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Weak imitative performance is not due to a functional 'mirroring' deficit in adults with Autism Spectrum Disorders

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Abstract

A large number of studies have demonstrated impaired performance on a range of imitation tasks among individuals with Autism Spectrum Disorders (ASD). The theory which suggests that these impairments are caused by a mirror system deficit has become increasingly prominent. Under this view, the capacity to match observed with executed actions or to 'mirror' is impaired in individuals with ASD. This study investigated the extent to which any impaired performance on imitation tasks is due to a functional mirroring deficit by comparing the performance of adults with ASD on imitative and non-imitative versions of the 'pen-and-cups' task. Participants in this task are required to observe transitive actions and to imitate them as fast as possible. Experiment 1 revealed impaired performance by high functioning adults with ASD on the imitative version of the task compared to IQ matched controls. The same participants then completed two non-imitative versions of the task in Experiment 2. The 'geometric' version of the task required participants to perform actions specified by the movement of abstract geometric shapes. The 'verbal' version of the task required participants to describe the observed actions. Adults with ASD were as impaired on each non-imitative version of the task as they were on the imitative version, suggesting that the impaired performance on the imitation task was not due to a functional mirroring deficit. Instead, more general factors contributed to the poor performance on this task. These findings add to the weight of evidence suggesting that impairments in imitation skills should not be cited as evidence consistent with a 'mirror system deficit theory' of ASD.

Keywords: Autism; Imitation; Mirror system; Pen-and-cups task

Imitation has been studied extensively in Autism Spectrum Disorders (ASD; for review see Williams, Whiten, & Singh, 2004). Despite a wealth of evidence, the literature is contradictory: although the majority of studies report an imitation impairment in ASD (e.g. Avikainen, Wohlschlager, Liuhanen, Hanninen, & Hari, 2003; Rogers, 1999; Rogers, Bennetto, McEvoy, & Pennington, 1996), others have found no evidence of such an impairment (e.g. Aldridge, Stone, Sweeney, & Bower, 2000; Beadle-Brown & Whiten, 2004; Carpenter, Pennington, & Rogers, 2001; D'Entremont & Yazbek, 2007; Hamilton, Brindley, & Frith, 2007).

Imitation is of relevance to ASD because it has been suggested that imitation typically underpins the development of social cognition, including theory of mind, empathy, and the development of language (Rogers & Pennington, 1991). Impairments in these abilities characterise individuals with ASD, which has prompted some theorists to suggest that an imitation impairment is the core deficit in ASD (Williams, Whiten, Suddendorf, & Perrett, 2001). It is therefore important to make sense of the conflicting findings in the literature and to understand fully the nature of observed imitation impairments.

Studies demonstrating impaired performance on imitation tasks are consistent with evidence of disturbed mirror system activity in ASD (e.g. Gallese, 2006; Iacoboni & Dapretto, 2006; Williams et al., 2001). In typically developing individuals, the mirror system, comprising inferior parietal cortex and frontal gyri, is active when actions are executed and when they are passively observed, and is maximally activated during imitation (Iacoboni et al., 1999). Given this profile of activation, it is plausible that the mirror system mediates one of the basic functions required for imitation—self-other mapping, or, more specifically, the capacity to match observed with executed actions

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(Brass & Heyes, 2005). If this is correct, then studies indicating disturbed mirror system activity in individuals with ASD (e.g. Gallese, 2006; Iacoboni & Dapretto, 2006; Williams et al., 2001) raise the possibility that these individuals perform poorly on tests of imitation, in part, because they are have a 'functional mirroring deficit', i.e. they are impaired in their capacity to match observed with executed actions. The present study investigates this possibility.

Even if individuals with ASD have a functional mirroring deficit, it is very unlikely that this would be sufficient to explain why they perform poorly in most imitation tests. Imitative performance typically involves a broad range of cognitive, motivational and praxic abilities, involving perceptual processing of complex stimuli, attentional control, executive function, motor control, theory of mind, language, and the comprehension of social cues (e.g. Rogers, Hepburn, Stackhouse, & Wehner, 2003; Pennington, Williams, & Rogers, 2006; Vanvuchelen, Roeyers, & De Weerdt, 2007). Impairments in all of these processes have been found in individuals with ASD (e.g. Baron-Cohen, Leslie, & Frith, 1985; Frith & Frith, 2003; Ozonoff, Pennington, & Rogers, 1991; Pennington & Ozonoff, 1996; Russell, 1997), making it likely that imitation impairments in ASD arise from impairments in a range of abilities. Therefore, the present study asks whether a problem with functional mirroring, the capacity to match observed with executed actions, is *one of* the impairments that contribute to poor imitation performance by individuals with ASD.

The capacity to match observed with executed actions is of particular interest, not only because it relates to recent research on mirror system functioning in ASD, but also because it is characteristic of imitation tasks that they require this ability. A variety of laboratory and everyday tasks require observed actions to be mapped in some way to executed actions, but only imitation tasks require the participant to *match* observed actions; to do the same thing as a model. Conversely, whereas the other abilities that contribute to imitative performance – for example, perceptual and motor processing, attentional and executive control, theory of mind – are involved in a range of non-imitative tasks, the capacity to match observed with executed actions is required only in imitation tasks. Therefore, matching observed with executed actions, or functional mirroring, may be described as an 'imitation-specific' ability, while other processes that contribute to imitative behaviour are 'non-specific' or 'task-general'.

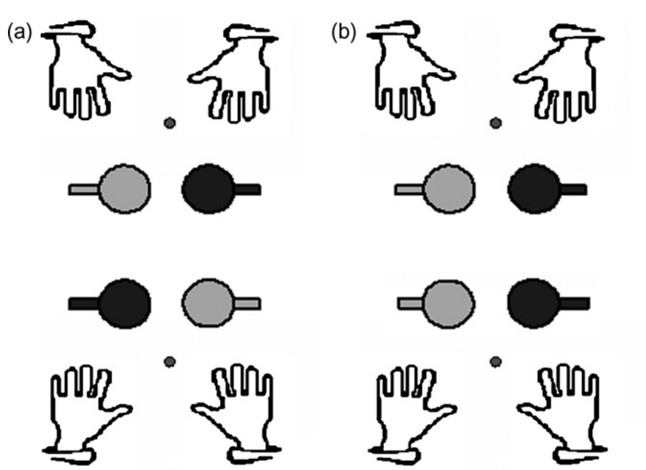

Fig. 1. Schematic diagram showing the layout of the stimuli in both the transpose (a) and mirror (b) conditions.

This study therefore sought to examine two possible explanations for the mixed findings in the ASD imitation literature. Under the first explanation, there is a functional mirroring impairment in ASD; that is, the processes that match motor outputs with perceptual inputs are in some way disturbed. Under the second explanation, there is no functional mirroring impairment in ASD. Rather, poor performance on tests of imitation is due to impairments of non-specific abilities – such as theory of mind and executive function – which are also required for successful performance on these tests. This study sought to distinguish these two possibilities by investigating whether observed impairments in imitative performance can be accounted for by more general abilities.

We investigated functional mirroring in ASD by testing the performance of a group of high-functioning adults with ASD, and a matched typically developing control group, on a test of voluntary imitation. We used the 'pen-and-cups' imitation task because it has previously been shown to produce greater errors in adults with ASD than in controls (Avikainen et al., 2003). On each trial in this speeded response procedure the participant sees a model move a centrally located pen into one of two coloured cups (object), using his right or his left hand (effector), while grasping the pen with his thumb pointing up or down (grip). Thus, the task is demanding because, in order to minimise errors, the participant needs to keep track of three dimensions of action: object selection, effector selection and grip selection (see Fig. 1).

Experiment 1 replicated the finding (Avikainen et al., 2003) that individuals with ASD make more errors in the pen-and-cups tasks. Experiment 2 sought to establish whether this finding reflects an impairment in the capacity to match observed with executed actions. In Experiment 2, participants completed two versions of the pen-and-cups task which dissociated the components of the imitative stimulus-response relationship instantiated in the original pen-and-cups task. In the original version, action responses are made to action stimuli. In Experiment 2, one task involved action responses being made to abstract geometric stimuli, while the other required participants to describe verbally the original action stimuli. Thus, the action stimulus and action response components were separately removed while all other aspects of the task were held constant. The tasks in Experiment 2 did not require matching of observed with executed actions, and therefore, if the impaired performance on the pen-and-cups task in ASD is due to a functional mirroring impairment, one would expect improved performance on these non-imitative versions of the task. Alternatively, if impaired performance on the pen-and-cups task is due solely to nonspecific mechanisms, then impaired performance would also be expected on the non-imitative versions of the task.

1. Experiment 1

The aim of Experiment 1 was to establish that the particular sample of individuals with ASD who participated in this study demonstrated an impairment in a test of voluntary imitation. If so, then the specificity of this deficit could be tested in Experiment 2. Accordingly, Experiment 1 sought to replicate the finding of impaired imitation on the pen-and-cups task by individuals with ASD reported by Avikainen et al. (2003). Therefore, as in the study by Avikainen et al., two conditions were completed by participants. Both were imitative, but the two conditions differed in terms of their imitative frame of reference. In the 'mirror' condition, participants were asked to imitate as if in a mirror; that is they were to imitate an action completed by the model's right hand with their spatially compatible left hand, and vice versa. Similarly, if the pen was placed into the cup on the model's right side, then the participant was to place their pen in the spatially compatible cup which was on the participant's left side. Conversely, the 'transpose' condition required participants to use an anatomical frame of reference; actions completed by the model with their right hand should be imitated with the participant's own right hand. Similarly, if the pen was placed in the cup on the right side of the model, the participant must place their pen in the cup on their own right side. Avikainen et al. found that although the control group were better able to mirror than to transpose, the performance of the ASD group was equivalent in the two conditions. The secondary aim of Experiment 1 was therefore to see if this effect of condition could be replicated.

The particular pattern of errors on the pen-and-cups task has been suggested to indicate an imitation hierarchy. For example, the typical pattern of performance (cup errors < hand errors < grip errors) has been claimed to indicate goal-directed imitation as performance is biased to imitation of the action goal over the means of achieving that goal (Wohlschlager, Gattis, & Bekkering, 2003). The meaning of 'goals' in this context is unclear, but it has been interpreted as the intention driving the action (Gattis, Bekkering, & Wohlschlager, 2002). However, a recent series of experiments suggested that the pattern of errors on the pen-and-cups task is not indicative of an imitation hierarchy but is instead a product of perceptual salience (Bird, Brindley, Leighton, & Heyes, 2007), and the ASD group in Avikainen et al. (2003) showed the typical cup > hand > grip error pattern in both the mirror and transpose conditions of the pen-and-cups task. Therefore, we used the total number of imitation errors made by each group, rather than the pattern of errors, as our measure of imitation ability. However, we also report data on the error pattern shown by both groups (which is orthogonal to the total number of errors) in order to enable comparison with the previous literature using this task.

The experiment was performed as in Avikainen et al. (2003) with one exception: we presented video recordings of the actions, rather than a live demonstrator performing the actions, to increase stimulus control. Use of video stimuli allows the interval between actions and their durations to be standardized across conditions and groups, and it has previously been shown with typically developing participants that presenting video stimuli does not alter either the error rate or error pattern on this task (Bird, Brindley, et al., 2007). It has been shown that, individuals with ASD perform better in response to computerized stimuli than they do to live stimuli across a range of tasks (e.g. Ozonoff, 1995; Ozonoff & Strayer, 2001). It is likely that this improvement arises from the reduced social interaction necessary in computerized tasks. Therefore, the use of computerized tasks in the present study ensured that any observed group differences were not accentuated by a lack of capacity or motivation to engage in direct social interaction.

1.1. Methods

1.1.1. Participants

Thirty-two individuals participated in the study; 16 participants with Autism Spectrum Disorder (14 male; 2 female) and 16 typically developing control participants (14 male; 2 female). Groups were matched on gender, age (ASD: *M*, 37 years and S.E.M., 3; control: *M*, 35 years and S.E.M., 4), and IQ (ASD FSIQ: *M*, 119 and S.E.M., 3; VIQ: *M*, 116 and S.E.M., 3; PIQ: *M*, 116 and S.E.M., 4; control FSIQ: *M*, 118 and S.E.M., 3; VIQ: *M*, 118 and S.E.M., 3; PIQ: *M*, 112 and S.E.M., 2). IQ was measured using the Wechsler Adult Intelligence Scale-3rd UK Edition (Wechsler, 1999). All participants in the ASD group had previously received a diagnosis from an independent clinician according to standard criteria. The Autism Diagnostic Observational Schedule-Generic (ADOS-G, Lord et al., 2000), was used in order to characterize the participants. On this measure ten participants met criteria for autism, while six participants met criteria for Autism Spectrum Disorder. All participants were right-handed, had normal or corrected-to-normal vision and were naive with respect to the purpose of the experiment. The experiment was performed with local ethical committee approval and in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All persons gave their informed consent prior to their inclusion in the study.

1.1.2. Stimuli and apparatus

Each video stimulus showed the hands, arms and torso – but not the face – of an adult female as she performed an action sequence involving two cups and a pen. These objects were laid out on a table in front of the model. Fig. 1(a) and (b) shows their spatial arrangement, and the location of the model's and the participant's hands at the beginning of each action sequence. There were eight action sequences which all involved the model grasping a centrally located pen and, reaching forwards, placing it upside down in one of the two cups, before returning the pen to its starting position.

The eight sequences in each set were constructed by factorial combination of three variables: the colour of the cup in which the pen was placed (red or blue), the hand used to perform the action (left or right), and the grip applied to the pen (up or down). When the model used the up grip, her thumb pointed upwards towards the cap of the pen, and when she used the down grip, her thumb pointed downwards, towards the base of the pen. The mean duration of the action sequence was 5255 ms (S.E.M. = 165) and the mean intertrial interval (ITI) was 610 ms (S.E.M. = 23).

Video stimuli were digitally recorded and presented in colour on an IBM compatible laptop computer with a 38-cm screen (resolution 1024 × 678 pixels), at approximately one third of life size. Video clips (720 × 576 pixels) were presented at a frame rate of 25 fps and a viewing distance of approximately 90 cm.

To make their responses participants used the same set of objects, in the same spatial configuration, as the model they observed (see Fig. 1(a) and (b)). For both the transpose and mirror conditions the cups were placed 35 cm from the front of the participant's body, 30 cm apart, and equidistant from the participant's midline. At the beginning of each trial, the pen was placed on a marker, a black dot, directly in front of the participant and 23 cm from their body. The pen (1.5 cm diameter, 14 cm high) was white with a green cap. A transparent plastic disk, 4.8 cm in diameter, was attached to the base of the pen to increase its stability when at rest in the upright position. The spatial relationship of the model's and participant's cups varied according to condition. In the transpose condition the cups were arranged so that they were spatially incompatible from the participant's perspective (i.e. the participant's blue cup was on their left side but the model's blue cup was on the participant's right side, see Fig. 1a). In the mirror condition the cups were arranged so that they were spatially compatible from the participant's perspective, i.e. both the participant's and the model's blue cup was on the participant's left side (see Fig. 1b).

1.1.3. Procedure

Participants were tested individually in a quiet room. Each sat at a table bearing the object set and, beyond it, the laptop computer on which the video stimuli were presented. They were told that they would be shown a video and that, while watching it, they should imitate the movement sequences as simultaneously as possible, paying equal attention to three aspects: the hand (left/right), the grip (up/down) and the cup (red/blue). Specific instructions varied according to condition. In the *transpose condition* participants were instructed: (1) to use their left hand when the model used her left hand, and to use their right hand when the model used her right hand; (2) to grip the pen in the same thumb up or thumb down configuration as the model; (3) to place the pen in the cup of the same colour as the model. In the *mirror condition* participants were instructed: (1) to use their left hand when the model used her right hand, and to use their right hand when the model used her left hand; (2) to grip the pen in the same thumb up or thumb down configuration as the model; (3) to place the pen in the cup of the same colour as the model. After giving the instructions, the experimenter demonstrated the correct response in each condition until the participants reported that they understood the task.

Each participant completed 10 practice trials followed by 80 test trials. The test trials comprised 10 presentations of each of the eight action sequences in random order. The order in which participants completed the mirror and transpose conditions was counterbalanced within groups.

Performance was videotaped and the experimenter recorded, for each trial, which hand, grip and cup had been selected by the participant. An error was recorded if the participant's selection did not match that of the model as specified in the instructions. Thus, there were three types of errors, relating to the hand, grip and cup components of the task, respectively. These were summed for each participant to give a total error score.

1.2. Results and discussion

The mean total number of errors made by each group in both the mirror and transpose conditions is shown in Fig. 2. These data were entered into an ANOVA with a within-subjects factor of condition (transpose and mirror), and a between-subjects factor of group (ASD and control). The main effect of group was significant ($F(1,30) = 5.7$, $p = 0.023$, $\eta_p^2 = 0.160$), indicating that the ASD group made significantly more errors than the control group. The main effect of condition was also significant ($F(1,30) = 25.3$, $p < 0.001$, $\eta_p^2 = 0.457$), confirming that the transpose condition was more challenging than the mirror condition, but the interaction between condition and group was not significant ($F(1,30) = 1.9$, $p = 0.183$, $\eta_p^2 = 0.058$). The non-significant interaction indicates that the degree of impairment shown by the individuals with ASD, relative to the control group, did not vary as a function of task condition. Simple effects analyses were used to test whether the groups' performance differed significantly in each of the conditions. This analysis confirmed that the performance of the ASD group was significantly less accurate than that of the controls in both the transpose ($F(1,30) = 4.2$, $p = 0.049$, $\eta_p^2 = 0.123$) and the mirror ($F(1,30) = 4.7$, $p = 0.038$, $\eta_p^2 = 0.136$) conditions.

As expected, both groups showed the usual cup < hand < grip error pattern (Table 1) in both mirror and transpose conditions as tested using linear contrasts (ASD mirror: $F(1,15) = 14.1$, $p = 0.002$; ASD transpose: $F(1,15) = 44.3$, $p < 0.001$; control mirror: $F(1,15) = 18.7$, $p = 0.001$; control transpose: $F(1,15) = 8.5$, $p = 0.011$).

The primary purpose of Experiment 1 was to establish whether the particular sample of adults with ASD who took part in this study show an impairment on both the mirror and transpose conditions of the pen-and-cups task. The results clearly show that the ASD group made more errors than the control group in both conditions.

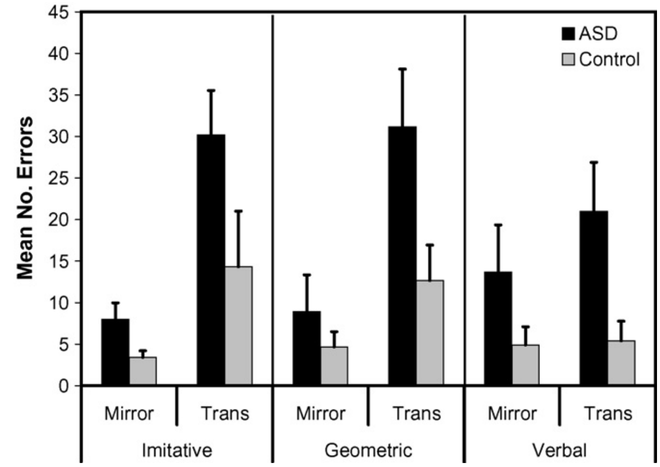

Fig. 2. Mean number of errors (out of a possible 240) made by the ASD and control groups on both the transpose and mirror conditions in each version of the task. Error bars indicate the standard error of the mean.

The secondary purpose of Experiment 1 was to examine the pattern of performance on mirror and transpose conditions in both groups. Avikainen et al. (2003) reported that, in contrast to the control group, individuals with ASD did not make more imitation errors when required to engage in transposition, rather than mirror, imitation. Such a pattern of results would have been manifested in Experiment 1 by a significant interaction between the condition and group factors, indicating that the difference in performance between the groups depended on whether imitating in a mirror or transposition fashion. However, this interaction was not significant. Indeed, the ASD group tended to show a greater impairment on the transpose condition, and therefore the finding of a selective impairment in mirror imitation in ASD was not replicated.

2. Experiment 2

Experiment 1 demonstrated impaired performance on the pen-and-cups task by a group of adults with ASD on a test of voluntary imitation. Experiment 2 aimed to identify whether the poor performance shown in Experiment 1 was due to a deficit in functional mirroring – the capacity to match observed with executed actions – or whether it was due solely to impairments in other abilities, not specific to imitation tasks. Accordingly, the same participants who had completed Experiment 1 were asked to complete two versions of the pen-and-cups task which did not require matching of observed with executed actions, but which included the same nonspecific task demands as in the original, imitative pen-and-cups task. In an imitation task, matching action responses are made to action stimuli. In order to remove the requirement to match observed with executed actions in the pen-and-cups task, we therefore changed the imitative stimulus-response relationship in two alternative versions of the task.

Table 1
Mean (and standard error of the mean) number of cup, hand and grip errors in Experiment 1 for the ASD and control groups

	ASD						Control					
	Mirror			Transpose			Mirror			Transpose		
	Cup	Hand	Grip	Cup	Hand	Grip	Cup	Hand	Grip	Cup	Hand	Grip
Mean	0.38	2.75	6.06	2.38	9.94	17.38	0.38	0.63	2.63	2.38	4.88	8.13
S.E.M.	0.15	1.44	1.42	0.57	2.24	2.28	0.20	0.30	0.45	1.39	1.92	2.39

In the ‘geometric’ version of the pen-and-cups task participants were required to make the same action responses as in the imitative version of the task, but in response to the movement of abstract geometric shapes rather than to action stimuli. In the ‘verbal’ version of the pen-and-cups task participants observed the same action stimuli as in the imitative version of the task but were asked to describe the sequences rather than to make action responses.

The performance of the ASD group in each of the non-imitative versions of the task was compared to their performance on the imitative version of the task. If the impaired performance shown by the ASD group on the imitative version of the task was due to a functional mirroring deficit, then removing the requirement to match observed with executed actions should result in improved performance relative to that of the control group. However, if the poor performance of the ASD group in Experiment 1 was due solely to nonspecific factors, such as a difficulty in the rapid shifting of attention between action components (Wainwright & Bryson, 1996) or other executive demands of the task, such as the sequencing of action components (Russell, 1997), then one would expect the performance of the ASD group to be as impaired in the alternative versions as in the imitative version of the task. This is because these task components are preserved in both non-imitative versions.

2.1. Method

2.1.1. Participants

Twenty-four of the original thirty-two individuals were able to attend the second testing session, 12 participants with Autism Spectrum Disorder (11 male; 1 female) and 12 typically developing control participants (11 male; 1 female). Groups were matched on gender, age (ASD: *M*, 38 years, S.E.M., 3, control: *M*, 37 years, S.E.M., 3), and IQ (ASD FSIQ: *M*., 118, S.E.M., 4, VIQ: *M*, 117, S.E.M., 4, PIQ: *M*, 113, S.E.M., 5, Control FSIQ: *M*, 118, S.E.M., 3, VIQ: *M*, 117, S.E.M., 3, PIQ: *M*, 110, S.E.M., 2). Full-scale IQ was measured using the Wechsler Adult Intelligence Scale-3rd UK Edition (Wechsler, 1999). Of the 12 participants with ASD who returned for the second session, seven participants met criteria for autism, while five participants met criteria for Autism Spectrum Disorder as measured by the ADOS-G.

Participants completed both the geometric and verbal version of the pen-and-cups task in a second session, which was scheduled between one and four months after the initial testing session.

2.1.2. Stimuli and apparatus: geometric version

Participants made the same responses, using the same apparatus, as in Experiment 1. The correct response on each trial was communicated to the participant by presenting a short stimulus animation. In these animations, the hands were replaced by squares, the grips by short rectangles attached to the squares, and the cups by ellipses (Fig. 3).

At the beginning of each trial one of the squares (replacing the hands) moved downwards with a curved trajectory until it reached a long rectangle (replacing the pen). While moving toward the long rectangle the square rotated 45° either clockwise or anticlockwise so that the short rectangle attached to it (replacing the grip) either pointed upwards to the top of the screen, (i.e. was positioned on the top of the square) or downwards to the bottom of the screen (i.e. was positioned on the bottom of the square) as it reached the long rectangle. After the square had reached the rectangle, both the long rectangle and square moved downwards together with a curved trajectory to one of the ellipses (replacing the cups). While moving towards the ellipse the objects rotated 90° either clockwise or anticlockwise so that the long rectangle and the direction the small rectangle pointed to (up or down) was inverted when it reached the ellipse. Once the objects had reached the ellipse they paused momentarily and then followed the above steps in reverse until they had reached their starting state (as the pen is replaced on the black marker in the imitative version of the task). The temporal and spatial parameters of these geometric action sequences were matched to those of the human model presented in Experiment 1.

The mean duration of each action sequence, from when the shapes started to move until they reached their initial state again, was 5255 ms (S.E.M. = 165). The animation stimuli were presented in colour on an IBM compatible laptop computer with a 38 cm screen (resolution 1024 × 678 pixels), at a viewing distance of approximately 90 cm. The animation stimuli for the mirror and transpose versions were distinguished according to the colouring of the ellipses (“cups”). During the transpose condition the colour of the ellipses and the cups with which participants made their responses was spatially incompatible from the participant’s perspective. For example, if the participant’s red cup was on their left, and the blue cup on their right, then the blue stimulus ellipse was on the left of the screen and the red stimulus ellipse was on the right of the screen. In the mirror condition the location of the stimulus ellipses and the cups was spatially compatible, for example both the blue cup and blue stimulus ellipse was on the left of the screen while the red cup and red ellipse was on the right of the screen.

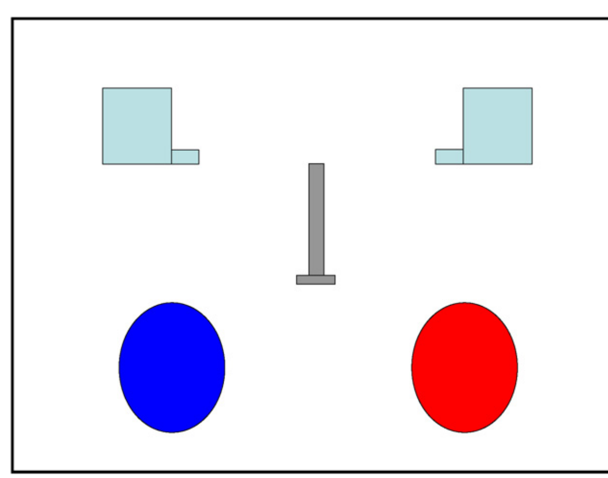

Fig. 3. Starting position of the animation stimulus. On each trial one of the squares (“hands”) moved to the long rectangle (“pen”) and one of the short rectangles attached to the square was selected (“grip”) to move the long rectangle to one of the ellipses (“cups”). These animations specified the action response to be made by the participants in the geometric version of the pen-and-cups task.

2.1.3. Procedure: geometric version

The procedure was the same as in Experiment 1 except as follows. Participants were told that they would be required to make some movements involving placing a pen into one of two cups. They were then told that they would see shapes moving on the screen that would indicate which movement to make. Specifically, in the transpose condition, participants were instructed: (1) to use their left hand when the square on the right of the screen moved, and to use their right hand when the square on the left moved; (2) to grip the pen in the thumbs up position when the small rectangle was positioned on the top of the square and to use the thumbs down position when the small rectangle was positioned on the bottom of the square; (3) to place the pen in the red cup when the objects moved to the red ellipse and in the blue cup when the objects moved to the blue ellipse. In the mirror condition, participants were instructed: (1) to use their left hand when the square on the left moved, and to use their right hand when the square on the right moved; (2) to grip the pen in the thumbs up position when the small rectangle was positioned on the top of the square and to use the thumbs down position when the small rectangle was positioned on the bottom of the square; (3) to place the pen in the red cup when the objects moved to the red ellipse and in the blue cup when the objects moved to the blue ellipse.

2.1.4. Stimuli and apparatus: verbal version

The stimuli were identical to those presented in Experiment 1. The participants were not given the object set (cups and pen) because action responses were not required.

2.1.5. Procedure: verbal version

The procedure was the same as that of Experiment 1 except as follows. All participants were instructed to describe, rather than to imitate, the model's movements. In order to match the temporal parameters of the imitation version of the task, participants were told that they would be shown some actions and that, while watching them, they should simultaneously describe the movement sequences. In the mirror condition participants were told: (1) to say 'left hand' when the model used her hand on the participant's left, and to say 'right hand' when the model used her hand on the participant's right; (2) to say 'up grip' or 'down grip' according to the orientation of the model's thumb; (3) to say 'red cup' or 'blue cup' in response to the model's object selection. In the transpose condition participants were instructed (1) to say 'left hand' when the model used her hand on the participant's right, and to say 'right hand' when the model used her hand on the participant's left; (2) to say 'up grip' or 'down grip' according to the orientation of the model's thumb; (3) to say 'red cup' or 'blue cup' in response to the model's object selection. Participants were not instructed as to the order in which they should report action components, but all did so in the order that the action components were selected in the stimulus video (hand, grip, cup).

2.2. Results and discussion

The aim of Experiment 2 was to compare the performance of the ASD group, relative to controls, in two non-imitative versions of the task with their performance in the imitative version completed in Experiment 1. The mean number of errors made by each group, in each condition, is shown in Fig. 2. These data were entered into an ANOVA with within-subjects factors of version (imitative, geometric, and verbal), and condition (mirror and transpose), and a between-subjects factor of group (ASD and control). This analysis revealed a significant main effect of condition ($F(1,22) = 21.5, p < 0.001, \eta_p^2 = 0.494$), reflecting the increased error rate in the transpose condition, and a significant main effect of group ($F(1,22) = 6.1, p = 0.022, \eta_p^2 = 0.216$), due to the greater number or errors made by the ASD group. The interaction between condition and group was significant ($F(1,22) = 4.4, p = 0.047, \eta_p^2 = 0.168$), indicating that the ASD group showed a greater impairment, relative to controls, in the transpose condition than in the mirror condition. As expected, the interaction between the version and condition factors was also significant ($F(2,44) = 6.2, p = 0.004, \eta_p^2 = 0.221$). The requirement to transpose (i.e. to respond in a spatially incompatible manner) had a less detrimental effect on accuracy of responding in the verbal condition, where manual responses were not required.

If the poor performance of the ASD group in the imitative version of the task was due to a functional mirroring deficit, then the performance of the ASD group should have improved on the non-imitative versions of the pen-and-cups-task relative to any improvement shown by the control group. This would be manifested as a significant interaction between the version and group factors. This interaction was not significant ($F(2,44) < 1, \eta_p^2 = 0.004$). Of theoretical interest also is the three-way interaction between the version, group and condition factors. It is possible that only one of the conditions would have demonstrated an improvement from the imitative to non-imitative version of the task. However, this interaction also was not significant ($F(2,44) < 1, \eta_p^2 = 0.020$).

The results of this analysis suggest that the ASD group were as impaired, relative to the control group, on both of the non-imitative versions of the task as on the original, imitative version. However, to test this conclusion further, analyses were carried out which separately compared each non-imitative version of the task with the imitative version.

ANOVA including the data from the geometric and imitative versions revealed significant main effects of group ($F(1,22) = 5.00, p = 0.036, \eta_p^2 = 0.184$) and condition ($F(1,22) = 30.00, p < 0.001, \eta_p^2 = 0.511$), reflecting the greater number of errors made by the ASD group in comparison to the control group and the increased difficulty of the transpose condition compared to the mirror condition. However, neither the interaction between the version and group factors ($F(1,22) < 1, \eta_p^2 = 0.006$), nor the three-way interaction between the version, group and condition factors ($F(1,22) < 1, \eta_p^2 = 0.014$) were significant.

Comparison of the verbal and imitative versions of the task using the same method demonstrated significant main effects of group ($F(1,22) = 6.2, p = 0.020, \eta_p^2 = 0.220$) and condition ($F(1,22) = 13.8, p = 0.001, \eta_p^2 = 0.385$), reflecting the greater number of errors made by the ASD group in comparison to the control group and the increased difficulty of the transpose condition compared to the mirror condition. In addition, the interaction between version and condition ($F(1,22) = 10.0, p = 0.005, \eta_p^2 = 0.311$) was significant, reflecting the greater effect of condition in the imitative version than in the verbal non-imitative version. Again, neither the interaction between the version and group factors ($F(1,22) < 1, \eta_p^2 = 0.003$), nor the three-way interaction between the version, group and condition factors ($F(1,22) < 1, \eta_p^2 = 0.008$), was significant.

Participants in Experiment 2 completed two non-imitative versions of the pen-and-cups task and their performance was compared to that on the original, imitative version of the task. The results indicated that the ASD group was as impaired, relative to the control group, on the non-imitative versions of the task as they were on the imitative version of the task. This outcome indicates that the poor performance of the ASD group on the imitation task was not due to a functional mirror deficit, i.e. to difficulties in matching observed with executed actions. Although performance differences between the groups did not vary according to whether they completed imitative or non-imitative versions of the task, there was an overall tendency for the ASD group to show relatively poorer performance in the transpose conditions of the task.

3. General discussion

This study examined whether the impairments on tests of imitation which have frequently been reported in ASD (e.g. Avikainen et al., 2003; Rogers et al., 1996; see Williams et al., 2004 for review) represent a functional mirroring deficit, that is problems in matching observed with executed actions. To address this question the performance of a group of high-functioning adults with ASD was compared with that of matched, typically developing controls on an imitative, and two non-imitative, versions of the pen-and-cups task.

In common with previous reports of poor performance on imitation tasks, the ASD group made more errors than controls in Experiment 1, on the imitative version of the task. Experiment 2 tested whether this weak performance was due to an impairment in the capacity to match observed with executed actions, or solely to impairments in more general processes, by asking the same participants to complete two non-imitative versions of the task. If the poor performance on the imitative version of the task had been due to a functional mirroring deficit, one would have expected better performance when the task was changed so that it presented equally challenging general task demands, but was non-imitative. However, the ASD group were as impaired, relative to the control group, on each of the non-imitative versions of the pen-and-cups task. This pattern of results provides no support for the hypothesis that individuals with ASD have a functional mirroring deficit. Rather, it suggests that weak imitative performance in ASD is due to impairments in some or all of the many non-specific abilities required for successful imitation.

The results of Experiment 1, which showed poor imitative performance among individuals with ASD, are consistent with the majority of previous findings. Like the present study, the majority of previous studies have employed complex voluntary imitation tasks to assess imitative abilities in ASD. Given that the results from the present study suggest that poor performance on complex imitation tasks may be explained by non-specific impairments, poor performance observed in previous studies may also have been due to these non-specific factors. This idea has already been suggested by a number of authors who have found correlations between imitation performance and processes not specific to imitation, such as motor control and social reciprocity (Green et al., 2002; McDuffie et al., 2007; Smith & Bryson, 1998).

The idea that weak imitative performance may be due solely to impairments in task-general abilities may explain some of the mixed findings in the ASD literature. It is possible that in studies reporting equivalent performance on voluntary imitation tasks for ASD and control groups (Aldridge et al., 2000; Carpenter et al., 2001; Hamilton et al., 2007), general task demands were not sufficient to generate group differences.

Pursuing this line of thought, it might be argued that we did not find evidence of a functional mirroring impairment in ASD because our imitation task did not make substantial demands on the ability to match observed with executed actions. This possibility cannot be excluded, but it is unlikely for two reasons. First, accurate performance in the pen-and-cups task requires that participants match, not only the effects of the models actions (getting the pen into the correct cup) but also two dimensions of the body movement used to achieve those effects (use of the right or the left hand, in an up or a down grip). Relative to their effects on objects, body movements tend to give rise to more disparate perceptual inputs when performed by the self and by another, and therefore matching body movements – even hand movements – is likely to challenge the ability to match observed with executed actions. Second, recent studies of automatic imitation provide convergent evidence that individuals with ASD do not have an impairment in the capacity to match observed with executed actions (Bird, Leighton, Press, & Heyes, 2007). Tests of automatic imitation assess the spontaneous or uninstructed tendency to match observed with executed actions in the context of simple tasks that make minimal demands on non-specific processes. In a task of this kind, Bird, Leighton, et al. (2007) found no difference between individuals with ASD and controls in automatic imitation of opening and closing hand movements.

Most studies using neurological indices of mirror system functioning in individuals with ASD have reported weaker activity in this group than in controls (e.g. Dapretto et al., 2006; Williams et al., 2006). If the mirror system, as it is currently delineated, mediates functional mirroring – matching of observed with executed actions – then these findings are inconsistent with those of the present study, and of Bird, Leighton, et al. (2007), that sought and did not find behavioural evidence of a functional mirroring impairment in ASD. However, the corpus of work on mirror system function in ASD includes many contradictory findings. For example, Avikainen, Kulomaki, and Hari (1999) studied motor cortex excitability using MEG and found no difference in activity between ASD and control participants when observing simple hand movements, suggesting typical mirror system activity in the ASD group. When the same group compared mirror system responses during imitation of orofacial movements, they found that activity in frontal, but not parietal, mirror areas was delayed and weaker in participants with ASD (Nishitani, Avikainen, & Hari, 2004). In addition, different studies have localised the mirror system deficit in ASD to different neurological areas. Dapretto et al. (2006) found that individuals with ASD show normal activity in the parietal mirror area but reduced activity in the inferior frontal gyrus, whereas Williams et al. (2006) reported the opposite pattern of results. Until the results of studies investigating mirror system activity in ASD show a more consistent pattern it is unlikely to be possible to relate them coherently to behavioural investigations of imitation in ASD.

Experiment 1 did not replicate the particular pattern of errors reported by Avikainen et al. (2003), who found that the ASD group failed to benefit from imitating in a mirror fashion. In contrast, the ASD group in the present study benefited as much as the control group from mirror imitation. Indeed, the ASD group showed a greater impairment in performance in the transpose conditions of the pen-and-cups task. We suggest that an impairment in transposition imitation is consistent with the inhibition problems reported in ASD (Russell, 1997). Many studies have demonstrated that spatially compatible responses are faster and more accurate than spatially incompatible responses (Simon, 1969). In the transpose condition, the tendency to make a spatially compatible response (which would result in mirror imitation) has to be inhibited. An inhibition impairment would result in increased mirror imitating and therefore greater errors in the transpose condition. However, this explanation is at odds with the findings of Avikainen et al. One possible reason for the conflicting results may be differences in the instructions used for the mirror condition. In the present experiment participants were explicitly told how to map stimuli onto responses (e.g. to use their right hand when the model used her left hand, and to use their left hand when the model used her right hand), while in the Avikainen et al. study participants were told only to "imitate as if looking in a mirror". The less explicit instructions used in the latter study may have caused uncertainty in the ASD group as to what response was required, and thereby masked any performance improvement which could have been observed when mirror imitating. This explanation is clearly speculative, and the effect of imitative frame of reference is a potential area for future research on ASD.

Two limitations of our study should be noted. First, following Avikainen et al. (2003), we examined performance on imitative and non-imitative tasks by high-functioning adults with ASD, whereas the majority of previous studies have involved adults with lower IQ, or children, with ASD. The fact that our participants with ASD showed a substantial impairment on the imitative version of the pen-and-cups task suggests that, in spite of the sample characteristics, our results contribute to ongoing enquiry concerning imitation in ASD. However, further research, seeking evidence of a functional mirroring deficit in less able individuals and children with ASD, should be a priority for future research.

Second, although Experiments 1 and 2 clearly showed that the weak performance of our ASD participants on the imitative version of the pen-and-cups task was not due to a functional mirroring deficit, they did not isolate the specific cause of the weak performance (i.e. the increased error rate) common to all three versions of the task. A possible explanation is the requirement for rapid shifting of attention between the three action components inherent in all versions of the pen-and-cups task. Many studies have detailed attentional impairments in ASD; examples include allocating attention in the presence of distractors (Burack, 1994), and switching the attentional focus rapidly between spatial locations (Landry & Bryson, 2004; Wainwright & Bryson, 1996, although see Leekam, Lopez, & Moore, 2000, Experiment 2 for contradictory findings), and object features (Courchesne et al., 1994). Further studies, for example those that incorporate measurement of on-line attentional focus within imitative and non-imitative tasks, are required in order to investigate this hypothesis.

In summary, Experiment 1 demonstrated that this particular sample of high-functioning adults with ASD showed impaired performance on a test of voluntary imitation. Experiment 2 revealed that the impaired performance shown by this group on the test of imitation was not due a functional mirroring deficit as performance was equally impaired on two non-imitative versions of the task. Therefore, these experiments suggest that individuals with ASD may show weak performance on tests of voluntary imitation, not because there are impaired in their capacity to match observed with executed action, but because of impairments in abilities that are involved, not only in imitation, but also in other complex tasks.

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References

Aldridge, M. A., Stone, K. R., Sweeney, M. H., & Bower, T. G. R. (2000). Preverbal children with autism understand the intentions of others. *Developmental Science*, *3*, 294.

Avikainen, S., Kulomaki, T., & Hari, R. (1999). Normal movement reading in Asperger subjects. *Neuroreport*, *10*, 3467–3470.

Avikainen, S., Wohlschlager, A., Liuhanen, S., Hanninen, R., & Hari, R. (2003). Impaired mirror-image imitation in Asperger and high-functioning autistic subjects. *Current Biology*, *13*, 339–341.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a theory of mind. *Cognition*, *21*, 37–46.

Beadle-Brown, J. D., & Whiten, A. (2004). Elicited imitation in children and adults with autism: Is there a deficit? *Journal of Intellectual and Developmental Disability*, *29*(2), 147–163.

Bird, G., Leighton, J., Press, C., & Heyes, C. M. (2007). Intact automatic imitation of human and robot actions in autism spectrum disorders. *Proceedings of the Royal Society B*, *274*, 3027–3031.

Bird, G., Brindley, R., Leighton, J., & Heyes, C. (2007). General processes, rather than 'goals', explain imitation errors. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 1158–1169.

Brass, M., & Heyes, C. M. (2005). Imitation: Is cognitive neuroscience solving the correspondence problem? *Trends in Cognitive Sciences*, *9*, 489–495.

Burack, J. A. (1994). Selective attention deficits in persons with autism: Preliminary evidence of an inefficient attentional lens. *Journal of Abnormal Psychology*, *103*, 535–543.

Carpenter, M., Pennington, B. F., & Rogers, S. J. (2001). Understanding of others' intentions in children with autism. *Journal of Autism and Developmental Disorders*, *31*, 589–599.

Courchesne, E., Townsend, J., Akshoomoff, N. A., Saitoh, O., Yeung-Corchesne, R., Lincoln, A. J., et al. (1994). Impairment in shifting attention in autistic and cerebellar patients. *Behavioural Neuroscience*, *108*, 848–865.

D'Entremont, B., & Yazbek, A. (2007). Imitation of intentional and accidental actions by children with autism. *Journal of Autism and Developmental Disorders*, *37*, 1665–1678.

Dapretto, M., Davies, M. S., Pfeifer, J. H., Scott, A. A., Sigman, M., Bookheimer, S. Y., et al. (2006). Understanding emotions in others: Mirror neuron dysfunction in children with autism spectrum disorders. *Nature Neuroscience*, *9*, 28–30.

Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalising. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences*, *358*, 459–473.

Gallese, V. (2006). Intentional attunement: A neurophysiological perspective on social cognition and its disruption in autism. *Brain Research*, *1079*, 15–24.

Gattis, M., Bekkering, H., & Wohlschlager, A. (2002). Goal-directed imitation. In A. N. Meltzoff & W. Prinz (Eds.), *The imitative mind* (pp. 183–205). Cambridge: Cambridge University Press.

Green, D., Baird, G., Barnett, A. L., Henderson, L., Huber, J., & Henderson, S. E. (2002). The severity and nature of motor impairment in Asperger's syndrome: A comparison with specific developmental disorder of motor function. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *43*, 655–668.

Hamilton, A. F., Brindley, R. M., & Frith, U. (2007). Imitation and action understanding in autistic spectrum disorders: How valid is the hypothesis of a deficit in the mirror neuron system? *Neuropsychologia*, *45*, 1859–1868.

Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, G. (1999). Cortical mechanisms of human imitation. *Science*, *286*, 2526–2528.

Iacoboni, M., & Dapretto, M. (2006). The mirror neuron system and the consequences of its dysfunction. *Nature Reviews Neuroscience*, *7*, 942–951.

Landry, R., & Bryson, S. E. (2004). Impaired disengagement of attention in young children with autism. *Journal of Child Psychology and Psychiatry*, *45*(6), 1115–1122.

Leekam, S. R., Lopez, B., & Moore, C. (2000). Attention and joint attention in preschool children with autism. *Developmental Psychology*, *36*(2), 261–273.

Lord, C., Risi, S., Lambrecht, L., Cook, E. J., Leventhal, B., DiLavore, P. C., et al. (2000). The autism diagnostic observation schedule-generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders*, *30*, 205–223.

McDuffie, A., Turner, L., Stone, W., Yoder, P., Wolery, M., & Ulman, T. (2007). Developmental correlates of different types of motor imitation in young children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *37*, 401–412.

Nishitani, N., Avikainen, S., & Hari, R. (2004). Abnormal imitation-related cortical activation sequences in Asperger's syndrome. *Annals of Neurology*, *55*, 558–562.

Ozonoff, S. (1995). Reliability and validity of the Wisconsin Card Sorting Test in studies of autism. *Neuropsychology*, *9*, 491–500.

Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of Child Psychology and Psychiatry*, *32*, 1081–1105.

Ozonoff, S., & Strayer, D. L. (2001). Further evidence for intact working memory in autism. *Journal of Autism and Developmental Disorders*, *31*, 257–263.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry*, *37*, 51–87.

Pennington, B. F., Williams, J. H., & Rogers, S. J. (2006). Conclusions. In S. J. Rogers & J. H. Williams (Eds.), *Imitation and the social mind: Autism and typical development*. New York, NY: Guildford Press.

Rogers, S. J. (1999). An examination of the imitation deficit in autism. In J. Nadel & G. Butterworth (Eds.), *Imitation in infancy* (pp. 254–283). Cambridge University Press.

Rogers, S. J., Bennetto, L., McEvoy, R., & Pennington, B. F. (1996). Imitation and pantomime in high-functioning adolescents with autism spectrum disorders. *Child Development*, *67*, 2060–2073.

Rogers, S. J., & Pennington, B. F. (1991). A theoretical approach to the deficits in infantile autism. *Development and Psychopathology*, *3*, 137–162.

Rogers, S. J., Hepburn, S. L., Stackhouse, T., & Wehner, E. (2003). Imitation performance in toddlers with autism and those with other developmental disorders. *Journal of Child Psychology and Psychiatry*, *44*, 763–781.

Russell, J. (1997). *Autism as an executive disorder*. New York: Oxford University press.

Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology*, *81*, 174–176.

Smith, I., & Bryson, S. E. (1998). Gestures imitation in autism: Nonsymbolic postures and sequences. *Cognitive Neuropsychology*, *15*, 259–273.

Vanvuchelen, M., Roeyers, H., & De Weerdt, W. (2007). Nature of motor imitation problems in school-aged boys with autism: A motor or a cognitive problem? *Autism*, *11*, 225–240.

Wainwright, J. A., & Bryson, S. E. (1996). Visual–spatial orienting in autism. *Journal of Autism and Developmental Disorders*, *26*, 423–438.

Wechsler, D. (1999). *Wechsler adult intelligence scale* (3rd ed.). London: Harcourt Assessment.

Williams, J. H., Waiter, G. D., Gilchrist, A., Perrett, D. I., Murray, A. D., & Whiten, A. (2006). Neural mechanisms of imitation and 'mirror neuron' functioning in autistic spectrum disorder. *Neuropsychologia*, *44*, 610–621.

Williams, J. H., Whiten, A., & Singh, T. (2004). A systematic review of action imitation in autistic spectrum disorder. *Journal of Autism and Developmental Disorders*, *34*, 285–299.

Williams, J. H. G., Whiten, A., Suddendorf, T., & Perrett, D. I. (2001). Imitation, mirror neurons and autism. *Neuroscience and Biobehavioral Reviews*, *25*, 287–295.

Wohlschlager, A., Gattis, M., & Bekkering, H. (2003). Action generation and action perception in imitation: An instance of the ideomotor principle. *Philosophical Transactions of the Royal Society of London B*, *358*, 501–515.