

The present study sought to examine the effect of an induced motor perturbation on one of the participants. It was predicted that the blocking of the stimulation trials would result in the employment of different strategies by the participant pairs in the perturbed and control trials. Specifically, it was posited that orientation condition would affect ROTA only in the control condition. The results of Experiment 3 did not conform to the hypothesis that participants would adopt a flexible strategy if they were given foreknowledge of the conditions on each trial. Instead, the evidence overwhelmingly supported the notion that participants kept to a single, predictable strategy, albeit one that accommodated the increased difficulty faced by the Passer on balance. It seems that the mere knowledge that some trials would involve a hindrance led the Passer to apply an overall more balanced strategy in terms of workload by not rotating the object. This strategy was applied consistently regardless of which condition occurred first. Not only were there no interactions between perturbation and orientation conditions for ROTA but large positive correlations were found when comparing behaviour on the perturbation and control trials for both r_ROTA and r_TTP. In these respects, the results closely resembled the findings of Experiment 2, as did the large effect of perturbation on the number of online adjustments made by each actor.

Some aspects of the results did not entirely match those of Experiment 2, however. For one, here there was no effect of orientation condition on ROTA. It appeared that in general the Passer did not rotate in Experiment 3, whereas in Experiment 2 they had. Although seemingly anomalous, this result is interpretable if one assumes that participants adopted an overall strategy that took into account the increased demands placed on the Passer in the task as a whole. Relative to Experiment 2, where only 30% of trials were perturbation trials, here 50% of the trials included a perturbation. Thus, Passers may have responded by rotating the object even less in Experiment 3 than in Experiment 2, with the bulk of the rotation occurring after the object was passed. It is tempting to conclude that whereas participants in joint action tasks easily form an awareness of their partner's task, it may be that the flexibility of strategies they employ as a result are somewhat limited.

Perturbation had an effect on OA-Pass, OA-Rec and TTP. Similar to Experiment 2, perturbation resulted in an increased number of online adjustments for both participants. OA-Pass and OA-Rec were larger in the perturbation condition due to the fact that the Passer received magnetic stimulation which made them experience involuntary contractions. However, what is interesting is that OA-Pass and OA-Rec were somewhat similar. When the Passer received stimulation, they made more online adjustments to compensate for their trembling, and simultaneously the Receiver followed the Passer's path trajectory and as a result made more online adjustments as well.

A result that differed from that found in Experiment 2 was the reversal of the effect of perturbation on time to pass (TTP). Unlike Experiment 2, where TTP was smaller during the perturbation trials, in the current experiment TTP was increased in the perturbation condition. This is an interesting difference, given that the two experiments gave similar results in other respects. Our analysis of these results is that foreknowledge of the perturbation is likely the mitigating factor. In Experiment 2, in which the perturbation was unexpected, the noise and stimulation likely had a startling effect on the participants. Conversely in Experiment 3, participants knew when a perturbation trial was upcoming and could prepare for it in advance of each trial. It is assumed that pairs in Experiment 3 may have deliberately chosen to move more slowly in the perturbation condition in order to accommodate the increased difficulty of passing the object. Furthermore, it enables participants to effectively plan their movements and consider the stimulation within their action planning, resulting in a longer movement. In conjunction with the TTP results from Experiment 2, this suggests that participants did adopt a flexible strategy in at least one respect. Regardless of how one chooses to explain the effects of the perturbation on TTP in Experiments 2 and 3, the perturbation did have the expected effect of increasing the difficulty of executing the task, as evidenced by the increases in the number of online adjustments for both participants when the perturbation was applied.

The present results suggest that when one member of a cooperating pair has a motor perturbation, different compensatory strategies are employed in comparison to when people have random perturbations. It could be postulated that the Passer opted for a more relaxing strategy of not rotating the object as a result of their increased task demands in comparison to the Receiver. The Passer acknowledged that their task demands exceeded that of the Receiver's task and perceived this within their own action planning, resulting in the deliberate effort of performing a lesser 'share' of the task. This would be in line with previous studies on joint motor actions (Blakemore & Decety, 2001; Chartrand & Bargh, 1999; Elsner, Hommel, Mentschel, Drzezga, Prinz, Conrad & Siebner, 2002; Glover & Dixon, 2012; Knoblich & Flach, 2001, 2003; Knoblich & Jordan, 2003; Sebanz, Knoblich & Prinz, 2003, 2005), which have shown that individuals perceive other people's actions and incorporate this perceived action onto their own action system. Consequently observing other people's actions influences an individual's choice of action planning.

On the whole, the current experiment demonstrated that Passers had shown themselves to be highly inclined to adopt a consistent strategy in planning whether and how much to rotate the object prior to hand off, not only when the conditions differed but also when they had foreknowledge of the presence of such a difference on the upcoming trial. One of the drawbacks of a flexible strategy is that it requires an increase in cognitive effort relative to using a consistent strategy. Given that the means of executing the task in Experiments 2 and 3 did not radically differ in the perturbation condition relative to control condition (the object was still passed over the table between participants), it may be that participants found it preferable to adopt a consistent strategy even when one of the participant's movements were impaired using magnetic stimulation.

The next experiment set out to examine what factors contribute to the concept of performing a joint action so effortlessly. One possible factor contributing to this role may be eye gaze. It has been shown that gaze direction provides important social information and clues to people's intentions (Allison, Puce & McCarthy, 2000), which alternatively influence action planning. To address this issue, the next experiment examined whether eye gaze is used as a factor to predict the outcome of a partner's movement.

5. Effects of gaze direction during an object passing task amongst dyads

Synopsis

Research has shown that eye gaze provides us with important social information, which allows us to infer people's goals and intentions (Allison et al., 2000; Baron-Cohen, Campbell, Karmiloff-Smith, Grant & Walker, 1995). Observing somebody else's gaze draws our attention to the direction of their gaze and enables us to predict their consequent action. Eye gaze could potentially play an important role amongst joint action since the direction of a gaze influences partners to orient their focus on to a common target of interest, as well as enabling us to communicate with a partner as an alternative or supplement to verbal communication. The aim of the current chapter was to examine the effects of eye gaze on the effects of joint action.

The current chapter removed facial information of both participants through the use of an occluder between the dyads. Based on previous research, it was hypothesised that predictability of a strategy formation would be reliant on gaze direction (Allison et al, 2000; Castiello, 2003), which is thought to act as a cue to allow participants to plan their movements. Consequently, it was hypothesised that the removal of such vital information would increase time to pass the object when eye gaze was removed.

The results showed that the removal of gaze cue through the insertion of the occluder did not have an effect of joint cooperation. Specifically ROTA was not modulated by gaze but was determined solely by orientation condition. Further, the high positive correlations found for r_ROTA and r_TTP in the previous experiments was also evident here, suggesting that both participants employed an overall single strategy and adopted this throughout the experiment, irrespective of the presence of the occluder. Finally, no effect of the removal of gaze information was found on either OA-Pass or OA-Rec. As such, the current data suggests that although gaze cues have an important function in social situations, they may not necessarily affect joint action.

Introduction

Social interaction is dependent on a variety of factors, such as verbal communication, body language and facial expressions. These factors allow us to share information about our emotions, mental states and actions. Eyes are the most frequently fixated region and the most vital aspect of the face giving insight to people's emotions, feelings, state of minds and intentions; it has been found that humans are born with an innate preference for observing eye-gaze (Batki, Baron-Cohen, Wheelwright, Connellan & Ahluwalia, 2000). Eye gaze is a very powerful tool to social cognition, as it allows people to communicate without the need of verbal communication (Emery, 2000). Focusing on somebody's gaze direction enables us to orient our attention to its focal point. Orienting our attention to the same object or target that another individual is looking at helps us to infer their mental state and predict their possible thoughts and future actions. This interest enables us to form a shared joint attention with our partner to successfully understand the person's intention and preference for the item (Bayliss, Paul, Cannon & Tipper, 2006).

Gaze is important in joint action, since people are able to infer people's intentions and goals through the mere observation of another person's eye gaze, and without gaze information problems could arise with planning these actions. Castiello (2003) examined the effects of eye gaze on an observer's kinematics. An actor had to reach for a spherical target object presented with a distracter object to the left or right of the target object. The distracter object, which was of same shape but different size, aimed to cause interference in the actor's movement kinematics (Tipper, Lortie & Bayliss, 1992). An observer then had to perform the same action as the actor with the exception of the distracter being absent. Although the distracter had been removed, a kinematic interference effect was demonstrated by the observer when eye gaze was visible. However, when the actor's eye gaze was hidden or when their gaze was fixed on the target object, no interference effect was observed in the observer. This implies that the observer was influenced by the actor's gaze direction, resulting in a representation of the distracter object and thus affecting the observer's action.

Pierno, Becchio, Wall, Smith, Turella & Castiello (2006a) tested the idea whether the sight of eye gaze would activate the same neuronal system as that of observing a motor (grasping) task. Participants observed 3 different videos that showed an actor performing a motor movement, a gaze condition, in which the actor solely looked at the object and a control condition, where the actor was standing behind the object neither grasping nor looking at the object. The results showed that the gaze condition evoked the same network of areas as the observed object-oriented grasping condition. This implies that following a partner's eye gaze facilitates motor activation within one's own action system.

Previous studies have shown that gaze direction is taken into consideration from an early age. However, children with autism have shown that although they are able to follow gaze, they are unable to infer to theory of mind and people's intentions (Baron-Cohen et al., 1995). In another study by Pierno, Mari, Glover, Georgiou and Castiello (2006b), an observer and a human model were seated opposite one another and observed three different experimental blocks. The observer, who was either a healthy child or an autistic child, watched the model either grasp an object, gaze towards the object or gaze away from the object. Consequently the observer had to grasp the object. Facilitation in relation to movement speed was observed in healthy children after they observed the model grasping the object or even gazing at the object. However, the autistic children failed to show any facilitation. Facilitation was not demonstrated in either the healthy and autistic children when the model's eye gaze was turned away from the object. When eye gaze was removed, the healthy children did not show a priming effect on their kinematics and thus showed longer movement duration. The results imply that eye gaze can have a priming effect and help facilitate a motor action. On the other hand, children with autism not only have difficulty inferring to the mental states of others through the mere observation of eye gaze, but the results of the current study also shows that deficit extends to future motor executions. A reason behind this may be due to functional abnormalities in the superior temporal sulcus (STS) and the inferior parietal lobule (IPL), which are known to activate during action observation.

Pierno, Becchio, Turella, Tubaldi & Castiello (2008) examined the regions involved in observing social interaction as well as observing gaze direction. Using fMRI, participants observed pictures of social or individual actions performed by two human agents whose gazes were either present or masked. In the social action, two individuals worked together whereas in the individual action, the two agents performed individual goal-directed tasks. The results showed that the social interactions evoked activation in the dorsal sector of the medial prefrontal cortex (dMPFC), an area known to be implicated in representing shared attention and goals. Gaze evoked activity in the inferior frontal gyrus (IFG), amygdala and the posterior superior temporal sulcus (pSTS) known to play a crucial role in the interpretation of actions and social intentions through the analysis of biological motion cues (Alison et al., 2000; Perrett, Smith, Potter, Mistlin, Head, Milner & Jeeves, 1985). Hence it would appear that gaze perception is intimately linked with processes involved in understanding others' intentions, which in turn would play a vital role in predicting their actions. As a consequence, removal of gaze information could presumably impair joint action representation, causing problems with maintaining predictability and possibly with planning joint actions more generally, in turn leading to a greater reliance on online control processes.

Experiment 4

In the joint passing and placing task used here, one might speculate that gaze information could play an important role in strategy formation and execution. For example, the Passer may indicate their intention to begin the movement by subtle gaze cues such as fixating on the block, or their intention to rotate the object and/or move it to a particular area by changes in gaze and/or facial expression. The removal of gaze information in the present paradigm might thus potentially have a detrimental effect on the ability of pairs to plan and execute the joint task. In particular, one might expect the Receiver to be especially sensitive to gaze information as the Passer is the one who initiates the action and also who decides where to pass the object and how much to rotate it. If gaze is important for joint action planning by allowing actors to understand each others' intentions, then removing it ought to lead to greater reliance on online control, reflected in an increase in all of TTP, OA-Pass and OA-

Rec in the blocked gaze condition. Conversely, if gaze is not important, there should be no effect of removing gaze on these variables.

Regardless of the effects of gaze on online control parameters, there is no reason to believe that removing gaze will change the overall strategy employed. Thus, as in the previous experiments, it is expected to observe a significant positive correlation for r_ROTA and r_TTP. Conversely, if removal of gaze information leads to the utilisation of a different strategy between the joint actors, then neither r_ROTA nor r_TTP should be significant.

Method

Participants

Ten pairs of participants took part in Experiment 4. All were healthy, right handed individuals with normal or corrected vision, and all were naïve as to the exact purpose of the study. All participants provided their informed consent prior to participating and received course credit.

Stimuli and Apparatus

Stimuli and apparatus were the same as in Experiment 1, except that an occluder was employed on one block of the trials to prevent both participants from seeing each other's faces. The occluder was a wooden partition that was placed in between both participants. The partition was 91cm wide and 46.5cm high and was secured onto two stands (legs) of 60cm in height and 45.5cm long. The occluder was placed in the centre of the table, at a distance of 29.25cm from the Passer and 26.75cm from the Receiver. The height between the end of the bottom partition and the surface of the table was 39cm. The partition was large enough to block the view of the faces of all participants irrespective to their heights. Figure 5.1 shows the experimental setup when the occluder was present. The current experiment also employed a wooden box to define the target area, which had not been utilised in the preceding 3 experiments. This required participants to precisely set down the rectangle in the box. The target area of this box measured 7.1 x 2.4 cm.

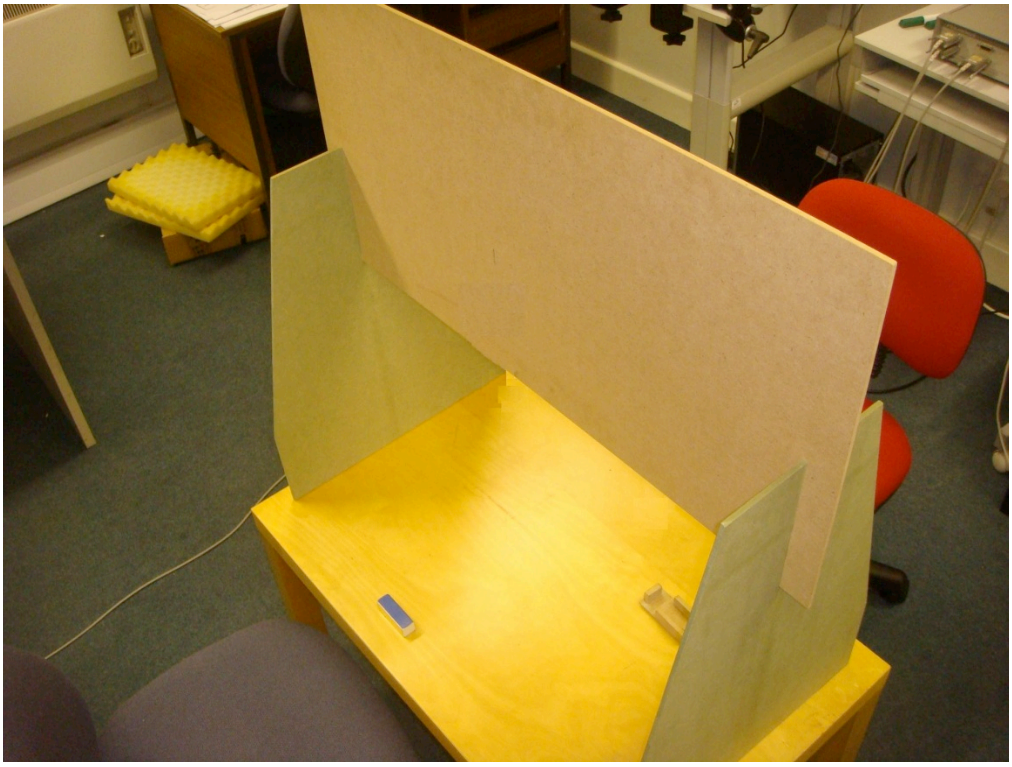

Figure 5.1: Experimental setup depicting occluder.

Data Analysis

Analysis was carried out on kinematic data as in Experiment 1, except that occluder was entered as a (blocked) second independent variable along with orientation. The occluder and orientation were both within-subject factors with order as the between-subject factor. Data were analysed using a mixed measures 2 (order) x 3 (orientation) x 2 (occluder) ANOVA.

Procedure

The procedure was identical to that of Experiment 1, except that pairs of participants were exposed to the occluder on one block of the trials (30 trials, or 10 per orientation) and a control block where the occluder was removed (30 trials, or 10 per orientation), with order of blocks counterbalanced across participant pairs. As with the previous experiments the Passer was instructed to pass the object in mid-air to the Receiver who then had to place it down in the defined target area. The occluder was large enough to block the participants’ view of each other’s faces, but high enough not to obstruct the passing of the block itself.

Results

A total of 29 trials (M = 4.83%, SD = 2.88%) from all participants were excluded from the final analysis because the task was not completed successfully. Fig. 5.2 shows mean ROTA as a function of orientation in the occluder and no-occluder condition. There was a main effect of orientation on ROTA (F [2, 16] = 1185.65, $p < .001$), however the occluder had no effect on ROTA (F [1, 8] = 1.33, $p > .05$).

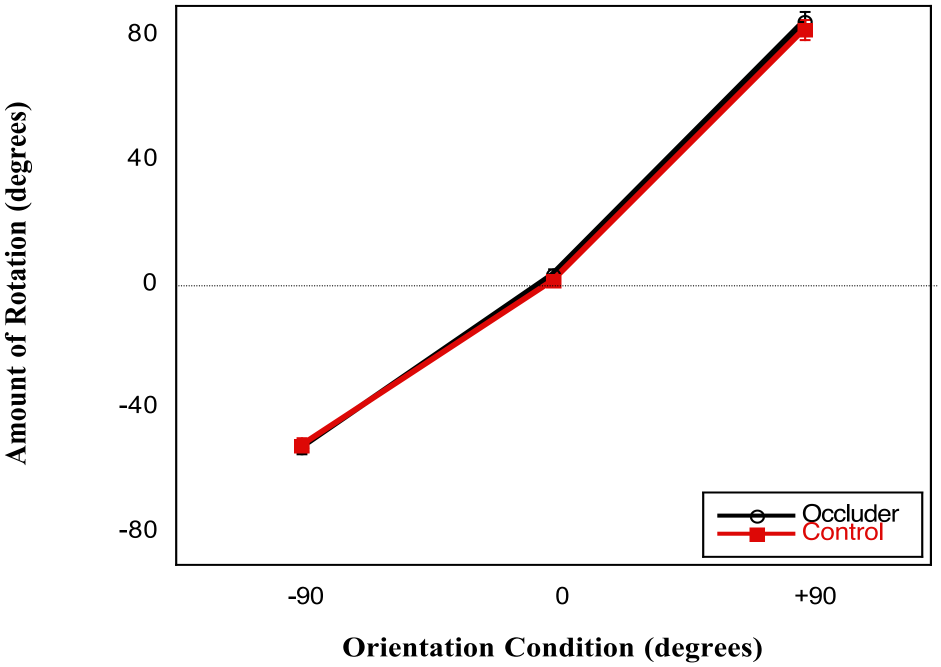

Figure 5.2. Mean degree of ROTA as a function of orientation in the occluder and control conditions. Error bars represent standard errors of the mean

A large positive correlation existed for r_ ROTA, r = 0.81, *p* < .01 showing that Passers rotated a similar amount in both the occluder and the control conditions (Figure 5.3, left panel). A large positive correlation was also found between the occluder and control condition for r_TTP, r = 0.88, *p* < .001, indicating that pairs who took longer to pass the object in the occluder trials also took longer on the control trials (Figure 5.3, right panel).

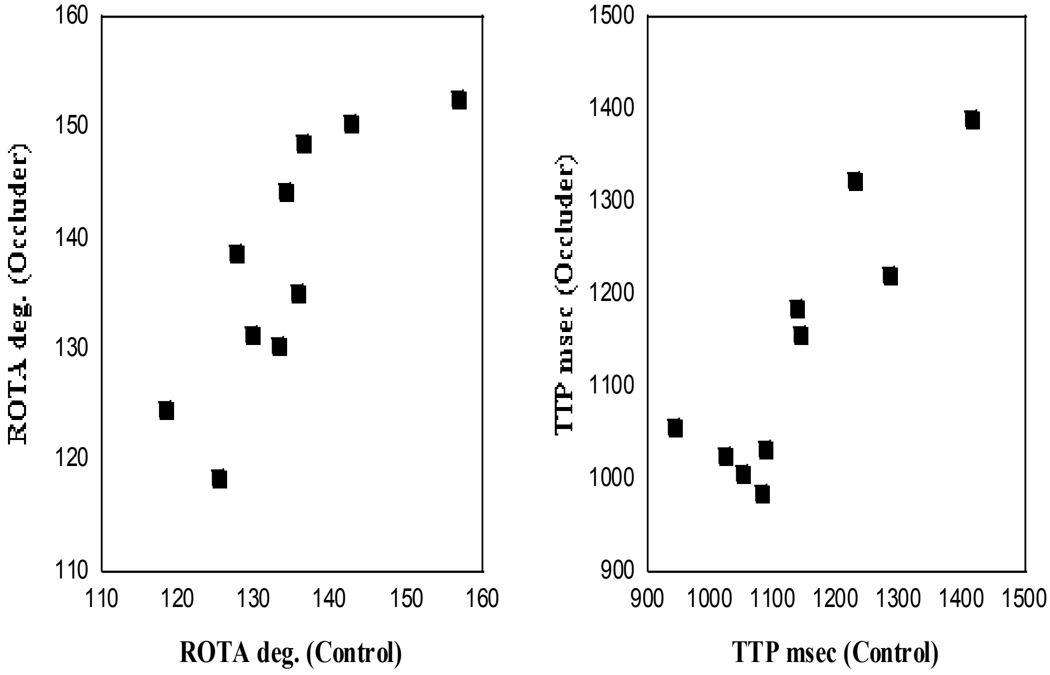

Figure 5.3. Comparison of mean ROTA (left) and TTP (right) of individual pairs between the control (x-axis) and the occluder (y-axis) conditions.

Unlike our prediction, there were no effects of the occluder on OA-Pass (F [1, 8] = 0.70, p > .05) or OA-Rec (F [1, 8] = .09, p > .05). This implied that the occluder did not have an effect on the online control system for both participants. The occluder also had no significant effect on TTP (F [1, 8] = .001, p > .05). However, there was a significant effect of orientation condition on TTP (F [2, 16] = 1.902, p < .001) with TTP being shorter for the 0° condition in comparison to the conditions requiring rotations of +90° and -90° (Figure 5.4).

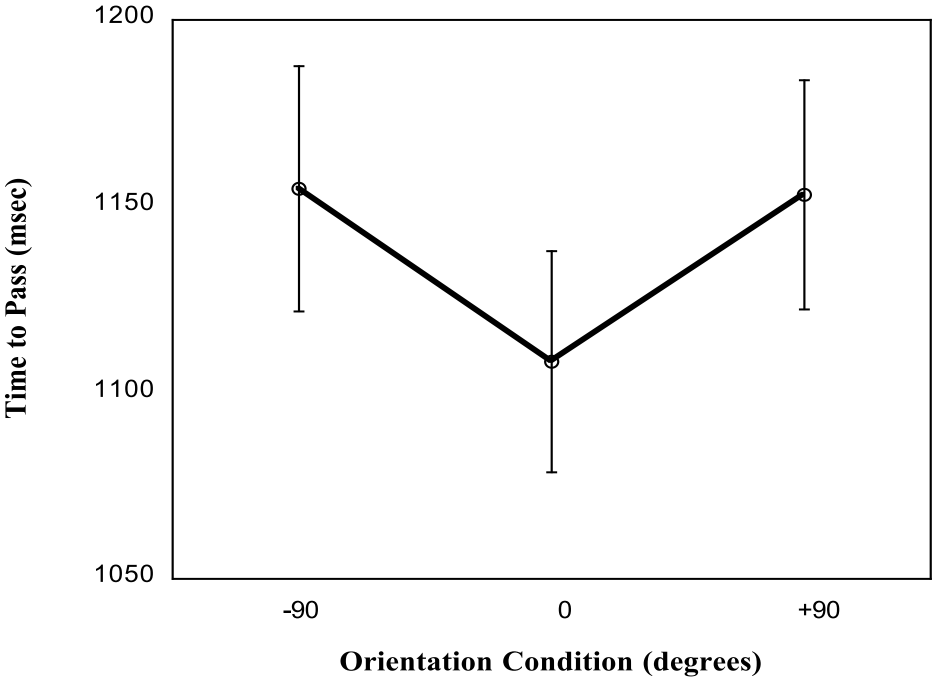

Figure 5.4. Mean time to pass (TTP) as a function of orientation. Error bars represent standard errors of the mean.

Discussion

Experiment 4 aimed to examine whether gaze direction would give clues as to people's intentions and forthcoming actions in order to predict a partner's movement. Previous research has shown that eye gaze plays an important role within social interactions. To examine this, participants had to pass the block amongst each other with their view blocked of one another. Here, however, the results revealed that the removal of gaze direction did not influence the way participants interacted with another. The results showed that the presence of the occluder did not significantly impact the overall ability of participants to execute the movement – none of the indices of online control, either time to pass or the number of online adjustments, were raised when gaze information was removed.

Further, irrespective of the presence of the occluder, participants continued to apply a single, consistent rotation strategy and a consistent timing. These were evidenced by the large correlation values for r_ROTA and r_TTP. Bayliss et al. (2006) have demonstrated that gaze direction provide us with important cues to infer a partner's state of mind and predict their actions. It was expected that gaze direction would help both participants orient their attention to a common focal point, which would have facilitated their understanding of each other's intentions. Therefore, the removal of such information should have hindered their performance. As a result, it was expected that TTP would be prolonged, due to an inability to gather information on a partner's intention and their choice of movement. Similarly this would have resulted in increased online adjustments for both the Passer and the Receiver. However, this was not demonstrated in the current experiment; the occluder had no significant effect of any of the measures.

An unexpected result in the present study was the effect of orientation condition on time to pass. Here, the object was passed more quickly in the condition requiring no rotation than the two orientations requiring rotation. However, when we looked back at the data from the previous experiments, this pattern of means also existed, although it was not statistically significant. Hence, we are inclined to think the effect is real, but small. A simple explanation for this result would be that the hand off can be completed slightly more quickly when no rotation is required than when the object is rotated.

Nevertheless, analogous to the previous experiments, participants maintained the strategy of being predictable towards their partner. The results of the current experiment also provided further confirmation that performance of the Passer was influenced by mental representations of their partner's affordances; the Receiver's task and end-state comfort was clearly considered when planning their own movement.

Although there was no effect of the occluder on ROTA, there was nevertheless a strong effect of orientation on ROTA. However, the Passer rotated the object (+83 degrees) in the +90° condition and only rotated the object (-52 degrees) in the -90° condition. A possible explanation for this could be related to the end-state comfort of the Passer. Specifically, it may have been easier for the Passer to rotate the object forward, as this may have put little or less strain on their wrist than rotating it backwards.

The results of ROTA also show a significant difference in the amount of rotation performed by the Passer in the current experiment in comparison to the previous three experiments; the Passers of the current experiment rotated vastly more in the rotation conditions. A likely reason for this is that the current experiment employed a defined target area in the form of a wooden box, which forced the Receiver to set the target object in its location with a distinct movement (thumb and index finger placed parallel on the right side of the object). In the previous experiments, where no defined box was utilised, the Receivers were able to freely place the object with their thumb and index finger in any position. The target box allocated participants to a more controlled and consistent movement. This new target area ensured that the Receivers rotated their hand prior to placing the target, as rotating the object after the pass off point would have resulted in an awkward placing position and interference of the thumb and index finger in relation to the target box. However, the findings of the current experiment suggest that the Passer considered that the target box would have increased the Receivers' task difficulty and resulted in a more noticeable end-state posture, thus the Passers compensated for this movement through the additional amount of rotation for the rotation condition in contrast to the previous experiments.

Overall, the results of the current study suggest that during a joint action eye gaze is not necessary to assist in motor performance. Although eye gaze was blocked, the mere presence of the target object may have been sufficient to enable participants to predict one's action and perform a smooth joint action. The results may have not shown an effect of eye gaze due to participants generally focusing on the target object and hence applying an extended forward model to predict their partner's movement (Wolpert, Doya & Kawato, 2003). A forward model computes the relationship between an input and its output by comparing the predicted result of an action to the actual position of the body. Forward models provide individuals with internal feedback in terms of an efference copy, a copy of the motor commands. This efference copy provides feedback on which the movement can be accurately evaluated in terms of its relation to the end goal. The forward model cannot only explain motor movement within individuals, but can in principle also be applied to dyads performing a task together. Initially people may assume others will act the same as they themselves would in the other's position. They use this 'expected' action to anticipate their partner's movement and plan their actions accordingly (Wolpert et al., 2003). Although using this type of extended forward model may provide a reasonable means of approximating a partner's actions early in an encounter, it is unlikely to be perfect. For example, Keller et al. (2007) found that expert pianists performed better when they played with a recording performed by themselves than other pianists. This shows that people have a better forward model of themselves than of other people.

One way of overcoming this issue would have been to improve the experiment through the addition of a supplementary target. Instead of a single target object, the Passer would be provided with two target objects, one of which would have served the purpose of a distracter object. In one experimental condition, the Passer would be looking at the target object, in another the Passer would solely be looking at the distracter task, whilst still continuing to pass the original object. An alternative option would be to have two target areas located at opposite ends of one another, which again would serve the purpose of being a distracter. In one condition, the Passer would be actively gazing at the 'correct' target area and in another experimental condition the Passer would be purposely starring at the 'incorrect' target area. For the purpose of this experiment, movement trajectories would have to be recorded to examine whether participants would be inclined to pass the object further towards the 'distracter' target area and whether the Receiver would be following the Passer's movement pattern. Furthermore, if eye gaze were to affect joint action, then one would expect to observe an increase in online adjustments, in particular TTP and OA-PASS and OA-REC. The addition of a supplementary distracter task would be providing us with a better insight into the role of eye gaze, as opposed to having an occluder where participants assume their partner's gaze would be focused on the target object.

It can also be argued that although eye gaze was blocked, participants were still able to see their partner's body. This could have provided participants with essential information on their partner's intentions. In the present study, subtle changes in posture prior to movement initiation may have provided important clues as to the partner's intentions. Consequently, eye gaze information may not be necessary to infer people's intentions. It could be argued that eliminating the view of the entire body might impair effectiveness of joint interaction. Of course removing vision of the partner entirely would obviously make the task very difficult if not impossible. However, it might be possible in the future to refine the experiment to include removing vision of the partner's hand until the movement began (using LCD goggles, for example) which would at least remove any posture-based cues that may have been used early in each trial in the present experiment.

The previous experiments suggested that joint action strategies were highly resilient to alterations in experimental conditions, even when these had significant impacts on online control. The Passer in each experiment seemed highly motivated to maintain a consistent strategy across conditions. The present study showed that information regarding a cooperating partner's gaze was not a significant factor in joint action planning (at least in the present paradigm) and that its removal did not alter strategy formation. In the next experiment, we sought to alter the requirements of the task in a grosser way through the addition of a precision task to examine whether this would encourage joint actors adopt a flexible strategy.

6. Effects of increasing passers' task difficulty amongst dyads

Synopsis

The experiments carried out so far have demonstrated that participants adopt a consistent strategy in planning their actions with that of their partner, irrespective of whether the agents had foreknowledge of the conditions that would occur in the following trial. However, the choice of applying a consistent strategy could presumably be offset if the conditions were made to differ in a more fundamental way, especially when increasing the Passer's task through the addition of a supplementary constraint. This may force the participants to employ flexible strategies.

The current experiment examined this by increasing the Passer's work-load through the addition of a precision task. The Passer was required to pass the object through an aperture, which was attached to the bottom of the occluder used in the preceding experiment, prior to being passed to the Receiver. The addition of this aperture limited the Passer to rotate the object 0, 90, 180, or 270 degrees on each trial. To emphasise precision and accuracy and ensuring that no contact was made between the object and the frame, participants were made to believe that an additional trial would be added at the end of the block if contact was to occur.

It was predicted that the added precision task would result in Passers adopting a flexible strategy in planning the amount of rotation prior to passing the object. In particular it was expected that the Passer would be less inclined to rotate the object in the aperture condition than the control condition. The results showed that participants rotated the object in the precision task as well as the control condition. Thus the overall strategies were remarkably similar for the Passers across the two different conditions. The Passer seemed highly motivated to maintain a consistent strategy across conditions implying that the benefit of being predictable to one's partner override even rather dramatic changes in task constraints. The precision task also had a great impact on the online control processes of both the Passer and the Receiver. Both participants had a large increase in the number of online adjustments and an increased TTP in the aperture condition relative to the control condition.

Introduction

Marteniuk et al. (1987) provided subjects with the task of grasping a disc to place it in a tight slot or to toss it in a large container where speed and accuracy were emphasised. The placing task was a precision task and thus it was expected that subjects would have had longer movement times. The results were in line with this prediction; subjects had increased movement times for the precision task followed by a longer deceleration phase, which permits longer reach durations and allows individuals to apply increased online control to account for errors within their movement (Cooke et al., 1989). Comparatively, movement time decreased when the disc was thrown in to the bucket. Individuals applied a power grasp when precision was not reinforced, enabling them to reach for the item more rapidly, thereby reducing movement time.

In another experiment, Marteniuk et al. (1987) presented subjects with the task of using a pincer grasp to either pick up a tennis ball or a light bulb. Despite the texture, both these objects are of similar shape; however the light bulb is more fragile in contrast to the tennis ball. If the grasp was not predetermined by the experimenter, we would have expected subjects to be applying a precision grasp for the light bulb and a power grasp for the tennis ball due to its extrinsic features. Nevertheless, comparing movement trajectories of both objects, it has been identified that subjects had longer movement times for the light bulb than for the tennis ball, even though the experimenter stressed no emphasis on the speed or accuracy for the task. A possible explanation for this is that the light bulb is more fragile and required more precision in comparison to the tennis ball, thus affecting movement time. Furthermore, analogous to their previous experiment, the precision task led to a longer deceleration phase to enable the user to account for variability and gain a better control over their fine movement resulting in an increased demand for online control. The findings also demonstrate that subjects anticipate the actions involved in each task and consider the task demands prior to planning their movement. The objective of a goal helps to pre-determine and anticipate the kind of grip that will be applied. Claxton, Keen & McCarty (2003) replicated the study by Marteniuk et al. (1987) on 10-month-old infants and showed that the tendency to plan movements in advance based on precision requirements was acquired at an early age.

A possible account as to why precision tasks require longer movement times can be explained in terms of Fitts Law (1954). Fitts (1954) stated that the speed and accuracy of a task are commonly related; increasing the speed of a task results in decreasing the accuracy of the task. Therefore, increasing task complexity results in more errors and increased movement times.

Kelso, Southard and Goodman (1979) asked subjects to make rapid aiming movements with two hands to small and large targets that varied in their distances. Large targets with short distances were measured as having a small index of difficulty (ID), whereas smaller targets with longer distances were regarded as more difficult with a larger ID, as per Fitts (1954). The results showed that movement times were slowest for the high ID in comparison to the small ID. The reason for this is that the smaller targets required more precision and accuracy resulting in longer movement times as well as an increased demand of online control.

Wing, Turton and Fraser (1986) measured how reaching and grasping objects at natural speed and fast speed affected kinematics. When movement time was faster than normal, subjects had a tendency to increase their grasping aperture to account for more variability within the movement. When subjects are asked to perform a task as quickly as possible, people have less direct control over their movement and are more prone to errors.

The current study increased the Passer's task difficulty by increasing the required precision of the Passer's movement. The setup included a rectangular aperture through which the target object had to be passed prior to handing it to the Receiver, who had to place it in the target area. The Passer's task was made more difficult in two ways: First, it required a precision movement to get the object through the frame. Second, it limited the Passer to either 0°, 90°, 180°, or 270° of rotation. Apart from 0°, all of these rotations were likely to be awkward and inefficient for the Passer. It is known that people have less fine control of the body when in extreme joint angles (Bernstein, 1967). Each joint has a range of motion and at extreme angles the body has less precise proprioceptive feedback, making it more difficult for the brain to judge where the body is and to make precise and controlled movements. The extreme joint angles also strain and add discomfort on the joints (Fuentes & Bastian, 2010).

Experiment 5

The results of the previous experiments indicated that participants preferred to adopt a consistent strategy in terms of rotation regardless of condition. The present study aimed to examine this more closely by including a supplementary condition in which the Passer was required to make a precision movement that placed great constraints on their choice of actions. The general idea behind this experiment was to determine whether tightly constraining the Passer's movement relative to the control condition would result in subjects adopting different planning strategies in the two conditions. This experiment resembled the stimulation studies, in which the magnetic stimulation added difficulty to the Passer's task, causing the Receiver to take over the rotation. However, the magnetic stimulations were an unnatural hindrance to the Passer, whereas in the current experiment task difficulty was increased in a less intrusive way. As such, this manipulation was intended to add both an extra constraint and an extra precision demand to the joint task, resulting in a qualitative change to the task, beyond the more quantitative increase in difficulty imposed by the perturbation used in Experiments 2 and 3.

A wooden frame with a tight fitted hole was attached to the occluder used in Experiment 4. Figure 6.1 shows the experimental setup. The object had to be passed through the small opening prior to passing it to the Receiver. Similarly to the previous experiments, the object had to be rotated on some occasions before it was placed in the target location. The primary goal of the current experiment was to determine the effects of introducing a tightly constrained movement path on the formation of action strategy. Furthermore, it served to assess the effects of increasing the constraints of the Passer on their tendency to rotate prior to the pass off point.

It was predicted that the introduction of a more constrained movement path would result in the adoption of flexible strategies. Specifically, it was hypothesised that the Passer would be less inclined to rotate the object in the aperture condition, although the Passer would still be inclined to rotate the object in the control condition. On this analysis, there should be an effect of aperture condition on ROTA. Further, there should be no effect, or only a small effect evident in r_ROTA (an effect in the r_TTP data would still be expected as presumably faster participants in the aperture condition would also be faster in the no aperture condition).

Alternatively, participants may continue to adopt a consistent strategy despite the heavy precision demands placed on the Passer in the aperture condition. If this is true, then the aperture should have no impact on ROTA, and thus the predicted effect of aperture condition on ROTA would not be observed. Further, there should be a significant positive correlation evident in the r_ROTA data.

Beyond the effects of the aperture on action planning, it was hypothesised that the extra precision requirement of the aperture condition would have a large effect on online control processes (Fitts, 1954; Marteniuk et al., 1987), resulting in increases in all of TTP, OA-Pass and OA-Rec relative to the control condition. If the precision task, on the other hand, did not increase task difficulty for the participants, then TTP, OA-Pass and OA-Rec should not differ between the aperture and control conditions.

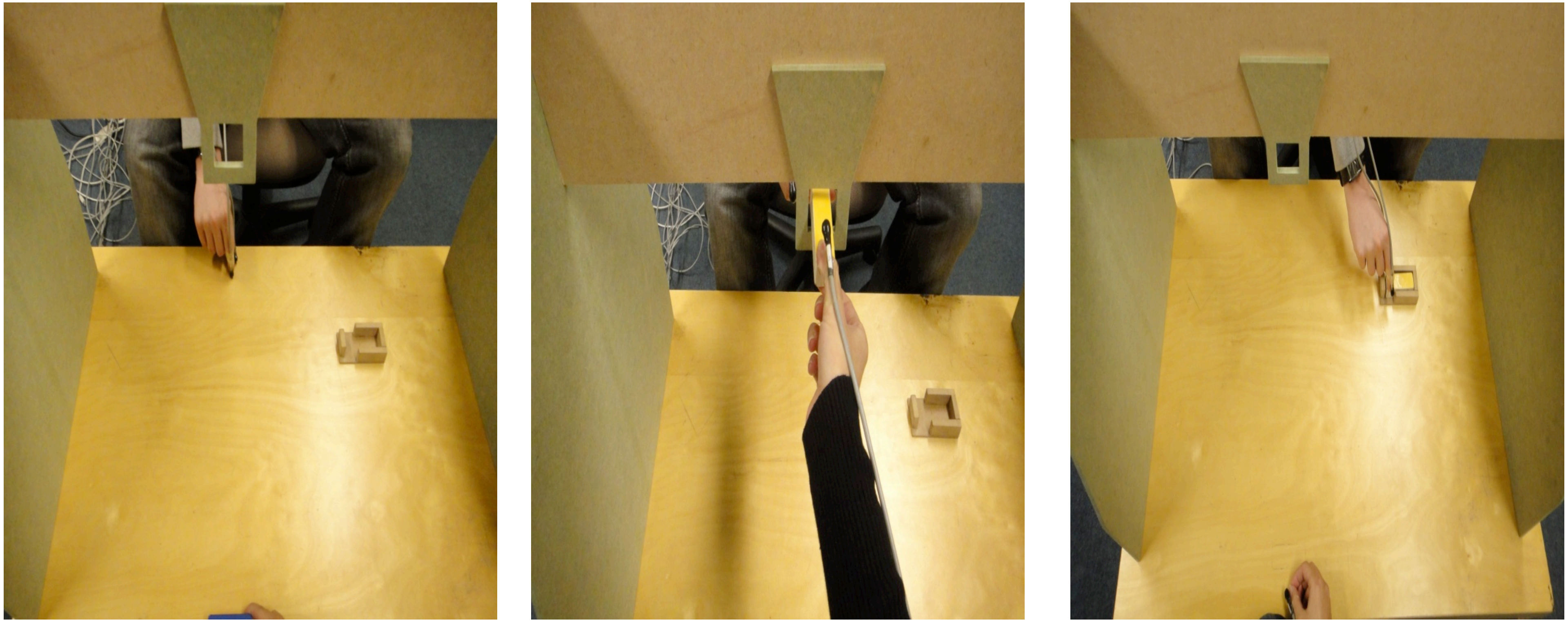

Figure 6.1: Figure depicting aperture study from the Passer's perspective. Participants could not see each other. The Passer had to pass the object through the aperture prior to handing it to the Receiver. The Receiver then had to place the object in the target area. In this scenario, the object had to be rotated +90° forwards.

Method

Participants

Nine pairs of participants took part in Experiment 5. All were healthy, right handed individuals with normal or corrected vision, and all were naïve as to the exact purpose of the study. All participants received course credit and provided their informed consent prior to participating.

Stimuli and Apparatus

Stimuli and apparatus were the same as in Experiment 4, except that the occluder had a small aperture attached to it. A square-shaped wooden aperture, which was 5cm in height and 6.5cm in width, with an opening of 3.5cm x 3.5cm was attached to the bottom of the occluder. The centre of the aperture was 36cm to the left of the Passer's starting position and 37cm above the table's surface. Not only did it prevent both participants from seeing each other, it also increased the Passers' task difficulty.

Data Analysis

Analysis was carried out on kinematic data as in Experiment 4, except that aperture replaced occluder as a within subjects factor. Data were analysed using a mixed measures 2 (order) x 3 (orientation condition) x 2 (aperture) ANOVA.

Procedure

The procedure was identical to that of Experiment 4, except that in one block of trials the Passer was required to pass the target object through the aperture, to be taken by the Receiver without the target touching the sides. The experiment consisted of 60 trials, which were divided into two blocks of 30 trials (10 for each orientation condition) with and without the aperture, with order of blocks counterbalanced across participant pairs.

On trials when the aperture was present, the Passer was instructed to pass the object through the small frame, ensuring that it did not touch the frame. The Passers were led to believe that every time the object would make contact with the frame, they would be penalised and an additional trial would be added at the end of the trials. This was to ensure that the participants performed the task as accurately as possible; and both participants were fully debriefed at the end of the study. The aperture was only a few millimetres bigger than the actual object. As before, the Receiver's task was to uptake the object from the Passer and place it down in the target area. Although the Passer's task difficulty increased, the Receiver's task became somewhat easier, as the Receiver was now aware of the precise location where the target would be passed, thus they were able to anticipate where to position their hand when reaching out for the object.

Results

A total of 24 trials (4.44%, SD = 3.33%) from all participants were excluded from the final analysis because the task was not completed successfully. Figure 6.2 shows mean ROTA as a function of orientation condition in the aperture and control conditions. There was a main effect of orientation condition on ROTA (F [2, 14] = 9.67, $p < .01$). Aperture also had a significant effect on ROTA (F [1, 7] = 12.55, $p < .01$, with ROTA values being more positive when the aperture was present. There was also evidence of an interaction between aperture and orientation condition on ROTA (F [2, 24] = 5.76, $p < .05$), as the greatest increase in ROTA score for the aperture trials occurred in the -90° orientation condition. There was no evidence for an effect of order, or that order interacted with orientation condition or aperture (F [2, 14] = 0.807, p >.05).

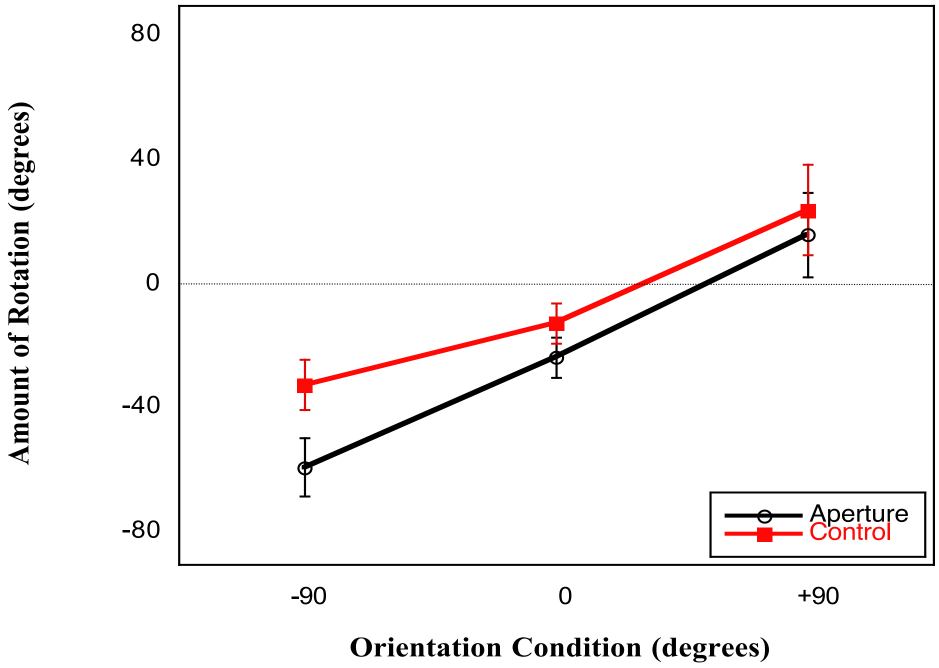

Figure 6.2. Mean degree of ROTA as a function of orientation condition in the aperture and control conditions. Error bars represent standard errors of the mean.

As in Experiments 2 and 3, and contrary to our predictions, large positive correlations existed between the aperture conditions for r_ ROTA, r = 0.95, *p* < .001 and r_TTP, r = 0.70, *p* < .05 (Figure 6.3). Passers who rotated the most in the aperture condition were also strongly inclined to rotate the most in the control condition, and passing time was similarly related across conditions.

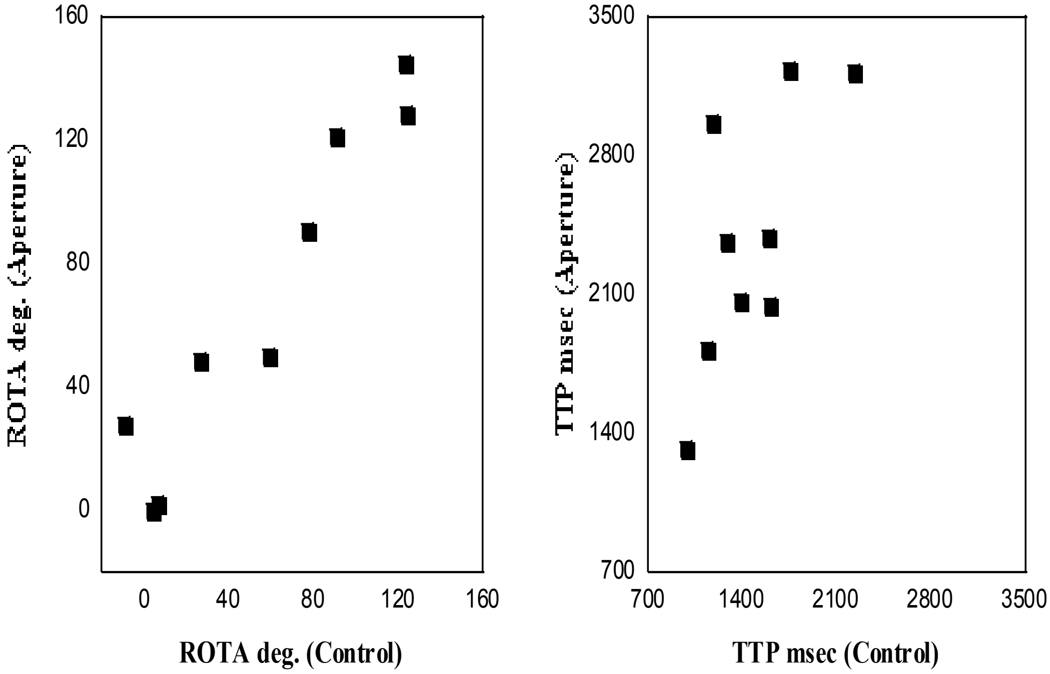

Figure 6.3. Comparison of mean ROTA (left) and TTP (right) of individual pairs between the control (x-axis) and the aperture (y-axis) conditions.

The analysis of online corrections showed a significant effect of the aperture on both OA-Pass (F [1, 7] = 37.31, $p < .001$) and OA-Rec (F [1, 7] = 17.62, $p < .01$). The Passer made many more corrections in the aperture condition than in the control condition (Figure 6.4). This was vastly more than even in the stimulation conditions of Experiments 2 and 3. The aperture also had a significant effect on TTP (F [1, 7] = 41.51, $p < .001$), with TTP being 921msec greater in the aperture condition (2383msec) than in the control condition (1462msec). These data supported the hypothesis that the increased constraints and greater precision requirements of the aperture condition would significantly impact online control.

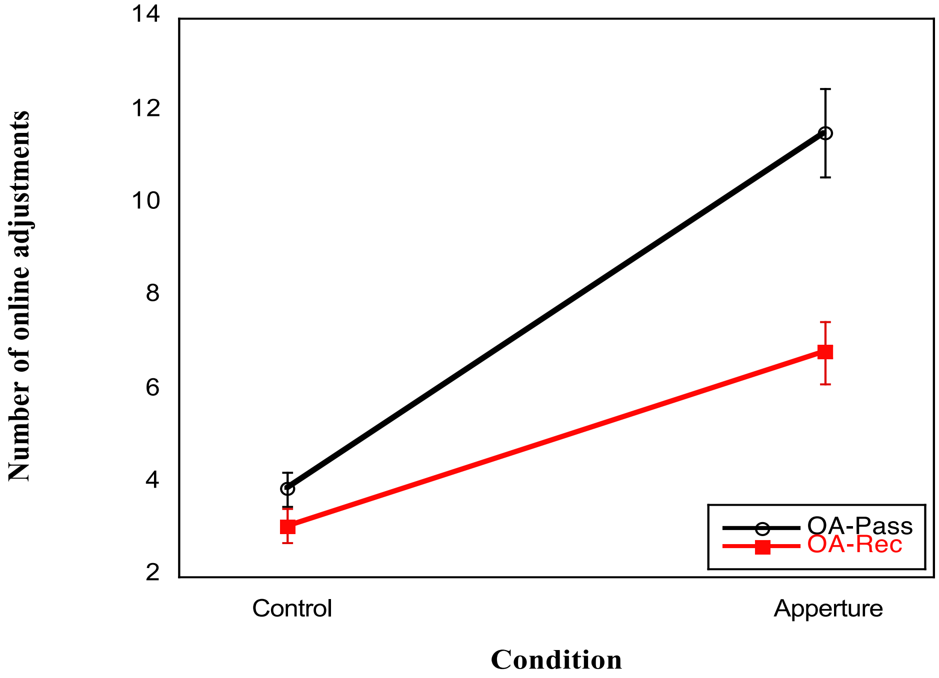

Figure 6.4. Mean number of online adjustments for the Passer (OA-Pass) and Receiver (OA-Rec) in the control and aperture condition. Error bars represent standard errors of the mean.

Discussion

Experiment 5 greatly increased the precision requirements of the task, but more importantly, it changed how the task had to be done in a fundamental way. Previously, participants could pass the object across the table at any position they chose and in any orientation they chose. Here, however, they were required to pass the object through an opening that tightly constrained the position of the object at pass off, and allowed for only one of four possible orientations.

The presence of the aperture had a significant effect on rotation. It was expected that adding this additional task would hinder the Passer from rotating the object due to the increased task demands on the Passer. The results were surprising; despite the fact that the Passer's task difficulty was increased, it did not prevent them from rotating the object. Nevertheless, the data obtained for ROTA varied considerably in comparison to the previous experiments. A possible explanation for this could be that the aperture made it very awkward for the Passer to rotate in a positive direction, causing the results for the +90° condition to be near to zero, whereas the results in the 0° and -90° conditions were more consistent with the other experiments. However, another interesting finding is that the results from the control condition were very similar to those observed in the aperture condition, which suggests that despite the two different experimental conditions, there was a motivation for participants to be predictable in their action.

Although the aperture limited participants to pass the object at one of those particular four orientations, the person could always tilt the object without turning their wrist the equivalent amount. Glover and Dixon (2012) found similar findings; they asked participants to pick up a bar that varied between 5° and 35°, however the orientation of the hand during the reach to grasp movement did not vary nearly as much as that of the bar. This could be explained in terms of the motor system avoiding extreme joint angles; as a result it recruits additional degrees of freedom and implements other joints than just the wrist (Bernstein, 1967; Fuentes & Bastian, 2010. Furthermore, the graphs (Figure 6.2) do not show rotation of the object to precisely 0°, 90°, 180° or 270° angles due to the fact that the results of all the trials had been averaged. For example, if participants turned the object 90° 2/3 times and 0° 1/3 times, then the mean would be 60° although they never actually turned it 60°. Another possible reason for this is that the markers were placed on top of the thumb and index finger; although the object may have been rotated 90° forwards or backwards, the same amount of rotation was not necessary for the fingers to obtain the result. The fingers could slide back and forth, while the object rotated, meaning the rotation of the finger and thumb did not match entirely the rotation of the object.

This kind of measurement error is unavoidable in motor control research, as placing the markers outside the body is presently the only practical way to measure kinematic movement and this by necessity results in unavoidable measurement error. Indeed, the only way to get an entirely precise measurement would involve actually implanting markers *insid*e a person's body.

Experiments 2 and 3 suggested that joint action strategies were highly resilient to alterations in experimental conditions, even when these had significant impacts on online control. The Passer in each experiment seemed highly motivated to maintain a consistent strategy across conditions. The presence of the precision task also had an immense impact on the online control processes of both the Passer and the Receiver. The Passer had a large increase in the number of online adjustments in the aperture condition relative not only to the control condition, but even to the perturbation conditions of Experiment 2 and 3. This increase was also evident in the Receiver, even though it was the Passer who had to initially thread the object through the small frame, and the Receiver only had to accept it. The increase in OA-Pass was perhaps not surprising, as the Passer had to pass the object through the tight fitted frame, which required a lot of precision and accuracy. This precision resulted in small adjustments to pass the object through without touching the borders of the frame. However, the increase of OA-Rec in the aperture condition was somewhat surprising. In Experiment 2 and 3, the Receiver was struggling to predict the Passer's movement path resulting in the need for more online adjustments. Although the Receiver could accurately predict the location of the object in the current experiment, they nonetheless seemed to be making fine adjustments to the Passer's movement trajectory. The data on Figure 6.4 shows how the Receiver had almost as many online adjustments as the Passer. It may be that the Receiver was subconsciously following the Passer's movement and imitating their move, resulting in an increased number of OA-Rec. Another possibility is that the Receiver's movement did actually require more precision, as they had to ensure a stable grasp on the ends of the object in order to draw it successfully through the frame. This may have led them to make a number of fine online adjustments as the object was being passed through the frame to them by the Passer.

Not surprisingly, the time required to pass the object was more than 900msec greater in the precision than control conditions, a 63% change. Yet, as in the previous experiments, individual participants adopted fairly consistent strategies across conditions. The overall strategies were remarkably similar, and across individuals, generally consistent as evidenced by the large value for r_ROTA. This suggests that the benefits of being predictable to one's partner override even rather dramatic changes in task constraints. Performance of the Passer had been influenced by the mental representations of their partner's affordances. Although the Passer had an increased work load, they considered the Receiver's task and end-state comfort when planning their own movement.

The previous experiments suggested that joint action strategies were highly resilient to alterations in experimental conditions, even when these had significant impacts on online control. The Passer in each experiment seemed highly motivated to maintain a consistent strategy across conditions. In the next experiment, we sought to approach the question of strategy selection in joint action from a different perspective. Given the resilience participants have shown in adopting a consistent strategy across conditions, we examined whether this tendency towards consistency was nonetheless flexible enough to accommodate a change in roles. In Experiment 6, we had participants swap roles halfway through the experiment such that the original Passer became the new Receiver, and vice-versa.

7. Effects of swapping roles during an object passing task

Synopsis

The previous experiments have shown a tendency for participants to adopt a consistent strategy in a joint passing and placing task, even when one participant had their movement perturbed or when one condition required a dramatic increase in precision. The present experiment sought to determine whether this consistency was specific to a particular actor or to a particular role by having participants swap roles halfway through the experimental session.

The experiment consisted of two blocked trials; after the first block participants had to swap their seat and roles, meaning that the Passer took on the Receivers' task and vice versa. To avoid confusion, block 1 refers to the original Passers and Receivers and block 2 indicates the new Passer and Receivers. It was predicted that participants would code the task as having distinct roles which could be filled by either participant. As such, we expected, as in Experiment 1, that ROTA would be affected by orientation condition, and that this would be true whether or not the roles had been switched. That is, both the block 1 and block 2 Passer would rotate the object prior to handing the object off. Further, if the task was encoded as having distinct roles, and the aim was to be predictable to their partner, we should see large positive correlations between the values of r_ROTA and r_TTP for the first and second blocks. Essentially, participants in their new roles (block 2) should seek to emulate the behaviour exhibited by their partner. That is, the Passers in block 2 should behave as had the Passers in block 1. Analogous to Experiment 1, we do not expect to observe any effects on online adjustments in either participant after the swap.

The results showed that participants adopted a general strategy for the different blocks; the Passers in both block 1 and 2 rotated the object prior to passing it to the Receiver. Furthermore, when roles were swapped, participants' movement trends closely resembled that of their partners; it appeared as if the participants were imitating each other's movements. Participants applied a consistent role in relation to the demands of their given role throughout the experiment.

Introduction

When people work together they automatically form an interpersonal bond and create a sense of unity. In order to engage in this form of unity, one needs to understand their partner's actions and make sense of the observed behaviour. We are able to infer people's thoughts and intentions through their overt behaviour. Comprehending another person's intentions enables us to establish a relationship with the other person and to perceive them as a partner to cooperate with, a competitor or even a danger to us. From an evolutionary aspect, being able to 'read' your co-actors and predict their intentions is a survival method; it allows us to anticipate a partner's action and take appropriate actions, i.e. escape from harmful and threatening situations (Gallese, 2009).

Mirror neurons are activated during the execution as well as the observation of movements (Gallese et al., 1996; Rizzolatti et al., 1996). However, the discharge is not solely dependent on an objective movement, but also fires in relation to an anticipated action goal (Buccino, Lui, Canessa, Patteri, Lagravinese, Benuzzi, Porro

& Rizzolatti, 2004; Umilta, Escola, Intskirveli, Grammont, Rochat, Caruana, Jezzini, Gallese and Rizzolatti, 2008; Umiltà, Kohler, Gallese, Fogassi, Fadiga, Keysers & Rizzolatti, 2001). The activation of these neurons provides an observer with a real practical understanding of the action it observes and allows one to understand a partner's task and consider this within one's own action planning.

Later, Cattaneo, Caruana, Jezzini and Rizzolatti (2009) demonstrated that there was a difference in neuronal processing between observing motor acts and imagining motor acts. The motor activity of imagery motor movements resembled those of performing the movement regardless of whether the movement was goal-directed or not. The thought of executing a movement acts as a primer and allows the observer to mentally prepare for the movement. However, motor activity differed for movements that were observed; these were dependent on the goal of the movement. When the observed movement had no goal the observers' motor excitability was dependent on the observed movement. Yet when a goal was present, in the form of picking up a peanut, the excitability of the motor cortex reflected the movement goal as opposed to movement behaviour. Thus the motor system is sensitive to the objective of the movement as well as the physical movement observed. This proves to be efficient, as there are different ways of achieving one goal. Consequently the observer maps the alternative methods onto their motor system to accomplish the goal. This is important to the current experiment, as it suggests that the observation of movement behaviour in addition to the goal of a task will facilitate action understanding within one's own action system. This not only allows participants to prepare for a forthcoming movement and plan their actions prior to execution, but also activates the same motor repertoire as if the action was carried out by the observer, thus acting as a primer for motor execution and facilitating imitation.

Iacoboni, Molnar-Szakacs, Gallese, Buccino, Mazziotta and Rizzolatti (2005) argued that intentions are also a fundamental part of social behaviour and these would influence the neuronal system. They tested this idea using functional magnetic resonance imaging (fMRI). Participants were shown three different types of clips that illustrated a context, an action or an intention. The agent was performing similar movements in both the action and intention clip, apart from the fact that context was embedded in the intention clip. Intention and action facilitated increased activity in the parietal and frontal areas, which are known to be activated during the observation, imitation and the execution of grasping movements. This was not observed in the context scenario, as no grasping movement was applied. However, the context scenario activated the inferior frontal area of the brain; a region known to contain cells that fire in the presence of graspable objects or during grasping execution but do not discharge during the observation of grasping actions. When the intention scenario was compared to the context and action clip, an increase in neuronal activity in mirror neurons was observed. The difference in the activation of these neurons for the intention clip and action clip suggest that intentions are also coded and represented within the neural system, thus the observer is able to understand the agent’s intentions. If the two actions were identical, then we’d expect the same or similar activity for both the conditions. Since this has not been observed, it can be suggested that the intention of accomplishing a goal also activates the mirror system. Based on the intentions of a partner, participants can plan and adjust their own actions in accordance to that of their partner.

The activation of this mirror system enables us to map the mental states of others onto our own action repertoire and put ourselves in their perspective. Studies on joint action have also shown that people have a tendency to mimic and imitate the behaviours of others. If action observation and action execution facilitates a common neural substrate, then we are more likely to copy our partner's behaviour. Interestingly enough, we seem to be doing this involuntarily with a lack of conscious awareness. The mirror neuron system is fundamental to social interactions, as mirroring the actions of others contributes to the foundation of a more likeable and efficient joint interaction (Chartrand & Bargh, 1999).

The findings of the previously discussed studies have demonstrated that mirror neurons are responsible for mapping a person's actions, intentions and the action goal onto our own action repertoire, which influence our decision for our consequent choice of actions. In the current experiment, participants experienced their partner's task by physically taking on their role. However, considering their understanding for their partner's task and the general action goal, are individuals likely to be influenced by their partner's behaviour and imitate their previously observed role or will they apply a previously learnt role throughout the experiment, even after role have been exchanged? In other words, will the Passer in block 1 continue to rotate and act as the person who rotated the object when they swap roles and become the Receiver in block 2, or will the Passer in block 2 imitate the actions of the previously observed Passer of block 1?

Based on previous research, it was predicted that participants would be likely to imitate their partner's action of being the Passer or the Receiver after swapping roles. Thus participant pairs may encode the task as having two distinct roles independent of who was assigned to each, with the Passer tending to do the majority of the rotation of the object prior to passing the target to the Receiver, who would then complete the rotation. If this were the case, then we would expect the Passer in block 2 to rotate to a similar extent as the Passer in block 1, even though they were two different people. Alternatively, the pairs may encode their individual roles as fixed, in that if the Passer in block 1 did most of the rotation, they should do most of it as the Receiver in block 2, meaning the Passer in block 2 would do less.

Experiment 6

Given that participants tended to adopt a consistent strategy in the previous five experiments, the question of the present study was how cooperation strategies would be affected if the block 1 Passer swaps their role with their partner and becomes the Receiver in the second block. Specifically, would people tend to imitate what their partners did, thus maintaining a consistent strategy, or would they adopt new strategies? Based on studies showing unconscious mimicry (Bargh et al., 1996; Chartrand & Bargh, 1999) and the role of mirror neuron system in imitation (Gallesse et al., 1996), we expected the block 2 Passer to behave as the block 1 Passer did, and the same for the Receiver. Observing the behaviour of one another can influence a person's choice of actions (Sebanz et al., 2005; 2006). Since the Receiver will have observed the Passer's behaviour in the first block of the experiment, it can influence the Passer of block 2 to imitate the behaviour of the block 1 Passer. This will lead participants to take on the exact role of their observed partner in the second block. As a result, participants would adopt a consistent strategy in relation to the demands of their given role throughout the experiment. Thus it was predicted that participants would adopt a general strategy with the

Passers in both blocks 1 and 2 rotating the object, leading to a significant effect of orientation on ROTA.

Further, if participants adopted a consistent strategy across conditions, there should be no interaction between role order and orientation conditions for ROTA, and large positive correlations should exist across conditions for r_ROTA and r_TTP. In other words, it was expected participants would imitate the previously observed behaviour of their partner after the role swap. However, if participants decided not to imitate their partner's action and instead employ a flexible strategy relative to the demands of the task role by deciding for one person to continuously rotate the object, then we would expect no effects present in either of the r_ROTA or r_TTP analyses. Regardless of any effects of role order on the other variables, there was no reason to expect any difference of TTP, OA_Pass or OA_Rec to vary over block. Thus any such effects of role on these variables would be considered anomalous.

Method

Participants

Ten pairs of participants took part in Experiment 6. All were healthy, right handed individuals with normal or corrected vision, and all were naïve as to the exact purpose of the study. All participants provided their informed consent prior to participating and received course credit.

Stimuli and Apparatus

Stimuli and apparatus were the same as in Experiment 1 however the current experiment employed a box to define the target area as in Experiment 4 and 5. This enabled participants to precisely set down the rectangle in the box. Figure 7.1 displays the experimental setup.

Data Analysis

Analysis was carried out on kinematic data as in Experiment 1 except that role order (Passer first or Passer second) was entered as a second independent variable along with orientation. The data were analysed using a mixed design 3 (orientation condition) x 2 (role order) ANOVA, with orientation condition being the within subject variable and role order being the between subject variable.

Procedure

The procedure was identical to that used in Experiment 1, except that the 60 trials were divided into two blocks, each consisting of 30 trials. After the 1st block, participants were required to switch places, so that the Passer in block 1 would become the Receiver in block 2 and vice-versa. The number of trials in each rotation condition was balanced across blocks.

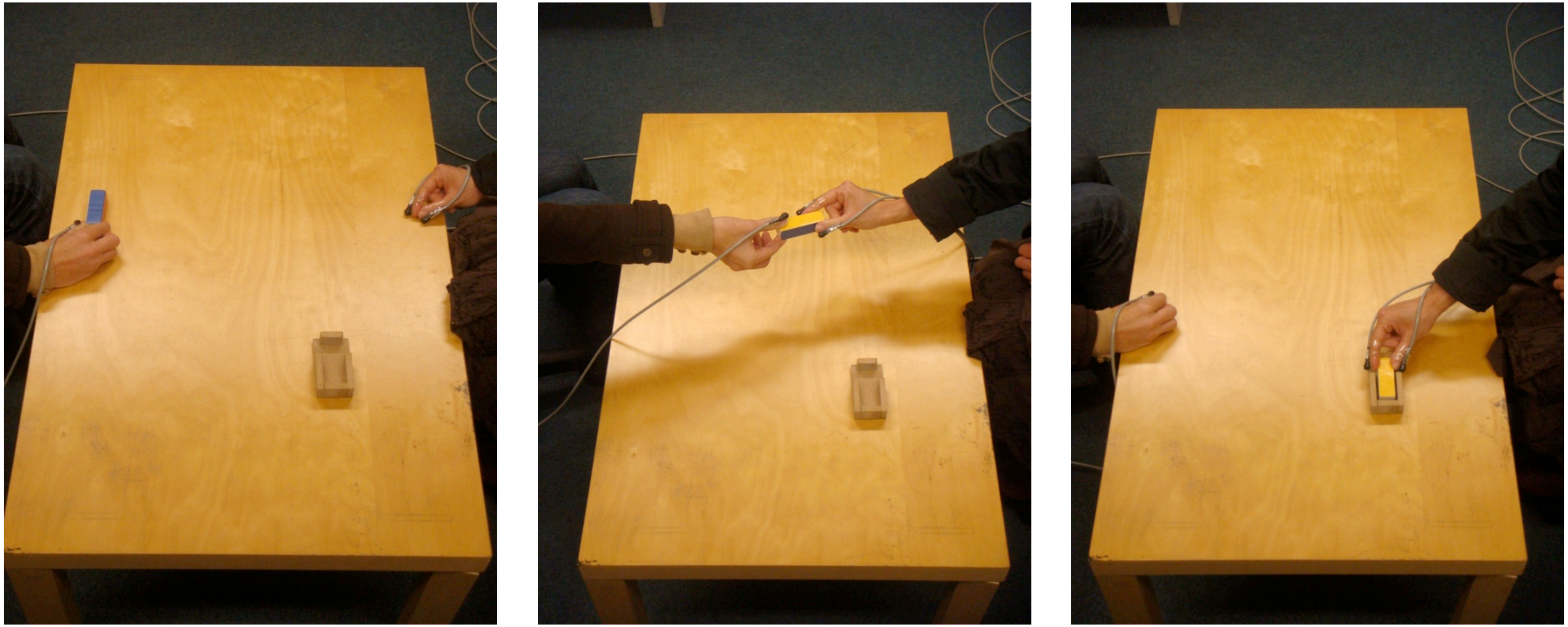

Figure 7.1: This experiment was similar to Experiment 1, however the target location was defined by a box. Like the previous experiments, the trial began with the Passer (left) holding the object and the Receiver (right) sitting with their hand resting on the table. On the go signal, the Passer handed the object off to the Receiver. The Receiver then had to place it down in the target area with the appropriate side facing up. In this example, the +90° forward orientation (yellow) is being demonstrated.

Results

A total of 40 trials (M = 6.67%, SD = 2.49%) from all participants were discarded because the task was not completed successfully. Figure 7.2 shows average ROTA in the first and second block. There was a main effect of orientation on ROTA (F [1.03, 18.58] = 136.74, p < .001), but no interaction between orientation and order (F < 1). The results demonstrate that the Passer was consistently rotating the object on the different orientation conditions both before and after they had swapped roles.

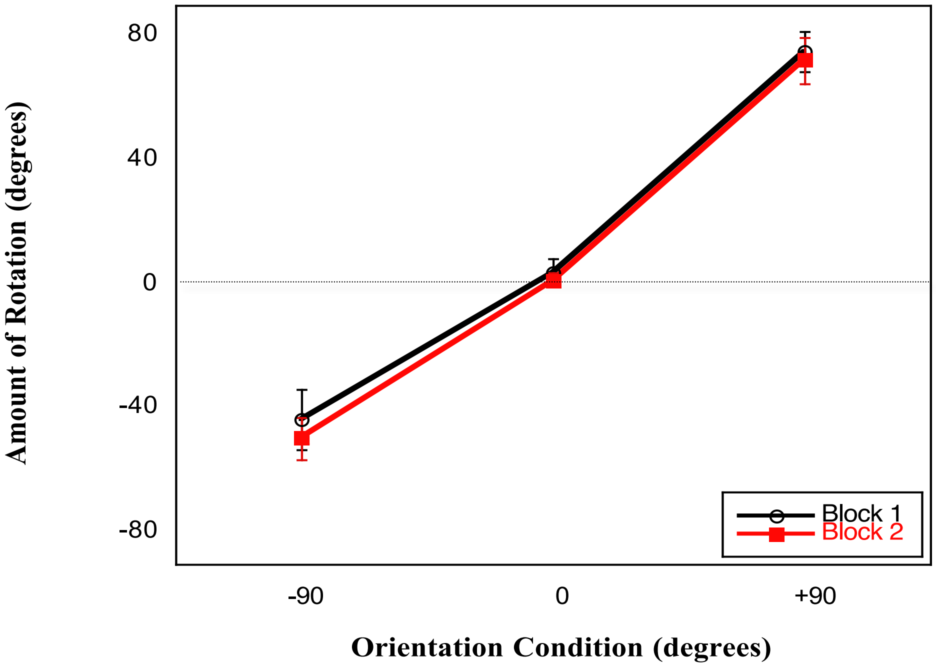

Figure 7.2. Mean degree of ROTA as a function of orientation in Block 1 and Block 2. Error bars represent standard errors of the mean.

A Kolgorov-Smirnov test showed that the ROTA data in Block 1 were not normally distributed (Z = 1.36, p <.05), thus r_ROTA was computed using Spearman's correlation. The result was a non-significant value for r_ROTA (rho = 0.31, p > .05) (Figure 7.3, left). Scrutiny of the data revealed the presence of an outlier pair in which both the Passer in the first block and the Passer in the second block rotated very minimally (leaving most of the rotating to the corresponding Receiver), the opposite pattern that was observed for all other participant pairs in which the Passer rotated much more. A moderate positive correlation was found for r_TTP between block 1 and block 2, r = 0.64, $p < .05$ (Figure 7.3, right).

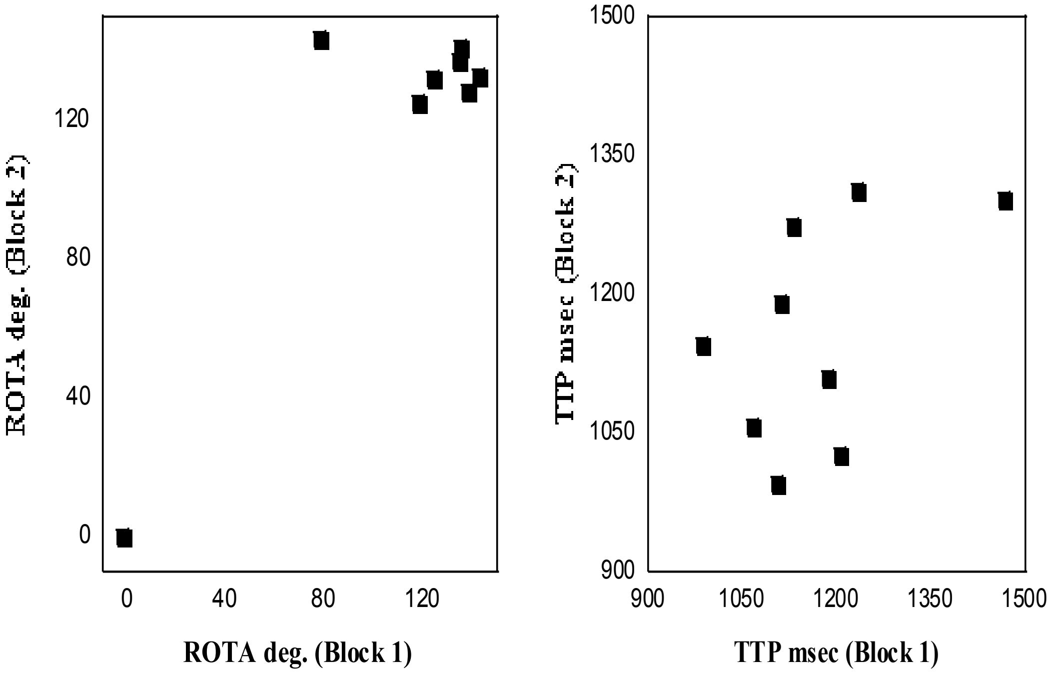

Figure 7.3. Comparison of mean ROTA (left) and TTP (right) of individual pairs between Block 1 (x-axis) and Block 2 (y-axis) conditions.

Similarly to Experiment 4, there was an overall effect of orientation condition on TTP (F [1.4, 25.6] = 6.10, $p < .01$), with time to pass being smaller in the 0° condition (1096 msec) than in the +90° (1149 msec) or - 90° (1165 msec) conditions (Figure 7.4). There were no effects or interactions of order on TTP, nor were there any effects or interactions of any variable on OA-Pass or OA-Rec (all Fs < 1).

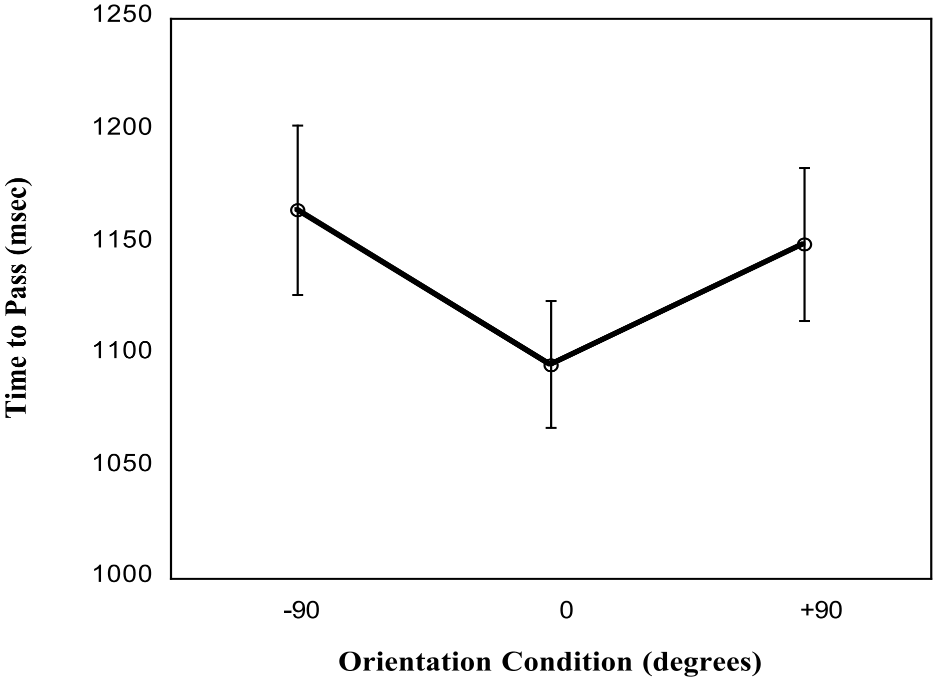

Figure 7.4. Mean time to pass (TTP) as a function of orientation. Error bars represent standard errors of the mean.

Discussion

Experiment 6 examined the effects of changing roles during the experiment on the execution of a joint action strategy. It was predicted that participants would adapt their behaviour so as to be consistent with their role as Passer or Receiver, and the evidence largely confirmed this. The main results of Experiment 6 were that there was a strong effect of orientation on ROTA. Figure 7.2 shows that the Passers in the second block generally rotated the object to a similar extent as had the Passer in the first block. More strikingly, the r_ROTA data showed that only one participant pair used a strategy in which the Passer did not rotate prior to hand off, and they did this consistently across blocks (Figure 7.3). This result strongly supports the hypothesis that participants would adopt a behaviour in the second block similar to that they had observed their partner do in the first block. As such, the evidence suggested that the task was encoded by the role being undertaken at the moment, and not the behaviour one had done in the first block. An interesting question that arises from this result is the mechanism by which this role adoption occurs. One possibility is that participants are simply inclined to imitate the actions of their partner when the roles are reversed, possibly through the mirror neuron system (Di Pellegrino et al., 1992; Rizzolatti et al., 1996). Observing an action will result in the activation of these neurons, which act as a primer for action execution. This has the presumably beneficial side effect of making each participant more predictable to their partner. However, the fact that r_ROTA between block 1 and block 2 Passer was insignificant suggests that this system operates within limits and that the extent of imitation is gross at best – either the block 2 Passer rotates or does not rotate depending on the actions of the block 1 Passer, but the extent to which they rotate otherwise varies to at least some extent across individual pairs.

The data, nevertheless, suggests that there was a general tendency to imitate for two reasons. First, r_ROTA may have not been significant, yet on a more basic level, the pairs where the Passer in block 1 rotated were the same as those where the Passer in block 2 rotated. It was one pair who did not rotate, even though they adopted a similar strategy throughout the experiment, whereby both the block 1 and block 2 Passer decided not to rotate the object after the role swap. One of the possible reasons as to why the correlation may have not been high could be due to the physical differences in how easy it was for each Passer in a pair to rotate. Participants may have not imitated their partner to an exact degree, they nevertheless imitated their partner in terms of rotation on a basic level. Secondly, there was a strong correlation for r_TTP across the two blocks, which confirms the notion that some form of imitation must have occurred.

Analogous to Experiment 4, the present study observed an effect of orientation condition on time to pass. It took participants longer to pass the object when the target object needed rotation. The pattern of means across all experiments was consistent with this, even if not all were significant. This suggests that across the experiments, there is probably an effect, but it is small and thus did not show up every time because of random variation.

The current experiment only measured a simple aspect of an object passing task; the rotation occurred in one dimension and thus there was naturally going to be variation across individuals. A way to improve the current experiment is through the addition of an additional constraint or task. The space between the Passer and the Receiver could be separated by a bar that could act as an obstacle along the centre of the table, which would require participants to decide whether to pass the object over or under it. Comparing the data from the block 1 and block 2 Passer would enable us to identify whether participants opted to perform the task in a similar manner to their observed partner.

An alternative method of determining whether participants have a tendency to imitate their partner would be through the employment of a confederate. To extend on the idea of the obstacle, a confederate would pose as the block 1 Passer and vary the extent to which he or she would pass the object. On trials, where the object would have to be rotated +90° forwards, they would perform this rotation and pass the object over the barrier. However, when the object requires –90° rotation, they would pass the object under the barrier. This would be counterbalanced across experiments, so that in each experiment the confederate would be performing a different movement pattern. In order to examine whether the participant would imitate the Passer's movement, one can record whether they adopt a similar strategy to what they previously observed the confederate to do. Not only would they be left with the decision to rotate the object, but also have to make the decision on how to pass the object (i.e. over or under the barrier). The question would be whether they would use a consistent strategy irrespective of their partner's choice of action, which may seem like a more preferred choice given the predictability of the movement. However if imitation overrides this predictability and ease of comfort, then one would expect to observe a strong correlation between their choice of object passing and what they had previously observed the confederate do.

If a strong correlation is observed, then there are alternative ways of manipulating the experiment to make the task more difficult. For example, the height of the obstacle could be lowered to increase the difficulty of passing the object under it. The confederate would nevertheless pass the object under the barrier. The question of interest would be whether participants would follow the same guidelines as the confederate, increase their own task difficulty and sacrifice their comfort for the sole purpose of imitating their partner. This would be an alternative and more complex way of exploring the role of imitation within a joint action concept.

Overall, this experiment set out to investigate the effects of role swap during an object passing task. The findings indicate that participants adopt a role during the task. However when their roles change, they automatically adjust their previously learnt role to match that of their observed partner. Not only did imitation occur on a basic level, but the results also implied that people preferred to maintain a consistent strategy, as opposed to applying a new strategy. The results are also in line with previous imitation studies, which show that participants prefer to generally imitate the behaviour of their partner (Chartrand & Bargh, 1999), even if this occurs on a more basic level. The present results imply that observing a partner's action facilitates one's own action planning and behaviour.

The previous six experiments examined the planning and online control of joint action. Specifically, it was tested whether joint action strategy would aim to be consistent and thus predictable to one's partner, or would be flexible to varying task demands within a session. Overall, participants in the six experiments showed a remarkable tendency to adopt a consistent strategy even when task demands varied considerably.

The final experiment, Experiment 7, varies from the previous experiments in that it is exploring the kinematic effects of increasing the complexity of the rotation component of the task through the employment of a cube that could be rotated along three dimensions. This experiment resembled the kind of interaction people carry out in everyday life, where objects have 3 dimensions and each can be rotated in a passing movement, i.e. passing a book or a mobile phone. We wanted to examine the effects of complex movements on joint action kinematics, specifically, on a higher level it is much harder to understand and represent the partner's affordances because the object can be rotated in three dimensions; and on a lower 'kinematic' level, execute a successful joint action - i.e., be able to pass the object off smoothly and accurately. Furthermore, the cube task made it difficult for the entire rotation to be performed by a single person, thus the experiment was interested in examining how much of the task would be shared amongst individuals. Rotating an object along three dimension results in more strain on the joints. Would this limit Passers to rotate the object to a comfortable end-state, or will they consider the end-state comfort of their partner and sacrifice their own comfort?

8. Effects of increasing difficulty levels between dyads using a 3D cube

Synopsis

The current experiment examined the effects of increasing overall task difficulty within joint motor action. Here, a cube was used for the purpose of passing an object along three dimensions to a cooperating partner. As opposed to the previous six experiments which examined how manipulating the tasks affected the tendency for participants to be predictable, the final study aimed to look at a more complex movement to examine in more detail the ability of participants to execute joint actions.

In the current experiment, the object could to be rotated to one of two possible sides (coloured red or green) in the experimental condition or, in the control condition the top (white) colour. Both the red and green sides had a vertical black arrow pointing up, which had to be set down in the target area with the correct colour facing up and the arrow pointing to one of three possible numbers indicating different directions. The purpose of this study was to examine the effect of task complexity on movement kinematics within joint action as well as the strategy formation employed by the two individuals, particularly in terms of rotating the object and planning one's movement.

Introducing rotation along more than a single dimension increased the task difficulty exponentially in a similar manner to the previous experiments. Although the previous experiments introduced additional robust variables in the form of stimulation, occluder or precisions, here the increased difficulty was made more subtle. Based on the findings of the simple object passing task utilised in the first six experiments, it was predicted that the Passer would continue to rotate the object and apply a consistent strategy throughout the experiment. However, since the task now involved rotation along multiple dimensions, Passers may choose to rotate solely on one dimension leaving the rest of the task to the Receiver. An alternative prediction would be that, despite the task being made more complex, participants would consider the overall action goal and their partner's end state posture when planning their movement; thereby they may choose to rotate along all three dimensions in anticipation of their partner's affordances. It was also expected that the increased task complexity would have a vast impact on the online control processes on both the Passer and the Receiver. TTP and OA for the Passer and the Receiver are expected to increase, as harder movements require more rotation and more action planning, resulting in an increase in these variables relative to the control condition.

The results indicated that although task difficulty was increased, the Passer consistently rotated their hand along all three dimensions when rotations were required by the task. This suggests that application of a single, predictable and consistent strategy is not limited to the relatively simple tasks used in the previous experiments, but is also formed during tasks involving complex movements.

Introduction

Interacting with objects, particularly the ability to reach and grasp objects of three dimensions, is essential for everyday tasks. The choice of movement and postures we apply enables us to gather useful information about the mechanisms underlying motor control. The previous experiments have demonstrated that people are influenced by the presence of a partner, which ultimately leads them to adjust their behaviour according to the affordances of their partner.

Most research on motor control has generally employed relatively simple movements, often examining one degree of freedom, to investigate the various effects on behaviour or the motor component (Castiello et al., 1993; Cooke et al., 1989; Fitts, 1954; Mason & MacKenzie, 2005; Mukamel et al., 2010; Paulignan et al., 1991a; Sebanz et al., 2003). The advantage of using simple tasks is that it allows us to address one factor at a time. The fewer variables there are to control, the easier it is to explain the results in terms of causality. Simple experimental tests cannot be directly generalised to the complex movements of real life situations, as they lack ecological validity, however they do provide a foundation for future research. Whilst the testing of simple tasks allow us to gain an insight into single aspects of motor control, it is nevertheless important to acknowledge that movement in everyday functioning often involves the integration of several motor components, resulting in more complex movements than are typically studied in an experimental setting.

Henry and Rogers (1960) were the first to examine the response complexity effect. Participants had to complete a series of three tasks that varied in complexity; the tasks were performed in response to an auditory signal. It was predicted that reaction time would increase with more complex movements. The first movement was a simple finger lift. The second movement required participants to lift their finger and grasp a ball by moving their right hand forwards and upwards. The third and most complex movement involved the participation of three movement parts; participants had to lift their finger followed by two arm movements to hit balls. Henry and Rogers (1960) found that reaction time increased for the more complex movements; the more complex a task was, the longer it took participants to execute the movements. This would imply that time to pass (TTP) the object should be longer for conditions when movement is made more complex. As a result, there should be a substantial difference in TTP for the current experiment in comparison to the previous six experiments.

However, some studies have indicated that increase in movement complexity does not always lead to increased reaction times (Fishman, 1984). In conditions where reaction time is not affected by movement complexity, the action is controlled during the movement through the application of online control. If movement sequences have been pre-programmed, then it would be expected that increasing the complexity of the movement should lead to increased movement times. However, in Fishman (1984) the findings imply that the movement was not planned for and instead the complexity of the task was processed at some point during the movement, which accounted for reaction time. Since reaction time did not increase, the movement was not entirely pre-planned and was moderated by online control (Rosenbaum, Hindorff & Munro, 1986; Garcia-Colera, & Semjen, 1987). In other words, another indicator of task complexity can be identified through the number of online adjustments within a movement. If the time to pass the object is consistent throughout all the experimental conditions, then this would imply that participants have pre-planned their movement and any complexity within the movement should be recorded in terms of online adjustments. Nevertheless, since time to pass consists of the reaction and movement time to complete the task, it could indicate that participants may have pre-planned their movements. However because the movement requires more rotation, it may prolong their movement times and thus affect their time to pass the object. Therefore, this variable makes it difficult to predict whether a movement has been pre-planned or not; yet it is still a valuable indicator to measure task difficulty.

A similar concept has been established by Fitts (1954) who stated that increasing task complexity results in more errors and increased movement times. If more errors occur, then it would be expected that participants would adjust their movements to overcome these errors, resulting in an increased number of online adjustments.

Van Donkelaar and Franks (1991) examined repetitive elbow flexion – extension movements that varied in complexity under high and low speeds. This allowed the researchers to examine the use of pre-planned actions versus online adjustments. The findings showed that movements that had to be executed under high speeds were pre-planned; reaction time increased with movement complexity whilst the amount of peak acceleration in their movement remained the same, indicating that no use of online control was applied. On the other hand, the reaction time of slower movements did not increase with task complexity; however these slower movements were affected by the use of online control as the number of movement units increased. The results imply that movement complexity is affected by the speeds at which the movement is performed. Movements that have to be executed as quickly as possible are pre-planned within a person's action planning, however, when the timing parameter does not become crucial to the purpose of the study, people are more likely to be applying online adjustments.

As with all the previous studies in this thesis, the current experiment required participants to perform the task as quickly as possible. Thus, according to van Donkelaar and Franks (1991), participants should not be relying on online control when the task is performed at high speeds. However, what is different about the study conducted by van Donkelaar and Franks (1991) and the current experiment is that participants operated alone in van Donkelaar and Franks' study. Furthermore, the task they used was more artificial with little relevance to daily situations.

When people are asked to cooperate with another, their movements become influenced by their partner's action (Sebanz et al. 2003; 2005). Not only do we consider the task of our partner, but it also limits a person's action planning, as a person's choice of movement is dependent on their partner's movement. Hence, participants may apply a pre-planned programme before they initiate their movement. However, this will have to become adjusted throughout the movement. Thus people's movement are likely to be moderated by online control.

The present study increased the functional complexity of the task. The rationale for the study was to examine the application of complex movement within a joint motor action in an experimental setting. The complexity of the task was increased exponentially because the task required rotation of the object along as many as three dimensions rather than just one (as had been the case in the previous experiments). The increase in difficulty was compounded because whereas previously the Receiver always grasped the object on its ends, they now had to choose on which side to grasp the object. The free choice of grasping location led to diverse orientation of the hand with different angles applied to the joints.

The benefit of studying a simple action in the first six experiments was that it allowed us to focus first on 'higher level' aspects of action, such as the ability to represent the other's affordances, while keeping the task relatively simple. Later, the difficulty of one participant was increased to see how their partner would compensate both on the higher level (e.g., rotation) and at a lower level (e.g., online adjustments).

This experiment is very novel and exploratory in nature. Although the overall task difficulty has increased, it would still be expected that individuals will consider their partner's task. It was therefore expected that the Passer would perform some of the rotation whilst the Receiver would have to take on the remaining movement. An alternative prediction would be that the Passer would perform rotation along all the three dimensions, resulting in majority of the rotation, leaving a minimal task for the Receiver. This will, nevertheless, take a toll on the Passer's own comfort, as it would lead to the implantation of uncomfortable joint angles, resulting in less control over the object. Based on the findings of Gonzalez et al. (2011), we would expect participants to consider their partner's end state posture within their own action planning, thereby applying an uncomfortable posture so that their partner would end up with a comfortable end state posture.

Furthermore, the increased complexity of these movements imply they would be relying heavily on the application of online adjustments as opposed to pre-planned actions; providing us with a better insight into the applicability of online control within joint action. Suffice it to say that it would be difficult to plan joint actions in the present experiment, particularly for the Receiver, as it requires the anticipation of the other's movement in three dimensions, consequently resulting in a longer time to pass the object.

Experiment 7

Figure 8.1 shows the experimental setup. The cube was painted white, apart from one side painted green and an adjacent side painted red. Each painted side contained a vertical black arrow pointing up at trial onset. Analogous to the previous experiments, the object had to be passed from the Passer to the Receiver, who then had to place the cube at a particular orientation in a set target area. Here the object also needed to be rotated on some occasions before being placed in the target location. The green colour required 90° forwards rotation along the x axis, which was rotation along the forwards plane (pitch), whilst the red colour required 90° rotation along the y axis, which referred to rotation along the left or right whilst the front and back remained constant (roll); therefore both colour conditions required the same amount of rotation, with the difference of rotation along different axes. Since the task complexity increased and put more constraints on both of the participants' movements it was predicted that the Passer and the Receiver would share the task load.

One way the participants could have shared the task is if each took on a certain role. For example, the Passer could have rotated along a single dimension in relation to the stated colour, whilst the Receiver would then perform the remaining role of the task by rotating the cube to the stated number. If this movement was consistently applied to every condition, it would enable the two participants to predict their partner's grasp allowing them to suitably grasp the cube with the use of minimal online adjustments.

An alternative prediction is that the Passer could rotate the object on the basis of colour as well as the direction of the arrow. Based on the results of the previous experiments, this might be the more expected result, since the Receiver had an increased task difficulty, given they had to anticipate their partner's action and move their hand accordingly. If the Passer was to sacrifice their own comfort and rotate the object along all the three dimensions, then it would imply the Passer's ability to anticipate and represent their partner's affordances. At the same time, the complex motor task would result in the increased application of online control; participants would require longer to pass the object, thereby resulting in a longer TTP. Furthermore, the option of the Passer performing majority of the rotation would lead to the usage of extreme joint angles leaving the Passer with less control over their movement, which could consequently result in the increased application of online adjustments (OA-Pass and OA-Rec) relative to the control condition. Alternatively, if movement was not affected by the complexity of the task, then TTP, OA-Pass and OA-Rec should not differ between the experimental and control conditions.

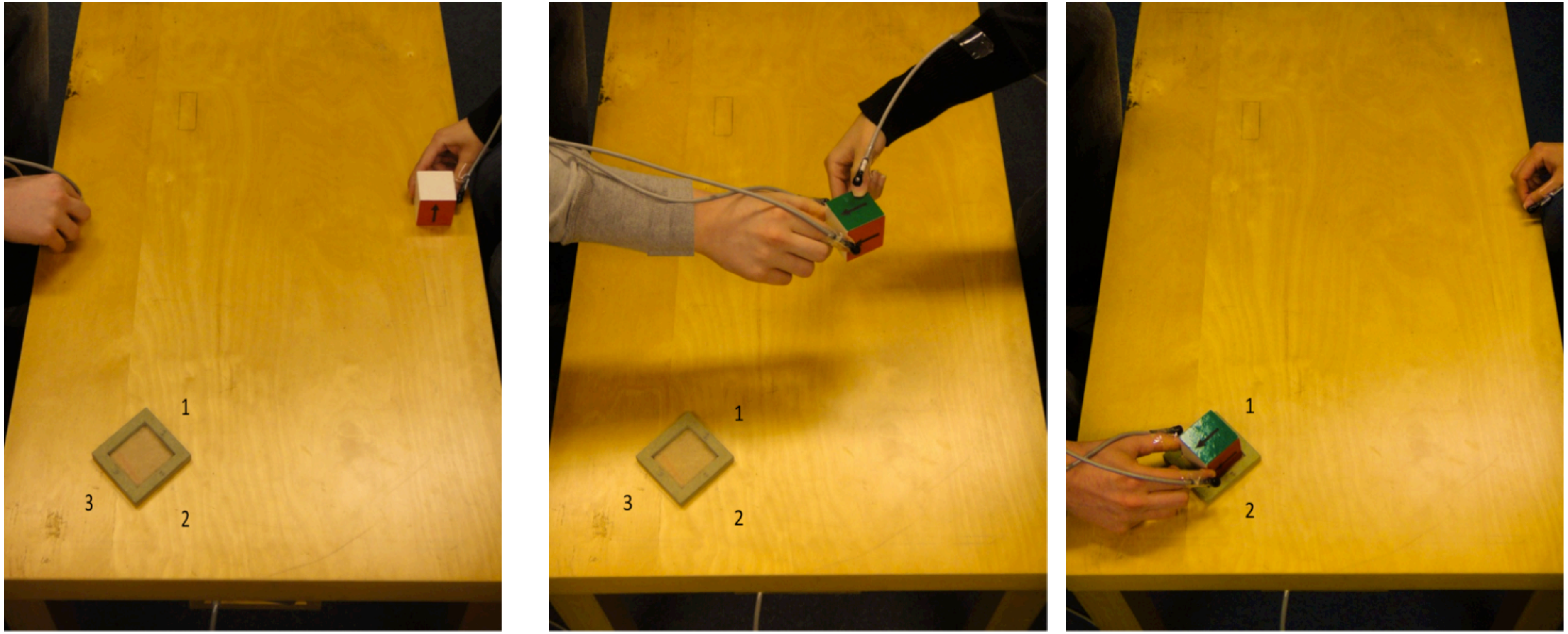

Figure 8.1: Figure depicting Cube experiment. The trial began with the Passer (right) holding the object and the Receiver (left) sitting with their hand resting on the table. On the go signal, the Passer handed the object off to the Receiver. The Receiver then had to place it down in the target area with the stated colour facing upwards and the arrow pointing to one of three numbers in the target area; in this example the condition was Green 3. For ease of illustration, larger numbers have been superimposed on the figures to represent the 1, 2 and 3 positions.

Method

Participants

Ten pairs of participants took part in Experiment 7. All were healthy, right handed individuals with normal or corrected vision, and all were naïve as to the exact purpose of the study. All participants provided their informed consent prior to participating and received course credit.

Stimuli and Apparatus

Pairs of participants were seated opposite each other along the same table that had been employed throughout the previous experiments. The table was marked in three positions: 1) the starting location of the target object was a 4.5 cm x 4.5 cm square drawn in pencil on the tabletop, located 2.8 cm from the edge of the table closest to the Passer and 32.5 cm right of the centre of the target area from the Passer's perspective. 2) The starting location of the Receiver's hand was centred 4.5 cm from the edge of the table closest to them, and 32.5 cm left of the centre of the target area from their perspective. 3) The final target location where the cube had to be set down was made from a wooden frame. The wooden frame was 7.5 cm x 7.5 cm, with a border of 1.1 cm and a carved area of 5.3 cm x 5.3 cm that was 0.5 cm deep. The frame, which was marked with 3 different numbers representing 3 different orientations, served as a container for the cube to be inserted into its final position. The squared frame was placed diagonally to the Passer and the Receiver centred 10 cm forward of the starting position of the Receiver. The number 1 orientation was located on the top left (45° to the left of the Receiver), number 2 was the top right (45° to the right of the Receiver) and number 3 was labelled on the lower right (90° towards the right of the Receiver). The target object was a wooden cube block (4.5 x 4.5 x 4.5 cm).

Every trial started with the target object being placed in front of the Passer with the green side facing them and the red side to their left. The arrows on the painted sides were pointing upwards. On all the trials, apart from the control condition, the object had to be rotated in three dimensions, along the x, y and z axes. From the Passer's perspective, the x dimension referred to turning the object in the forwards plane (pitch), here the left and right sides of the object stayed in the same place. The y dimension referred to rotating the object to the left or right (roll) whilst the front and back sides of the object would remain constant. Rotation in the z dimension referred to the object spinning side to side (yaw), whilst the top and bottom sides remained in the same place.

In the control (white) condition participants were asked to pass the cube to their partner, who then placed it down in the target area, with no rotation beyond what was required along the z dimension (since the target area was placed diagonally, the cube had to be rotated by about 45° along the z dimension).

In addition to the control condition, there were the G1, G2, G3 and R1, R2, R3 conditions, where the letters referred to the colour that had to be placed facing up in the target area with the arrow pointing towards the one of the three numbers positioned on the target place. For example, from the Passer's perspective, the G1 (green 1) condition required 90° forwards rotation along the x dimension (to rotate the green side up), and a 135° rotation towards the right along the z dimension (to rotate the arrow to the number '1' position on the target place). The recording markers from the Polhemus Fastrak system were attached to the participants in a similar manner to that of the preceding experiments.

Data Analysis

Analysis was carried out on kinematic data as in Experiment 1, except that ROTA was measured in three separate dimensions identified as x, y and z for the Passer, resulting in the measures of ROTA_X, ROTA_Y and ROTA_Z. To get a general idea of how much the Passer rotated on the whole, the absolute values of each dimension were added to provide an overall value termed ROTA_ALL. .

The data was entered into two separate repeated measures ANOVA; in one, data were analysed as repeated measures with three levels of orientation (colour) as the independent variable and participants as a random variable. This analysis considered the averages for the 2 experimental colour conditions relative to the control (white) condition, allowing for a consideration of how the increased complexity of the two colour conditions affected the movement. A second analysis was employed to analyse the colour and number condition in more detail using a repeated measures 2 (colour) x 3 (number) ANOVA.

Procedure

The procedure followed a similar structure to that utilised in the previous six experiments. Participants began each trial sitting opposite each other with the Passer holding the object using their right thumb and index finger; their right thumb was placed on the side of the object facing them, and right index finger on the side of the object facing the Receiver. The target object was placed in front of the Passer with the white side facing up, whilst the green side was facing them, the red side of the cube was located to their left and both arrows on the green and red side were facing up. The Receiver rested their right hand in their own starting location with the thumb and index fingertip closed together.

In the six experimental conditions, the experimenter first stated a colour and a number, meaning that the stated colour had to face upwards in the final target area with the arrow pointing to one of the three possible numbers reflecting different orientations. In the control condition (referred to as 'top') participants were required to pass the cube with the top (white) side being placed in the target area in no particular orientation. Following statement of the condition, the experimenter pressed a key which simultaneously began the kinematic recording and caused a tone to be initiated by the computer. At the tone, the Passer had to lift the object and hand it off to the Receiver who then had to place it down in the target area with the appropriate side facing upwards and, in the experimental conditions, with the arrow pointing to the stated number. Similarly to the previous experiments, the task instructions required participants to complete each trial as quickly and accurately as possible. Participants were only allowed to use their right thumb and index finger to grasp the object. Trials in which participants used more than the two permitted fingers or in which the object was dropped or otherwise not placed correctly within the target area were excluded from the study.

Each session consisted of 10 ordered repetitions of each of the two target colour conditions and three different number conditions, as well as 10 trials for the control condition (top), all randomly ordered, resulting in a total of 70 trials.

Results

A total of 34 trials (M = 4.86%, SD = 3.24%) from all participants were excluded from the final analysis because the task was not completed successfully. Kinematic data for the current experiment is summarized in Appendix B. Fig. 8.2

shows rotation of the Passer along the x, y and z dimension for the colour and control condition.

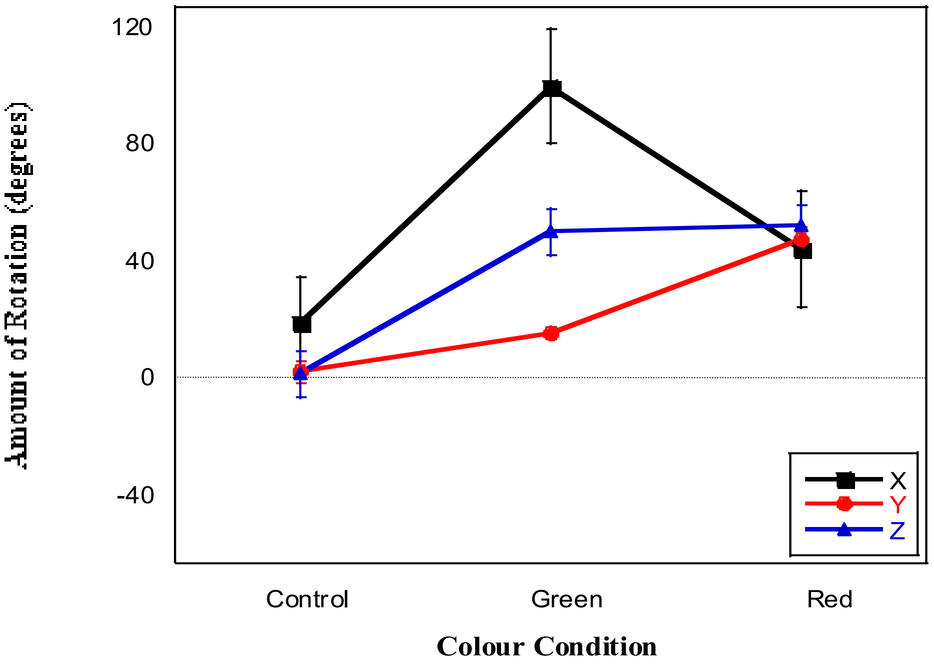

Figure 8.2. Mean degree of ROTA along the x, y and z dimension for the Passer as a function of colour. Error bars represent standard errors of the mean.

The first analysis concerned the effects of colour versus the control condition. The results showed that rotation along the 3 axes led to a significant effect on ROTA_X (F [1.3, 11.7] = 8.95, p < .01), ROTA_Y (F [2, 18] = 39.65, p < .001) and ROTA_Z (F [2, 18] = 13.33, p < .001). ROTA_X was largest in the green condition followed by the red condition and least for the control condition. ROTA_Y was smallest in the control condition, followed by the green condition and largest for the red condition. Examination of the means suggested that the no rotation (white) differed from the rotation (green and red); the post hoc results revealed a significant effect, t (19.79) = 5.62, p < .001. ROTA_Z, on the other hand, was similar for the green and red condition, whilst rotation was very minimal for the control condition.

The analysis of the three rotations (Figure 8.3), ROTA_ALL also revealed a significant effect of colour (F [2, 18] = 23.05, p < .001); the Passer rotated the least in the control condition and rotated along similar lines for the red and green colour condition, t (20) = -7.88, p < .001.

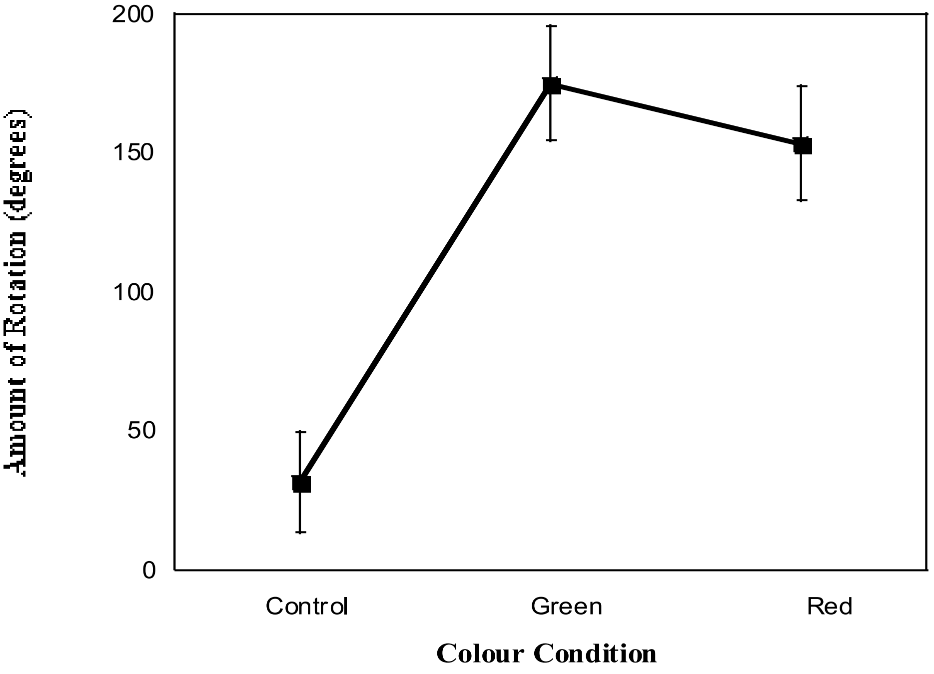

Figure 8.3. Sum of all rotations for ROTA_ALL as a function of colour condition. Error bars represent standard errors of the mean.

There was also an effect of colour on TTP (F [2, 18] = 50.27, p <.001), with time to pass being longest for the green condition, followed by red and fastest for the control condition (Figure 8.4). Effects of OA-Pass (F [2, 18] = 26.36, p < .001) and

OA-Rec (F [2, 18] = 7.16, p < .01) were also observed, with the control condition resulting in a smaller number of online adjustments, whereas the green condition led to the largest number of corrections (see Figure 8.5). The post hoc test for OA-Pass revealed a significant difference for the control and experimental conditions, t (28) = -2.48, p < .05. However, a significant difference for the control relative to the experimental condition was not observed for OA-Rec, t (28) = -1.19, p > .05.

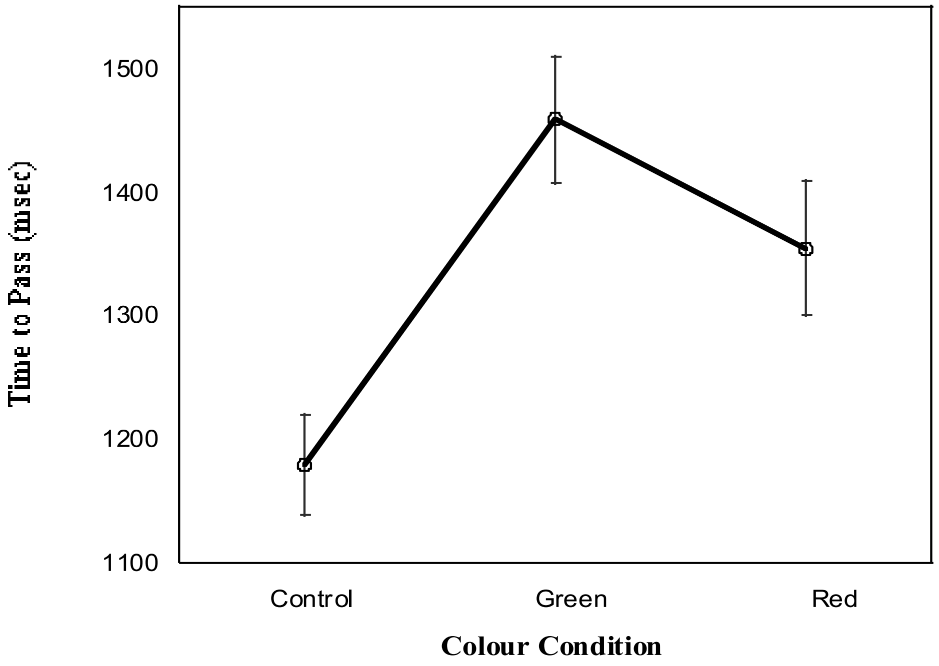

Figure 8.4. Mean time to pass (TTP) as a function of colour. Error bars represent standard errors of the mean.

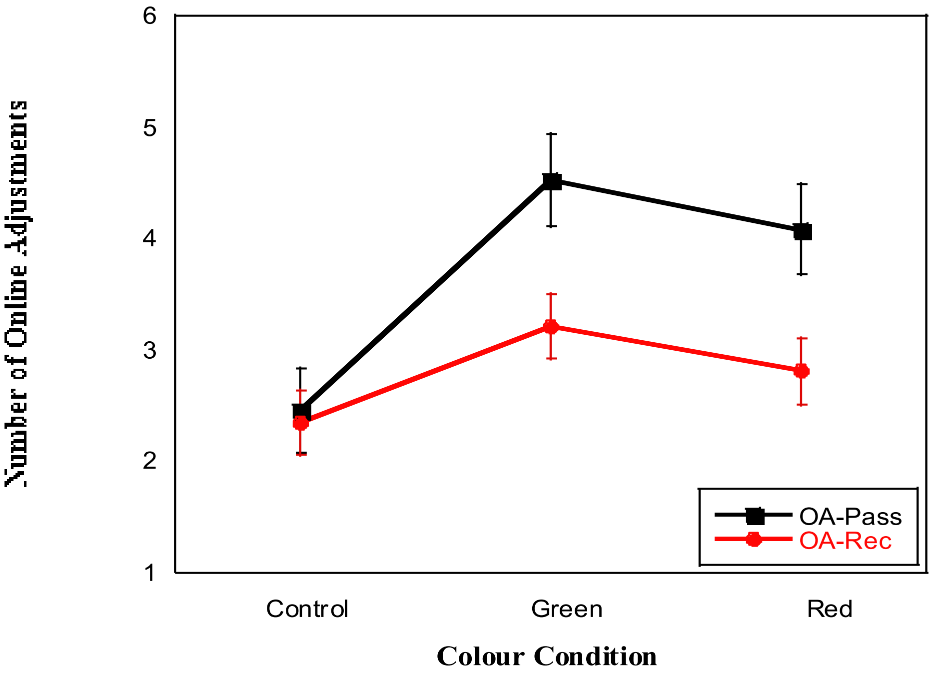

Figure 8.5. Number of online adjustments for OA-Pass and OA-Rec as a function of colour. Error bars represent standard errors of the mean.

The second part of the analysis focused on the two experimental conditions in regards to the effects of colour and number on the various kinematic variables. The results for colour indicated a significant effect for ROTA_X (F [1, 9] = 7.31, p < .05), with the green condition resulting in a larger amount of rotation. Colour also had an effect on ROTA_Y (F [1, 9] = 32.17, p < .001) reflecting a larger amount of rotation for the red colour.

Number had an effect on ROTA_X (F [2, 18] = 3.62, p < .05); the Passer rotated the least when the object had to be set in the target area with the arrow pointing to location number one and rotated the most along this axis when the arrow had to point to number three (see Figure 8.6). The results of ROTA_Y also indicated a significant effect (F [2, 18] = 6.63, p < .01); the Passer rotated the object further for the conditions involving number three and rotated the least for number two (Figure 8.6). Considering all three orientations, there was also a significant effect of number on ROTA_ALL (F [1.26; 1.39] = 5.56, p < .05); the Passer overall rotated the least for the conditions involving number one and rotated the most for number three (Figure 8.7).

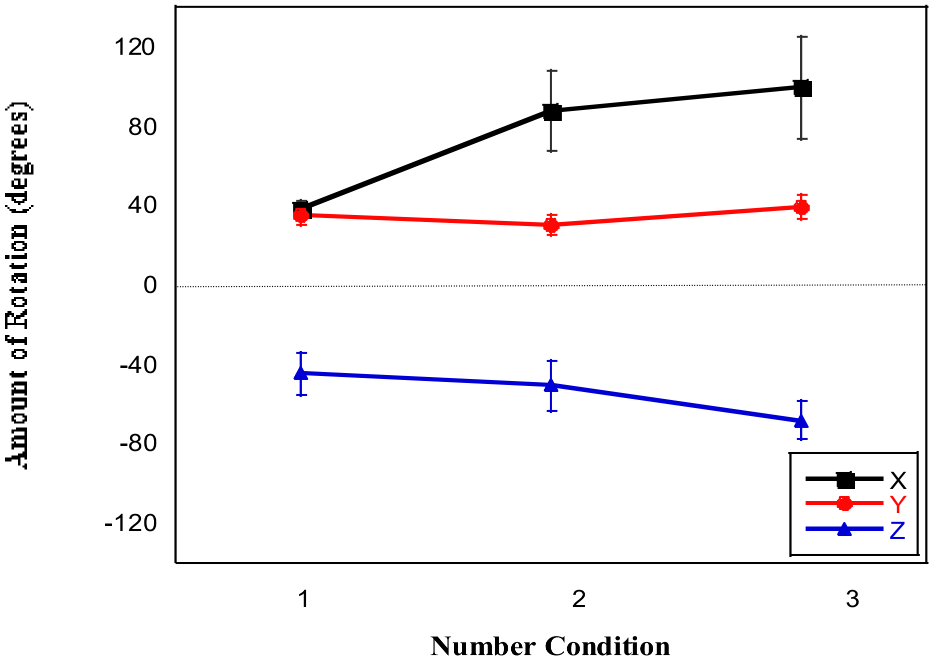

Figure 8.6. Mean degree of ROTA along the x, y and z dimension for the Passer as a function of number condition. Error bars represent standard errors of the mean.

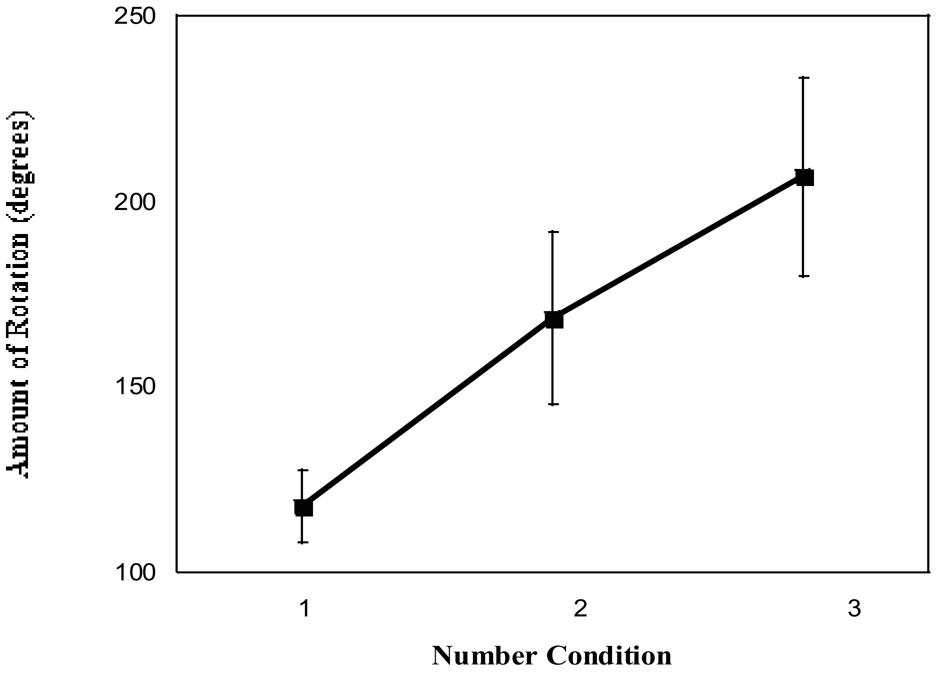

Figure 8.7. Sum of all rotations for ROTA_ALL as a function of number condition. Error bars represent standard errors of the mean.

An effect of colour was observed on TTP (F [1, 9] = 9.33, p < .05) with the green condition requiring a longer time to pass the object in comparison to the red colour condition. Furthermore, an effect of number on TTP was also observed (F [2, 18] = 4.29, p < .05). The orientation towards number one was fastest amongst the Passer and the Receiver, followed by orientation number three whilst orientation number two took the longest to pass the cube between one another (Figure 8.8).

There was also an effect of number on OA-Pass (F [2, 18] = 8.81, p < .05). The Passer made more online adjustments when the arrow on the object had to point towards orientation number two and made the least number of adjustments for orientation number one. A similar effect was observed for OA-Rec, however the results were not significant (F [2, 18] = 2.14, p > .05). Figure 8.9 displays the number of online adjustments for the Passer and the Receiver as a function of number.

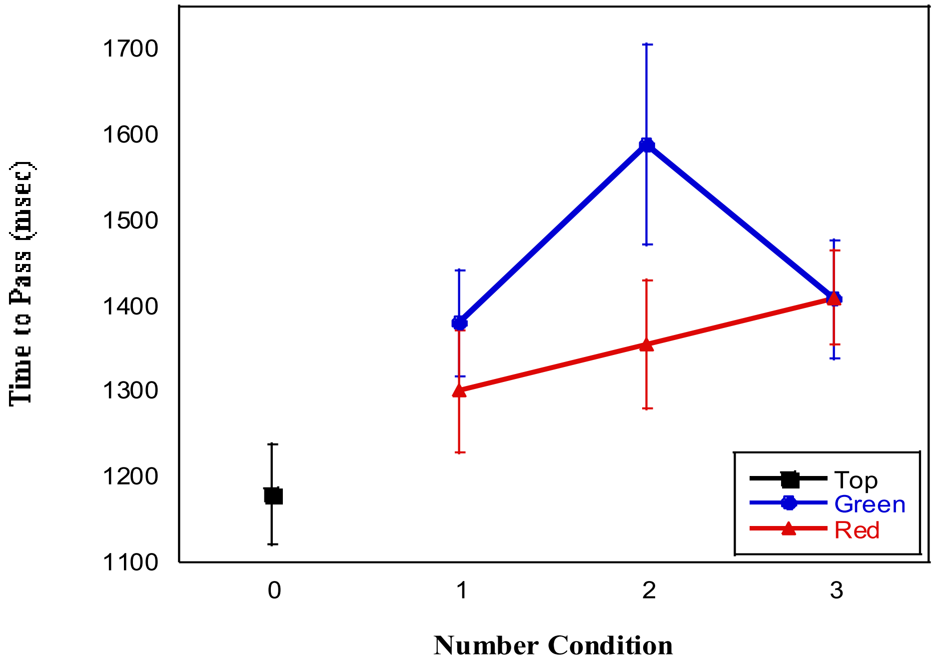

Figure 8.8. Mean time to pass (TTP) as a function of number and colour condition. Error bars represent standard errors of the mean.

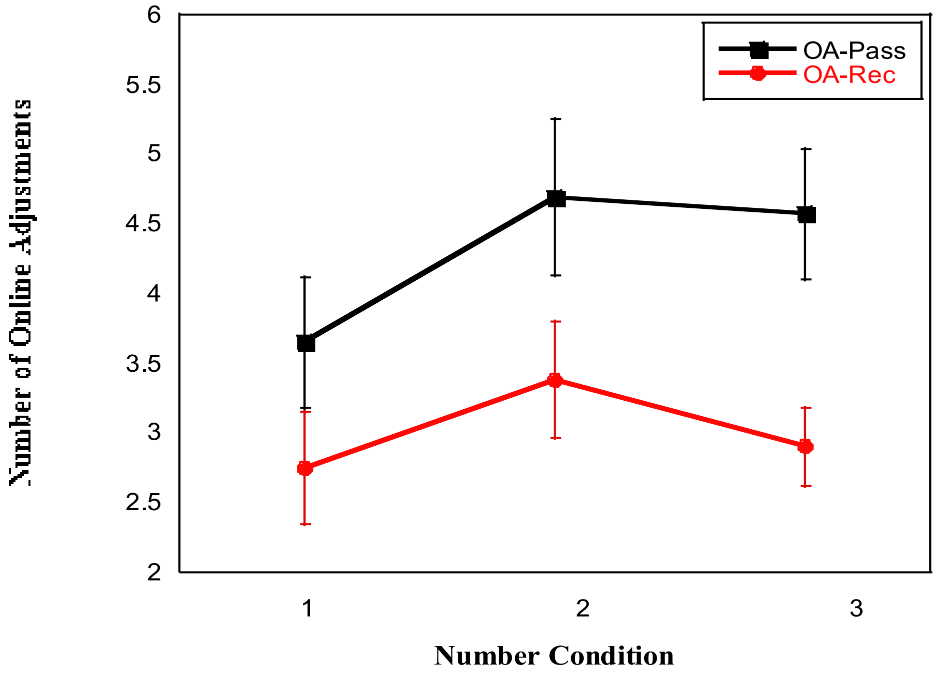

Figure 8.9. Number of online adjustments for OA-Pass and OA-Rec as a function of number condition. Error bars represent standard errors of the mean.

There was also a significant colour by number interaction for TTP (F [2, 18] = 7.23, p <.01) (Figure 8.8). Participants took the longest time to pass the cube for G2, followed by similar times for G3 and R3. Participants required a similar amount of time for G1 and R2 and were fastest for the R1 condition. A marginal effect of colour by number interaction was also observed for ROTA_Z (F [2, 18] = 3.40, p = .056) (See Appendix B). The results showed that the Passer rotated the same for G1, G2 and G3, whilst R1 started off with a low amount of rotation, followed by an increased rotation along the z dimension for R2 and the most rotation for R3.

Discussion

There were two main results of Experiment 7. First of all, the findings of the current experiment demonstrated that the manipulation worked and task difficulty was increased. This is evident in the increased number of online adjustments relative to the rectangular block where no additional constraints were imposed in Experiment 1. The findings showed that the complexity of the movement was modulated through online control. The results for the Passer indicated a larger number of online adjustments for the experimental conditions relative to the control condition, providing an indication that the complexity of movement along the three dimensions resulted in a number of movement corrections. Online adjustments for the Receiver were also influenced by the colour condition, resulting in increased movement adjustments for the red and green condition relative to the control condition. This effect was not only evident for online adjustments but was also manifest in time to pass the object. It took participants longer to pass the object in the colour condition as opposed to the control condition. This possibly indicates that the experimental conditions required more action planning and more rotation, thus it took participants longer to pass the object. Not only was this evident for the colour condition, but similar findings were observed across the number conditions, further supporting the idea that the task was difficult to execute.

Second and more interestingly, the Passer continued to do almost all of the rotating, even though this often put them in awkward postures at extreme joint angles. In contrast to the rectangle experiments, there is more complexity with the cube in relation to the rotation part of the task.

There was a main effect of colour on ROTA_X, ROTA_Y, ROTA_Z and ROTA_ ALL as well as a significant effect of number on ROTA_X, ROTA_Y and ROTA_ALL. The effect on ROTA_X showed that the Passer rotated their hand more along the x dimension for the green colour in comparison to the red. Rotation along the z dimension was similar for the red and green conditions. However more rotation was performed for the red colour along the y dimension. A possible explanation for the results is that the green colour condition needed to be rotated 90 degrees forwards along the x plane if the green colour was chosen as the target colour, whilst the red colour required 90 degrees rotation along the y plane. Hence there was a difference in rotation along those two dimensions for the two colour conditions. A similar amount of rotation along the z plane was observed for the green and red colour condition due to the fact that once the cube was rotated to the ‘correct’ colour on the x or y plane, participants then rotated along similar levels for both the colour conditions to ensure that the arrow would be oriented towards one of the ‘correct’ numbers. The reason why a similar pattern of rotation along the z dimension was observed could be that the Passer’s movement was limited. A larger amount of rotation would have led to extreme joint angles and the possible interference of their hand when trying to pass the cube to the Receiver. Hence, they rotated a similar amount across all the three different numbers for both the red and green colour.

It can be argued that the reason why the Passer rotated more along the x dimension for the green colour in comparison to rotation along the y dimension for the red colour could be that the green side was facing the Passer and thus the Receiver was at a disadvantage of not being able to see this side. To overcome this issue, the Passer may have decided to fully rotate to the green colour to allow the Receiver to obtain a better view of that side. This suggests that the Passer may have anticipated the Receiver's affordances and simulated their task, thereby rotating it further for the green side. Since the red side was to the Passer's left, it was viewable to the Receiver, and thus a full 90 degrees rotation along the y plane was not necessary to obtain a better view.

An alternative argument could be that it was easier for the Passer to rotate the object along the x plane, thus they fully rotated for the green colour condition. However, the fact that it took longer to pass the cube for the green condition in addition to the increased number of online adjustments suggests otherwise. Past research has also shown a positive relationship exists between task difficulty, movement times and number of online adjustments (Fitts, 1954; Meyer et al., 1988). Furthermore, casual observation showed that the green colour condition led the Passer to adopt an awkward posture of their wrist, putting strain on their joints and resulting in an uncomfortable end state. This implies that although the task of rotating to the green colour condition was more complex, the Passer decided to overall rotate more for this colour, as shown by the sum of all rotations along the three dimensions. Therefore the former explanation may seem more plausible.

Furthermore, considering the analysis of the three target orientations, the findings demonstrated that orientation 2 and 3 required the most rotation, which also means that it was the most complex movement. The results of the online parameters, TTP and OA-Pass support this notion; TTP was longer for both orientations 2 and 3 in addition to an increased number of online adjustments were observed for the Passer for those two orientations. Despite the fact that orientation 2 and 3 were difficult to execute, this task was nevertheless performed by the Passer leaving a minimal task for the Receiver. The findings imply that the Passer's choice of movement was modulated by the Receiver's task. Although it was easier for the Passer to rotate the object on the basis of colour, they sacrificed their own comfort for that of the Receiver.

While the results may not be in line with Rosenbaum's end state comfort effect, the results are nevertheless in line with the study conducted by Gonzalez et al. (2011). One of the possible reasons why the results obtained did not conform to Rosenbaum et al. (1990) study is that Rosenbaum's study was performed on single individuals. When interacting with others, an agent puts aside their individuality and becomes more aware of the overall action goal, which also implies considering the task of their partner (Sebanz et al., 2006; Wenke et al., 2011). Thus they put aside their own end-state comfort and focus on the end-state comfort of their partner, who forms an extension to their own movement. As opposed to regarding oneself as two separate individuals, the pair unite together to form one (Tsai et al., 2011). Therefore, when considering a partner as an extension to one's own movement, the results can also fit in with Rosenbaum's end-state comfort effect (Rosenbaum, 1990) providing us a 'group' end-state comfort.

According to Clark (1996) the common action goal is sufficient to enable both participants to form a representation of their partner's task, as the partner's task was not only related to the general action goal but also influenced the overall performance. In other words, the Passer needed to understand that their choice of action would influence the Receiver's choice of movements, which could have resulted in either a prolonged movement or an efficient outcome. Thus, if the Passer completed most of the task, then the Receiver was left with a less choice of decisions. This in turn reduced the overall timing parameter of the interaction, resulting in a more efficient interaction. In other words, it can be postulated that the Passer anticipated that if they completed most of the task, then the goal would be achieved more quickly. It can therefore be implied that the Passer acknowledged the Receiver's task for the egocentric purpose of fulfilling their own needs. Although it would have been more advantageous, in terms of their effort, for the Passer to minimally rotate the object, it nevertheless would have produced a disadvantage as their overall action goal would have not been completed as quickly as it would have had they performed the rotation themselves. It could be speculated that the Receiver's requirement of choosing a grasping location could have resulted in great difficulty of predicting and applying a consistent grasp resulting in a delayed completion time.

The findings of the current study are in line with the previous experiments and impliy that even when a task is increased in complexity to make it more difficult for the motor system to perform the movement, people still manage to represent their partner's affordances. It provides us with evidence for the formation of mental representation of a partner’s affordances resulting in the integration of their task within one’s own action planning (Georgiou et al., 2007; Glover & Dixon, 2012; Sebanz et al., 2003). While the previous experiments have employed simple tasks to allow us to focus on the ‘higher level’ aspects of action, the current experiment has enabled us to extend this to more complex tasks, as demonstrated in everyday situations.

Overall, the findings of the current experiment provide a valuable contribution to the understanding of joint action between individuals working together on a complex task. Despite the increased complexity of the task and the demands it imposed on the motor system, two individuals were still able to perform a successful and efficient interaction. The results of the current experiment revealed that although the task increased in difficulty, the Passer decided to rotate the cube along all three dimensions for the experimental conditions, leaving the Receiver with the minimal task of grasping the object and placing it down in the target area. The results imply that the overall action goal enables us to represent our partner’s task. One proposition that could be postulated is that the Passer was aware of their partner’s difficult choice of decision making leading the Passer to assist the Receiver with their task allowing participants to complete the task more efficiently.

The results were in line with previous research examining joint action within a minimal coordination context (Blakemore & Decety, 2001; Chartrand & Bargh, 1999; Elsner et al, 2002; Glover & Dixon, 2012; Knoblich & Flach, 2001, 2003; Knoblich & Jordan, 2003; Sebanz et al., 2003, 2005), which have shown that individuals perceive other people’s actions and incorporate this perceived action onto their own action system to form an overall action goal.

9. General Discussion

Experimental Overview

The experiments in the present thesis set out to examine the planning and online control of joint action. Specifically, it was tested whether joint action strategy would aim to be consistent and thus predictable to one's partner, or would be flexible to varying task demands within a session. Further, we sought to measure the impact of varying the conditions of the tasks on online control processes.

To explore the mechanisms involved in planning and controlling actions, the present thesis employed an object passing and placing task, in which not only a common goal was shared between two people, but also the task requirements of one of the participants may or may have not affected the behaviour of the other. Recent studies that investigated the cognitive and neural factors of joint motor actions observed that the same principles applied to individuals acting alone also applied to people working together (e.g., Georgiou et al., 2006; Jackson & Decety, 2004; Mottet, Guiard & Ferrand, 2001; Reed et al., 2006).

Overall, participants in the seven experiments showed a remarkable tendency to adopt a consistent strategy even when task demands varied considerably. Experiment 1 showed that the Passers could represent, and would accommodate, the end-state comfort of the Receiver. When the task required the target to be rotated at some point in the trial, prior to setting it in the target area, the Passer generally performed a significant portion of this rotation prior to handing it off to the Receiver. This allowed the latter to place the target in the goal position without having to rotate their hand to an awkward posture. This replicated the findings of Gonzalez et al.

(2011) while avoiding the possible experimenter demands that existed in their study by using a neutral object rather than common tools.

Experiment 2 examined the effects of an unpredictable mechanical perturbation of the Passer's arm on joint action strategy and online control. It was observed that while the Passer continued to rotate prior to handing the object off, they did so less than in Experiment 1. More importantly, the rotation strategy of the Passer did not vary depending on whether or not they had been perturbed. The perturbation was, however, effective in increasing the number of online adjustments made by both actors. Experiment 3 used the same perturbation condition as in Experiment 2 but blocked trials by type, meaning that unlike Experiment 2 participants had foreknowledge of whether or not a perturbation would occur on a given trial. Nevertheless, Passers continued to adopt a consistent strategy across conditions, although here this meant not significantly rotating the object in any condition. The perturbation again led to an increase in the number of online adjustments for both participants.

Experiment 4 investigated the effects of eye gaze. Eye gaze provides subtle information on another's person state of mind, allowing us to infer their goals and intentions (Allison et al., 2000; Baron-Cohen et al., 1995). The same object passing task was used as in the preceding experiments; however this time an occluder was placed between the two participants to eliminate any view of each other's faces. The results showed that the removal of gaze information did not hinder participants' ability to successfully plan and execute their task jointly. It did not result in a less efficient and more time consuming motor interaction since there was no increase in online control or time to pass the object. Despite the removal of eye gaze, participants continued to adopt a single consistent strategy, with the Passer rotating the object for the orientation condition, throughout the experiment.

Experiment 5 included a version of the task in which an extra constraint and new precision demands were applied by having participants pass the block through a small aperture during completion of the task. This led to large increases in online control parameters of time to pass and the number of online adjustments for both actors. Nevertheless, the amount of rotation done by the Passer was roughly similar across conditions, and again there was evidence that Passers employed a similar strategy, despite the gross changes in the constraints of the task.

In Experiment 6 participants completed the basic passing and placing task but swapped roles halfway through the session. It was found that, whereas the Passer on average did a large amount of rotating prior to passing the object, one pair existed in which the Passer executed only a minimal amount of rotation. Critically, this role adoption continued when the participants swapped seats. This suggested that the participants encoded the task in terms of two distinct roles, and that they adapted their behaviour to their new role when they changed positions. Further, how they enacted this role in Block 2 depended heavily on how they had seen their partner perform it in Block 1.

Experiment 7 examined the involvement of complex movement using a 3D cube. It was found that, despite the involvement of complex rotation along the three dimensions and the increased demands on the joints, the Passer rotated the object near to completion along all three dimensions. The rotation of the object along the three dimensions imposed additional strain on the Passer's motor system, allowing the Receiver to employ a more comfortable end-state posture. Furthermore, the increased decision choices of the complex movement affected participants' action planning and movement execution as seen by a vast increase in time to pass the object. The results demonstrate that the effects of end-state comfort do not only apply to single individuals or simple object passing tasks, but are also observed during complex movements of a joint action task. It can be proposed that the overall action goal enables people to represent a partner's task in addition to their partner's end state and consider this within their own action planning prior to executing a movement.

All told, the seven experiments here provide a valuable insight into how joint actors form their strategy under different conditions. As a rule, actors here tended to adopt a consistent strategy even across conditions that varied the requirement of the Passer's task significantly. However, they were flexible enough that this strategy accommodated the different demands the tasks placed on each actor. For example, when the movements of the Passer were impaired using a mechanical perturbation, they adjusted by rotating the object less, leaving more of the task to the Receiver. More interestingly, the Passers did this as a general compromise strategy rather than just on the perturbation trials, even when they had foreknowledge of the trial type. Thus, Passers achieved a balance between sharing the workload of the task, maximising the end-state comfort of the Receiver, and maintaining a consistent and predictable pattern of behaviour.

Scientific Perspective

Sebanz et al. (2003) have shown that people are able to form an awareness of their partner's task when working alongside each other, implying that individuals considered their partner's task within their own action planning. Glover and Dixon (2012) found that motor representations, used by individuals to facilitate their own performance, were also used for joint actions. Specifically, they observed that individuals used a representation of a partner's affordances to modify their own choice of posture. The findings of the current thesis are in line with these studies on joint action, implying that when two people work together on a task, they automatically consider their partner's task and the overall action goal when planning their own movement (Harrison & Richardson, 2009; Kourtis et al., 2010; Reed et al., 2006). We form a representation of our partner's task and utilise this to plan our own actions; this was evidenced by the application of increased efforts on the Passer's motor system and their choice of postures based on their partner's affordances. The novelty about this study was that it provided a groundbreaking kinematic analysis for dyadic interaction in terms of action planning and control, which has rarely been studied amongst joint action (Georgiou et al., 2007; Mason & Mackenzie, 2005).

One way the results of representing the actions of others can be explained is in terms of the mirror neuron system; the brain is uniquely developed for the perception and representation of others' actions. These neurons are known to 'mirror' the observed actions of others within our own action system, thus facilitating action planning during action observation (Di Pelegrino et al., 1992; Fogassi, Gallese, Fadiga & Rizzolatti, 1998; Gallese et al., 1996). It has been shown that action observation facilitated increased activity in the parietal and frontal areas of the brain, the same regions known to be activated during imitation and action execution of grasping movements (Iacoboni et al., 2005). However, it has been noted that activity in these neurons occur to a lesser degree when an action is observed in comparison to an action being executed. This implies that the perception of an action has a priming effect on action execution, particularly if the perceptual information is congruent with the motor execution (Calvo-Merino et al., 2005). This explains why the mirror neuron system is activated during the observation of a human arm movement but not a robotic arm (Tai et al., 2004). Nevertheless, Hamilton and Grafton (2006) suggested that this observed effect may have not been due to congruency of a familiar motor action, but may have occurred as a result of lack of variability in the robotic arms' movement. There is more variability in human arm movements, whilst the robotic arm movements are consistent, resulting in a strong habituation of the mirror neuron system. When habituation was considered, the observation of simple and complex movements performed by the human and robotic arm led to strong activation of the mirror neuron system. Mirror neurons activate during the observation of an action as well as the execution of the same action, which allows us to establish the observed person's intention, predict a response and plan our actions accordingly (Annett, 1996; Meltzoff, 1999).

Being able to represent the actions of others within a joint action is important in as much as it allows us to form effective joint strategies. A valuable planning strategy for joint cooperation is the application of consistency and being more predictable towards a partner, which was observed in the current thesis. Vesper et al. (2011) compared participants' individual and joint performance on the Simon task and found that those participant pairs who were more consistent in their behaviour also performed the best. Participants used predictability as a strategy to coordinate and synchronise their movements with those of their partners. However, their study did not vary the conditions as we did here.

Huber et al. (2009) also found that participants preferred to chose a more predictable movement by handing over a cube at a consistent height and distance. This enables participants to reduce variations within the online component of action planning. Not only was a decrease in reaction time observed throughout the trials, the findings also showed that through the applicability of being more predictable, partners became more efficient in passing the object. Here, we have added to the results by showing that this consistent strategic approach is not only beneficial, but may be a fundamental principle of joint action. In a real world cooperative joint task such as sports, knowing with a high likelihood what a teammate is about to do has obvious benefits. Interestingly, the opposite may be true when in competition with another – being unpredictable may make a player more competitive.

The study of bimanual coordination provides useful information that the motor system prefers to apply a symmetrically congruent movement due to the involvement of a reduced number of kinematic degrees of freedom (Fine & Amazeen, 2011; Otte & van Mier, 2006; Summers et al., 1993; Yamanishi et al, 1980). This has also been known to extend to cooperating pairs working alongside each other (Georgiou et al., 2007; Harrison & Richardson, 2009; Richardson et al., 2007; Schmidt et al., 1990; Schmidt & Turvey, 1994). Although people prefer to synchronise their movements with that of their partner, the study by Richardson et al. (2007) have shown that eye gaze is not crucial for a joint coordination to occur. People synchronised and coordinated their movements based solely on the presence of a partner. Thus the results suggest that eye gaze is not necessary to influence joint motor action. This is in line with the results of Experiment 4. It is possible to suggest that the mere presence of the target object may have influenced people to take into account their partner's task and intention; considering a partner's action task is sufficient to simulate the actions of others in order to predict their upcoming action (Iacoboni et al., 2005). Although the results of the current experiment may not be in line with previous studies on eye gaze (Allison et al., 2000; Bayliss et al. 2006; Castiello, 2003; Pierno et al., 2006a), the results, nevertheless, are in line with other studies on joint action. The presence of a person directly affects the action of another person; people have a tendency to simulate their partner's task and integrate this within their own action planning, even when people are asked to ignore their partner's task (Atmaca et al., 2011; Kourtis et al, 2010; Sebanz et al., 2003, 2005, 2006, Wenke et al., 2011).

The present study also extended the results of previous studies in individuals and pairs that examined the end-state comfort effect (Gonzalez et al., 2011; Rosenbaum et al, 1990; 1995; Weigelt et al., 2006). In individuals, Rosenbaum et al. (1990) showed that initial postures were selected such as to maximise the comfort in the final position. In pairs, Gonzalez et al. (2011) showed that Passers would accommodate the end-state comfort of Receivers when the task involved passing tools. The present study replicated the findings of Gonzalez et al. (2011) while avoiding the possible experimenter demands that existed in their study by using a neutral object rather than common tools; the results generalised to the passing of neutral objects without specific affordances, and maximum end-state comfort could at times be sacrificed when conditions warranted. The Passers anticipated their partner's task as well as the overall action goal and considered the Receiver's end state comfort when planning their own action (Atmaca et al., 2011; Glover & Dixon, 2012; Gonzalez et al., 2011; Kourtis et al., 2010; Marteniuk et al., 1987; Sebanz et al., 2003; 2005; Weigelt et al., 2006; Wenke et al., 2011). This allowed the Receiver to place the target in the goal position without having to rotate their hand in an awkward posture.

Finally, the present study offered the first real examination of online control processes in joint action. As in previous studies involving individuals (Fitts, 1954; Meyer et al., 1988; Paulignan et al., 2001a,b), joint actors adjusted online to variables that affected the general difficulty of the task. When one of the actors had their movement perturbed using electrical stimulation of the bicep, this not only led to an increase in the number of online adjustments they made but a corresponding increase in their partner as well. This was further evidenced in the precision task, where the task difficulty increased drastically, leading to the outcome of both participants making more online adjustments.

The results of TTP across the experiments showed that action planning was affected by the complexity of the task. The results of Experiment 1 showed that people planned their movement prior to action execution as evidenced by the comparable values for the different orientation conditions. This supports the view that action planning is influenced by internal cognitive processes requiring conscious awareness that occurs prior to movement initiation (Glover, 2004). Participants had decided on how to pass the object prior to movement execution since there was no significant difference in the time to pass the object for the different conditions.

The subsequent experiments examined the degree to which this pattern would hold when the Passer's task complexity was increased. The results of Experiments 3, 5 and 7 showed that increasing task demands resulted in longer action planning, as evidenced by the increased value for time to pass the object. Applying a longer time to pass enabled participant to pre-plan their movements prior to movement execution and counteract for the increased task complexity, in the form of a predictable perturbation, an added precision task or complex movement, to allow participants to gain more control over their movement. Increasing task complexity also resulted in an increased number of online adjustments in both the Passers and the Receivers. Participants adjusted their movement in accordance to that of their partners when their task was hindered and made more difficult. These fine adjustments enabled participants to gain more control over their movement and account for erroneous movements during flight (Fitt's, 1954; Glover, 2004). The introduction of perturbations and hindrances impinge on planned movements resulting in the application of online control and longer movement times (Day & Lyon, 2000; Komilis et al., 1993).

Shared representations not only serve the purpose of social interactions, but are also necessary for an efficient and smooth lifestyle. Imagine driving down the road and not being able to represent other people's intentions and actions; we would be driving without a care, leading to major accidents. When people drive, they need to be aware of what is going on around them, i.e. the car next to them that is about to merge into their lane, the cyclist pedalling next to us, the pedestrian crossing the street that will make the car in front of us slow down and hit the brakes. It is important for other's to be predictable, e.g., the driver who signals left and then turns left is much easier to cooperate with than the driver who signals left and turns right. We try to gauge other's intentions from their actions and body language, e.g., the cyclist in front of us slowing down and looking over their shoulder may want to cross our path or the pedestrian on a street corner looking towards the traffic may indicate their intentions to cross the road. We need to be able to react to the actions of other's in a short time frame, thus it puts us at an advantage to be able to simulate other people's actions.

Then there are scenarios when people intentionally need to coordinate their movements with others, for example, in the case of playing a piano duet, synchronised swimming or even rowing, where the timing parameter put constraints on the overall movement. The temporal coordination of movement is vital for this kind of joint action, although practise enables us to work on this to achieve better results. Further, various surgical procedures which require two or more surgeons to work simultaneously on a patient can have devastating effects if it is not accomplished successfully. During the extraction of a brain tumour, neurosurgeons need to fully cooperate with one another in a limited workspace and timeframe. Not only do the surgeons need to be able to predict the temporal aspect of their colleagues' movement, but they also need to be able to predict where the other person is moving, in order to avoid colliding or otherwise interfering with one another. If people were not able to form these sorts of representations, they would not be able to execute this kind of operation. Thus, the formation of a representation of the partner's task and role is essential and plays a crucial role in performing many day to day activities.

Suggestions for further Study

Joint action requires pairs to choose from an infinite number of different strategies. The current thesis identified that the choice of strategies can be modulated through constraints applied to one member of the pair and that people prefer to choose a consistent strategy when interacting with a partner. The following research ideas are possible suggestions for future projects that form a continuance and extension of the current experiments performed.

Extended Group Interactions

A way of extending this study would be to examine the role of joint actions involving more than two people. It has been noted that when two people work in a serial interaction, i.e., one in which each person acts in turn, as in the present study, the first person can take on the majority of the task, in order to achieve the goal more quickly and more efficiently. However, what would happen if three or more were asked to work together on a single serial task?

A way to test this idea would be to employ the same object passing task, but instead of having two people work together, we would now use three people. The Passer would still have to pass the object to a Receiver, yet in this case the passing distance between the Passer and the Receiver would be longer, making it more difficult to directly pass the object to the Receiver. Nevertheless, it would still be possible to conduct the experiment and pass the object to the Receiver, however, leading to an increased motor extension of the Passer's and Receiver's arm, resulting in increased difficulty of executing the task. At the same time, there would be another person present, known as the Connector, who would be sitting to the left side of the Passer. The Connector would be sitting at an approximately equal distance from the Passer and the Receiver. Here, the Passer is given the choice of either passing the object directly to the Receiver, or pass the object using the Connector. The Connector would then have to pass the object to the Receiver, who will have to place it in the target area with the appropriate orientation. Using the Connector may make the task easier for the Passer in terms of effort, however it would increase the overall time to pass the object, as it would involve a middle man. If the Passer decided to pass the object using the Connector, would they (the Passer) still rotate the object, or simply pass the object to the Connector, expecting the Connector to be rotating the object? Furthermore, would the Passer continue to employ the same strategy consistently throughout the experiment? This experiment can then be varied by increasing/ decreasing the distance between the Passer and the Connector. Will the Passer be more inclined to use the Connector when they are at a closer passing distance to them? Will the Passer stop passing the object when the Connector is at more than half the passing distance between them and the Receiver? To provide a better indication of the experiment, Figure 9.1 shows the experimental setup.

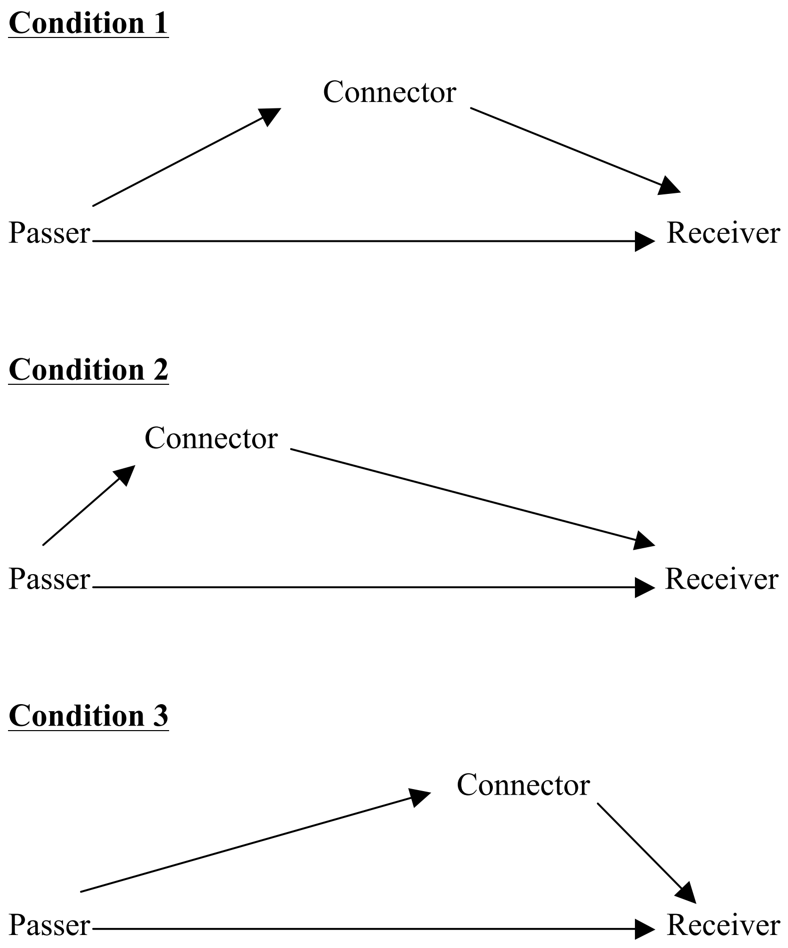

Figure 9.1. Experimental setup of future study of object passing task involving 3 people.

This kind of set up is often seen in many sporting endeavours, such as basketball, where the timing parameter can be very crucial. The aim of this experiment would be to examine the presence of a ‘middleman’ and the effects it would impose on joint strategy formation and action planning. Would people prefer to use a 'connector' to pass the object, knowing that it would not impose increased efforts on their behalf, although it would delay the overall process of the task. Or are people more inclined of taking on an additional task difficulty, and taking a risk of completing the task successfully, on the basis of completing the task more quickly? Could we expect the Passer to be representing the role of their immediate interacting partner or would they represent the overall goal of the task? What would be more interesting to see is whether joint motor coordination is limited to two people or whether this can be extended to a number of people working together. On the one hand, it would seem pretty clear on the surface they could, e.g. a number of dancers in a group can appear to coordinate their movements all together. Yet it is also possible that in a group people simply learn their own role and attend to the people nearest them. In any case, it might be useful to devise an empirical means of testing the limits of group coordination.

Confederate Interactions

Experiment 6 demonstrated that when people were asked to swap their roles, they decided to imitate the behaviour of their partner on a more basic level; thus being influenced by their partner's choice of movement. However, this setup made it difficult to examine whether participants were influenced by their partner's action or the overall action goal. One way to test this would be to use the same setup as Experiment 6, with the sole difference of using a confederate who would rotate the object in accordance to the exact opposite orientation to what the experimenter would request, i.e. –90° when in actual fact the object would need to be rotated +90° and vice versa.

Two things we could identify from this experiment would be whether the Receiver would be able to successfully predict the Passer's movements (despite the deliberate conflicting rotation). Furthermore, how will the Receiver react when they swap their role and take on the task of the Passer in the second block? Will they be influenced by the perceived observation of their partner's choice of conflicting rotation, resulting in the reproduction of their partner's movement or would they be influenced by the overall action goal and rotate the object in the correct direction, easing the Receiver's task, although the latter had previously increased their work load? This kind of experiment would enable us to determine the importance of the overall action goal. According to the mirror neuron system, it would be expected for participants to imitate the behaviour of their previously observed partner. However, many previous studies have demonstrated that the overall action goal determines the formation of a joint representation of the task (Glover, 2004; Marteniuk et al., 1987). This can establish whether the perception of an action overcomes the significance of the overall action goal.

Moreover, one can look at the social elements influencing joint action. It has been implied that people work best with others they consider similar to oneself (Flach, Knoblich & Prinz, 2003; Knoblich & Jordan, 2003); therefore it would be interesting to find out what happens if people know about their partner prior to working with them. In other words, participants would have to fill out a questionnaire about them and a confederate would be employed to either agree with the other person or strongly disagree prior to their interaction.

If we imagine a person to be very similar to us, then interaction should be more smooth and efficient, thus it would be interesting to discover how the motor component is affected by our prior knowledge of a person's background. Are people more cooperative towards a person they don't know anything about in comparison to a person who is the complete opposite of us? Do we favour people who resemble us and form a better interaction with them? This can provide us with some important information about joint action, which can be applied to the work field. If people work best with others they consider themselves to be similar with, then it would be a good idea to motivate people to perform better by uniting two forces to become one by focusing on their similarities.

Experimental Enhancements

There are a number of ways to extend specific experiments described within the thesis to improve the studies' validity. For instance, through the elimination of the TMS machine for Experiments 2 and 3. Instead of using the TMS machine to apply magnetic stimulation to perturb a person's movement, it would have been better to use an electrical muscle stimulator (EMS) to produce contraction of the muscles in the bicep. This would have involved a pad attached to the skin consisting of electrodes that would have sent electrical impulses to the relevant muscle groups. Because the EMS could be adhered to a person's skin, it would have made it more flexible for the Passer to be moving about despite the stimulation applied. The TMS machine that was attached to the Passer's bicep with the experimenter applying the stimulation during their movement may have provided an increased (and unintended) hindrance to the Passer, contributing to the obtained findings.

Another way of extending Experiment 2 and 3 would have been to use patients with real motor impairments; this would have enhanced the ecological validity of the study. Furthermore, what would be interesting would be to examine whether healthy individuals would be adjusting their own movement to adopt a similar movement pattern as that of the patients with the motor impairment in a situation in which their roles would be reversed halfway through the experiment.

A final alternative to extending the studies would be to focus on ‘digital’ interaction. It seems that nowadays people do not directly interact with one another physically, but through alternative means of technology. Instead of talking to people, we opt for the alternative option of texting or emailing people. The fast and evolving digital revolution make us less sociable beings. Thus it would be interesting to examine the interaction between two people trough a virtual medium, seeing that more people are able to communicate and work with others all over the world through the means of the internet. Will we still be able to represent and understand other people’s tasks, even if we do not physically interact with them? One way to tackle this point is by using a similar key pressing task that that was utilised by Sebanz et al. (2003). Instead of two people sitting in front of a computer, there could be three separate blocks of trials. Initially, in the first condition, participants sit in a room alone and perform the go/no-go task alone. In a second condition, the joint online condition, the same participant would be performing the go/no-go task with another person who is ‘online’ and who they can see by means of webcam. A third condition would involve the ‘online’ person to be performing the same task whilst being in the same room. Performances can then be compared across conditions, to see how well participants performed. Can we expect participants to be influenced by a partner’s task, even when a person is not physically present or do we only represent a person’s task/actions when we are in close proximity to them? Furthermore, can we expect the joint Simon Effect to appear even online? This sort of interaction is utilised by pilots when they communicate with air traffic controllers; many communicate to people miles away using high frequency radios for verbal communication whilst they also communicate in writing via Controller Pilot Data Link Communications (CPDLC). The CPDLC is a sort of satellite ‘email’ between the cockpit crew, air traffic control and the airlines’ dispatch facilities. Thus the findings can provide us with new insights into the world of ‘digital interaction’.

Overall, the concept of joint motor action can be extended to a wide range of scenarios, giving us a new insight into the neural and behavioural bases of interaction within society.

Conclusions

There were three central advances to this thesis. Firstly, the present study examined how a partner’s end-state comfort and varying task requirements affected the strategic planning and online control of joint actions. Secondly it examined the strategies employed by the Passer when conditions varied within a session. It looked at the effects of direct motor perturbations, the effects of eye gaze, the additional constraint of a precision task, swapping roles and increasing task complexity within a joint action. This is fundamental to understanding the nature of dyadic interactions to real life situations, i.e. looking at cooperation between healthy individuals and those suffering a chronic motor impairment and those involving complex movements. A third question was the extent to which the manipulations applied in Experiments 2-7 affected online control.

Overall, the results of the present thesis provide a valuable insight into how joint actors form their strategy under different conditions. Across a number of conditions that varied greatly in difficulty, participants adopted a strategy of maintaining a consistent pattern of movements while at the same time adjusting this pattern to the overall conditions of the session. This likely has the benefit of making actors more predictable to their partner, while allowing a compromise across the factors of joint effort and individual end-state comfort.

Taken in sum, this work provided valuable contributions to the overall understanding of strategy formation and motor coordination in the form of action planning and control in cooperating groups. The findings of the overall thesis have shown that individuals are influenced by their partner's affordances and consider this within their own action planning by maximising the end-state comfort of their partner, and maintaining a consistent and predictable pattern of behaviour.

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Appendix A

Table showing means for all the variables for Experiment 1 to 6. ROTA = Degree of rotation performed by Passer; TTP = Time to Pass object; OA-Pass = Online Adjustments for the Passer; OA-Rec = Online Adjustments for the Receiver

	ROTA (deg)	TTP (ms)	OA-Pass	OA-Rec
E1 - Control				
Orientation Condition	*	-	-	-
0°	2.96	1002.94	1.39	1.61
(+)90°	37.49	1020.15	1.41	1.54
(-)90°	-32.73	1034.71	1.51	1.56
E2-Unpred. Perturbation				
Orientation Condition	*	-	-	-
0°	2.31	1115.14	3.13	2.18
(+)90°	28.56	1164.54	3.04	2.23
(-)90°	-17.16	1156.57	3.02	2.32
TMS	-	*	***	***
Stimulation	4.05	1172.69	3.87	2.63
Control	5.09	1118.14	2.26	1.85
E3-Pred. Perturbation				
Orientation Condition	-	-	-	-
0°	8.64	1013.97	2.76	2.08
(+)90°	18.33	1064.25	3.04	2.22
(-)90°	-3.56	1036.93	3	2.1
TMS	-	-	**	**
Stimulation	8.78	1109.31	4.14	2.74
Control	6.82	967.46	1.73	1.53

E4-Gaze Cue				
Orientation Condition	***	***	-	-
0°	2.31	1108.48	2.08	1.89
(+)90°	83.56	1153.17	2.37	2.01
(-)90°	-52.18	1154.62	2.19	1.92
Gaze Condition	-	-	-	-
Occluder	11.81	1139.08	2.16	1.91
Control	10.65	1138.43	2.26	1.97
E5-Precision Task				
Orientation Condition	**	-	-	-
0°	-18.06	1893.84	7.38	4.86
(+)90°	9.82	192.00	7.68	4.74
(-)90°	-45.39	1953.56	8.06	5.27
Precision Condition	*	***	***	**
Aperture	-25.52	2383.19	11.53	6.82
Control	-10.24	1461.74	3.89	3.1
E6-Swapping Roles				
Orientation Condition	***	**	-	-
0°	2.87	1095.73	2.03	4.96
(+)90°	73.67	1149.31	2.27	4.89
(-)90°	-46.32	1164.95	2.2	5.34
Role	-	-	-	-
Block 1	12.04	1143.57	2.45	5.06
Block 2	8.11	1129.76	1.88	5.06

*   = statistically significant at the p < .05 level
** = statistically significant at the p < .01 level
*** = statistically significant at the p < .001 level

Appendix B

Table showing the means for kinematic data for Experiment 7. Conventions as in Appendix A.

	Rota_X (deg)	Rota_Y (deg)	Rota_Z (deg)	Rota_ALL	TTP (ms)	OA-Pass	OA-Rec
<u>E7 - Cube</u>							
Average Colour	**	***	***	***	***	***	**
White	21.79	5.32	4.69	31.79	1179.83	2.46	2.35
Green	102.93	18.68	53.40	175.01	1458.73	4.53	3.21
Red	47.31	50.72	55.50	153.53	1354.45	4.08	2.81
Colour	*	***	-	-	*	-	-
Green	102.93	18.68	53.40	175.01	1458.73	4.53	3.21
Red	47.31	50.72	55.50	153.53	1354.45	4.08	2.81
Number	*	**	-	*	*	*	-
1	38.21	34.82	44.68	117.72	1339.82	3.65	2.75
2	87.86	29.93	50.71	168.50	1471.66	4.69	3.38
3	99.29	39.35	67.95	206.59	1408.29	4.57	2.90
Interaction colour*number	-	-	p = .06	-	-	*	-

* = statistically significant at the p < .05 level
** = statistically significant at the p < .01 level
*** = statistically significant at the p < .001 level