Online action monitoring and memory for self-performed actions in autism spectrum disorder

Running title: Action monitoring in ASD

Catherine Grainger
University of Kent

David M. Williams
University of Kent

Sophie E. Lind
City University London

Contact information for authors:

Catherine Grainger
School of Psychology,
Keynes College,
University of Kent,
Canterbury,
CT2 7NP
Email: cg341@kent.ac.uk
Tel: +44(0)1227 823090

David M. Williams
School of Psychology,
Keynes College,
University of Kent,
Canterbury,
CT2 7NP
Email: D.M.Williams@kent.ac.uk
Tel. +44 (0)1227 827652

Sophie E. Lind
Autism Research Group
Psychology Department
Social Sciences Building
City University London
Whiskin Street
London
EC1R 0JD
Email: Sophie.Lind.2@city.ac.uk
Tel: +44(0)20 7040 3372

Correspondence concerning this article should be addressed to Catherine Grainger, School of

Psychology, Keynes College, University of Kent, Canterbury, CT2 7NP. Email: cg341@kent.ac.uk

Abstract

This study explored whether individuals with autism spectrum disorder (ASD) experience difficulties with action monitoring. Two experimental tasks examined whether adults with ASD are able to monitor their own actions online, and whether they also show a typical enactment effects in memory (enhanced memory for actions they have performed compared to actions they have observed being performed). Individuals with ASD and comparison participants showed a similar pattern of performance on both tasks. In a task which required individuals to distinguish person-caused from computer-caused changes in phenomenology both groups found it easier to monitor their own actions compared to those of an experimenter. Both groups also showed typical enactment effects. Despite recent suggestions to the contrary, these results support suggestions that action monitoring is unimpaired in ASD.

Keywords: Autism spectrum disorder; Action monitoring; Enactment effect; Source memory; Self-referencing; Agency.

Autism spectrum disorder (ASD) is a developmental disorder diagnosed on the basis of behavioural impairments in social-communication, and by fixated interests and repetitive behaviours (e.g., American Psychiatric Association, 2013). On the cognitive level, it has been suggested that ASD is characterised by diminished self-awareness (e.g., Hobson, 1990; Russell, 1996; Williams, 2010) and, more recently, that specific aspects of self-awareness are selectively diminished in this disorder. For example, it has been suggested that individuals with ASD have diminished awareness of *psychological* aspects of the self (e.g., awareness of one's own thoughts, personality characteristics etc.), but undiminished awareness of *physical* aspects of self (e.g., awareness of one's own physical appearance; Lind, 2010; Williams, 2010). In keeping with this proposal, studies have shown that individuals with ASD demonstrate difficulties representing and reporting their own thought processes (e.g., Hurlburt, Happé, & Frith, 1994), intentions (e.g., Williams & Happé, 2010), emotional feelings (e.g., Ben Shalom et al., 2006; Hill, Berthoz, & Frith, 2004) and beliefs (e.g., Williams & Happé, 2009b), all of which supports the suggestion that individuals with ASD show diminished psychological self-awareness. In contrast, several lines of evidence suggest that awareness of the physical self is relatively unimpaired in individuals with ASD. For example, individuals with ASD typically show undiminished performance on mirror self-recognition tasks (e.g., Ferrari & Matthews, 1983), delayed video self-recognition tasks (Lind & Bowler, 2009a), and action imitation tasks (Hamilton, Brindley, & Frith, 2007).

However, some researchers have queried whether awareness of physical aspects of self is truly undiminished in ASD, citing studies that apparently show diminished "action monitoring" in ASD (Russell & Jarrold, 1998, 1999). Russell and Hill (2001, p.317) define action monitoring as, "the mechanisms that ensure that agents know, without self-observation, (a) for which changes in perceptual input they are responsible and (b) what they are currently engaged in doing". As such, action monitoring allows an individual to distinguish those changes in perceptual experience that are "self-caused" from those that are externally-caused. Thus, action monitoring gives rise to the

experience of agency. If individuals with ASD do show impairments in action monitoring this contradicts theories that suggest awareness of the physical self is not impaired in ASD, despite limitations in awareness of psychological aspects of self (e.g., Lind, 2010; Williams, 2010).

Action monitoring ability is commonly assessed through tasks that examine an individuals' ability to monitor and correct their own errors. Typically, individuals are able to correct errors so rapidly that they cannot simply be relying on visual feedback alone. Instead correcting errors at this speed is thought to depend on monitoring so called 'efference copies' of motor plans. This enables errors to be corrected before a motor command for the particular action is initiated. Typically, error correction problems are found in individuals with schizophrenia (e.g., Frith & Done, 1989), and are normally interpreted as reflecting diminished action monitoring . Studies have also indicated that individuals with ASD show impairments in correcting errors (e.g., Russell & Jarrold, 1998). As such, this is one source of evidence that suggests action monition may be impaired in ASD. Another source of evidence, which has been taken as evidence that ASD involves diminished action monitoring ability, concerns findings from studies that have assessed relative memory for self-performed actions versus memory for observed actions. It is well established that typically developing individuals show reliably superior memory for actions that they themselves have performed, compared to actions that they have observed other people perform (e.g., Baker-Ward, Hess, & Flannagan, 1990; Engelkamp, 1998). Superior memory for self-performed actions over other-performed actions is referred to as the "enactment effect" and is thought to result from additional motoric components involved in performing an action leading to those actions being more deeply encoded than observed actions (e.g., Engelkamp & Zimmer, 1989). The fact that several studies have reported reduced or absent enactment effects in ASD has led to the suggestion that ASD may be characterised by diminished action monitoring (Farrant, Blades, & Boucher, 1998; Hala, Rasmussen, & Henderson, 2005; Millward, Powell, Messer, & Jordan, 2000; Russell & Jarrold, 1999; Wojcik, Allen, Brown, & Souchay, 2011; Zalla et al., 2010). Indeed, some studies

have even reported reversed enactment effects (i.e., an "observer effect"; superior memory for observed actions compared to self-performed actions) in ASD, suggesting a marked atypicality in physical self-awareness in this disorder (Millward, et al., 2000; Russell & Jarrold, 1999). All of these studies have lead researchers to conclude "the reduced enactment effect in adults with AS reveals an impaired action monitoring system" (Zalla et al., 2010, p.6).

However, in our view, there are grounds for questioning whether the results from these studies, and thus the conclusion that action monitoring is diminished in ASD, are indeed valid and reliable. In the studies by Farrant et al. (1998) and Hala et al. (2005), participants with ASD showed a flat profile of memory for self-performed and observed actions. However, in both of these studies comparison participants did *not* show a significant enactment effect either. Rather, they too showed a flat profile of performance and there were *no significant between-group differences* in this respect in either of the studies. Therefore, the failure of individuals with ASD to show an enactment effect in these studies cannot be taken to support the view that action monitoring/physical self-awareness is diminished in this disorder. Instead, because typically developing individuals in these studies also failed to show enactment effects, the failure to find an enactment effect among participants with ASD is likely to be due to methodological issues associated with the procedure/stimuli used in the studies.

In the study by Millward et al. (2000), comparison participants did show a significant enactment effect, whereas participants with ASD showed an atypical observer effect. This does indicate that action monitoring may be impaired in individuals with ASD. However, one major problem with this study is that Millward et al. (2000) did not match ASD and comparison participants for VIQ. Although the groups were matched for verbal mental age, the comparison group had a mean chronological age that was seven years below that of the ASD group. Thus, as Lind (2010) highlights, participants with ASD had VIQ scores that were approximately *54 points* below those of comparison participants. In our view, it is simply not possible to compare

meaningfully the experimental task performance of ASD and comparison participants in Millward et al.'s study. Matching for VIQ is essential in studies of cognitive function in individuals with ASD. It is possible that differences between groups in this respect can potentially entirely explain between-group differences in Millward et al.,'s experimental task (see Mervis & Klein-Tasman, 2004).

In an attempt to overcome this limitation, Millward et al. (2000) conducted a second study. This study assessed a sample of children with intellectual disability who, like the ASD group in their Study 1, had lower verbal mental ages than chronological ages. However, no ASD or typically developing comparison groups were included, and the group with intellectual disability in Study 2 was *not* comparable to the ASD or typically developing groups from Study 1 in terms of either verbal mental age or chronological age. Furthermore, the group of children with intellectual disability in Study 2 experienced a different set of events in different locations to those used in Study 1. As such, in our view, it is not possible to draw any meaningful conclusions from this study. In a more recent study Wojcik et al. (2011) also failed to find significant enactment effects among children with ASD. In contrast, on the same task typically developing children showed a clear enactment effect. However, the study does not report whether groups were matched for verbal intelligence. In our view, as is the case with Millward et al. (2000) it thus remains unclear whether group differences in VIQ could potentially account for group differences in memory performance.

It is difficult to draw conclusions from the studies by Farrant et al., (1998), Hala et al., (2005), Millward et al., (2000) and Wojcik et al., (2010) because of the methodological problems that are arguably inherent in the design of each study. However, in our view, the studies by Russell and Jarrold (1999), and Zalla et al. (2010) both used sound experimental procedures. In both studies, individuals with ASD and comparison participants were closely matched for age and verbal intelligence, and comparison participants in each study did show significant enactment effects. As such, if reliable, the findings of reduced/reversed enactment effects in ASD in these studies provide

a serious challenge to theories that action monitoring ability is typical in individuals with ASD. However, there is reason to question the reliability of the results reported by Russell and Jarrold. Using a slightly modified version of Russell and Jarrold's original task, Williams and Happé (2009a) found that participants with ASD showed a typical enactment effect in a source memory task. They did not observe significant differences between the (well-matched) groups of ASD and comparison participants, in this respect. This suggests that Russell & Jarrold's findings (1999) may not be replicable (see discussion for a greater discussion).

The fact that Williams & Happé (2009a) could not replicate the results of Russell and Jarrold (1999) highlights the importance of replicating methodologically rigorous studies with well-designed methods. With this in mind, the current study represents an attempt to replicate, in our view, the only other methodologically rigorous study that has failed to find an enactment effect in ASD; Zalla et al. (2010). Zalla and colleagues explored whether adults with ASD would show an enactment effect when their memory was tested for actions they themselves had performed, compared to actions that they had observed someone else perform in a video clip. Participants' memory for performed and observed actions was tested using three memory tasks; a free recall task, a recognition task and a source memory task. Zalla et al. (2010) found that participants with ASD showed similar performance to control participants on the recognition and source memory tests, showing better memory for actions they had performed compared to actions they had observed being performed by someone else. However on the *free recall task* participants showed no significant difference in the proportion of enacted actions they recalled, compared to the proportion of observed actions they recalled. In contrast, control participants recalled significantly more actions that they had performed compared to those they had observed.

As such, in order to provide clearer evidence of whether action monitoring abilities are diminished in ASD, the first experimental task reported in this paper attempted to replicate the findings of Zalla et al. In so doing, we aimed to test whether Zalla's findings were reliable, or

whether, as was the case with Russell and Jarrold's (1999) findings, they could not be replicated. If individuals with ASD do show impairments in their ability to monitor their own actions then you would expect to find a reduced or absent enactment effect on this task. However if, as predicted, action monitoring remains unimpaired in individuals with ASD, then performance on the task should be similar in both the TD and ASD participants.

We also included, as a second experimental task, a version of the "online" action monitoring task employed by Williams and Happé (2009a; Experiment 1). According to Russell (Russell & Jarrold, 1999), tasks which require individuals to discriminate online between their own actions and actions initiated by something/someone else provide a direct measure of action monitoring ability. Following Russell and Hill (2001), Williams and Happé employed a task that involved participants moving a computer mouse (which was placed inside a box, obscuring it from view) and were asked to decide which, from a number of moving coloured squares displayed on a computer screen, was the stimulus being controlled by their own hand movements. Success on the task relied on participants deciding which of the movements on the screen corresponded with their own proprioceptively experienced movements. The study also included a second 'Other' condition. In this condition participants placed their hand on the computer mouse, but the movements of the mouse were controlled by the experimenter. Thus, in this condition, participants experience no motor intentions for the movements of the mouse in the Other condition, and so cannot rely on feelings of agency to determine which of the stimuli is being controlled by the mouse. For an individual with a unimpaired sense of their own agency, this condition should be significantly more challenging than the Self condition. In contrast, if individuals are unable to accurately monitor their own actions then it should not matter who controls the mouse, because in both cases participants cannot rely on an experience of agency to perform the task, and instead can only rely on their ability to match felt actions with the observed consequences of these actions. Williams and Happé (2009a) did not observe any significant between-group difference in either the level or pattern of

performance shown by individuals with and without ASD on the task. Additionally, (when diagnostic groups were collapsed) Williams & Happé (2009a) found that performance on the *self* condition of the Squares task was significantly associated with source memory for *self* performed actions, independently of verbal mental age. The better participants' action monitoring ability on the squares task the greater the enactment effect shown by participants on the memory task. Thus, Williams and Happé found a direct link between online action monitoring and the enactment effect. We included this squares task in our study to provide an additional measure of action monitoring ability to the measures used by Zalla et al., (2010). Including this test of action monitoring also allowed us to investigate whether action monitoring ability as assessed by an online measure relates to action monitoring ability assessed by the enactment effect. It was predicted that individuals with ASD would show similar performance on the Self condition of the task as comparison participants, and that both groups would find the Self condition considerably easier than the Other condition. It was also predicted that individuals' action monitoring ability on both experimental tasks would be related. All predictions were in keeping with suggestions that, regardless of whether it is assessed online or via memory, action monitoring ability should be unimpaired in individuals with ASD.

Method

Participants

Ethical approval for this study was obtained from Durham University ethics committee. Seventeen adults with ASD and 17 neurotypical comparison adults took part in this study, all of whom gave written informed consent before participating. Participants in the ASD group had all received formal diagnoses of autistic disorder (n = 4) or Asperger's disorder (n = 13), according to conventional criteria (American Psychiatric Association, 2000; World Heath Organisation, 1993). Participants with ASD were recruited via an advertisement on The National Autistic Society website; ASD support groups; Durham University Service for Students with Disabilities; and word

of mouth. The majority of comparison participants were recruited through advertisements in local newspapers. However, a small number took part in order to receive course credits in partial fulfilment of their undergraduate psychology degrees.

Fifteen of the 17 participants in the ASD group were administered with the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000). The ADOS is an in-depth observational assessment of ASD characteristics. Two participants did not wish to complete the ADOS, because they did not feel comfortable being filmed. The mean ADOS total score for the ASD group was in the autism range (see Table 1). All participants who completed the ADOS received a total score ≥7, above the defined cut-off for ASD (Lord, et al., 2000). Additionally, all participants in the ASD group completed the Autism-spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), a self-report questionnaire that assesses ASD characteristics. Fourteen out of 17 participants scored above the defined cut-off for ASD on the AQ (total score ≥26; Woodbury-Smith, Robinson, & Baron-Cohen, 2005). Three participants did not self-report a score above this cut-off. However, all three of these participants scored well above the defined ASD cut-off on the ADOS (all scored ≥12).

All comparison participants completed the AQ and all scored below the defined cut-off for ASD. No participants, in either the ASD or TD group, reported using any psychotropic medication. Additionally, none of the participants reported a history of having a neurological or psychiatric condition (apart from ASD). The participant groups were closely equated for verbal and non-verbal ability, as assessed using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Groups were also closely matched for chronological age (see Table 1 for participant characteristics).

Design and Procedure

Enactment effect task. We attempted to replicate the procedure for the enactment task employed by Zalla et al. (2010). The task consisted of a study phase and test phase. During the

study phase participants were presented verbal descriptions and videos of 30 actions, 15 of which they simply observed being performed and 15 of which they observed being performed *and* performed themselves. Participants were informed that after the study phase they would be asked about what they had heard, seen and acted out, but were not explicitly told that their memory for the action phrases would be tested. Eight different 30-item lists of actions were used during the task, and list presentation was counterbalanced across all participants. Each 30 item-list consisted of actions phrases drawn from an overall set of 60 action phrases. Four lists were created using action phrases from one half of this set, and another four lists were created using action phrases from the other half of this set. Each list presented the action phrases in a different randomised order, and in each list 15 actions were randomly selected as the actions assigned to be performed. All eight lists were equated for mean syllable length of items and mean spoken word frequency as indexed by Kucera and Francis (1967), all of which were reported in the MRC Psycholinguistic Database (Coltheart, 1981). The adequacy of this matching was confirmed by a non-significant effect of List in a multivariate ANOVA (using Wilks' Lambda criterion) that included syllable length and word frequency as the dependent variables, F (14, 464) = 0.31, p = .993, η_p^2 = .01.

During the study phase actions were presented to participants on a computer screen which participants stood approximately 1.5 meters away from. Participants were instructed that the beginning of each trial would be signalled by the presentation of either a green or red dot at the top of the screen. Both green and red dots were identical in size (2x2cm) and appeared at the top of the computer screen for the entirety of a trial. After the dot (either red or green) had been presented for 1000ms it was followed by a recording of a male voice describing an action phrase (e.g. "pour some water"). All voice clips used in the task were 2000ms long. Immediately after auditory presentation of the action phrase participants were then presented with a video of an actor performing the appropriate action. All video clips were 6000ms long, during which a male actor acted out the

appropriate action and then adopted a neutral stance for the remainder of the clip. Figure 1 shows a representation of stimuli presentation on each trial of the task.

Participants were instructed that if a green dot appeared on the screen at the start of a trial they should listen to the action and then simultaneously mimic the action described while the video was being presented. If a red dot appeared at the start of a trial participants were instructed simply to listen to the action phrase and then watch the video clip of the actor performing the phrase. During these trials participants were asked to stand in a neutral position. At the end of each trial the experimenter clicked the mouse, after which the next trial began immediately. During green dot trials the experimenter moved onto the next trial only after the video had been fully presented and they had observed the participant adequately perform the appropriate action.

After a short 5 minute break participants completed the test phase. Firstly participants' memory for the action phrases was tested using a basic recall task in which participants were given five minutes to write down as many of the action phrases as they could remember. Secondly participants completed a recognition and source memory task. In this task participants were presented with 60 action phrases (15 they had performed, 15 they had observed and 30 novel 'lure' phrases). One of the remaining stimuli lists was used to make up the 30 novel actions phrases, and so novel phrases were matched to the 'old' action phrases for syllable length and word frequency (as stated above). Participants were asked to judge whether each action phrase was 'old' (had been presented to them previously during the study phase) or 'new' (had not been presented in the study phase). If participants thought that an action phrase was old they were also asked to decide whether they thought the action was one they had performed, or one they had observed being performed but not performed themselves. During this task participants were presented individually with each action phrase on the computer screen, and an experimenter recorded their responses, and then moved onto the next trial.

Action monitoring task. The action monitoring task employed in this study was based on the task used in Williams and Happé (2009a). There were two conditions (Self and Other) of the task. In each condition, a series of different coloured squares moved across a computer screen. All the squares moved whenever the mouse was moved and froze whenever the mouse was not being moved. However, during each trial only one of the squares (the target square) consistently moved in accordance with the movements of the mouse. In other words, only the target square was directly controlled by the participant. The remaining squares in each trial (the distractor squares) moved in a pseudo-random fashion.

In both the Self and Other conditions of the task there were a total of 18 levels, which increased in difficulty (Table 2 summarises each level of the task). Participants completed five 30s trials at each level, and moved onto the next level only if they successfully completed more trials than would be expected by chance. For example at level 1 four squares were presented on the screen, one of which was the target square and three of which were distractor squares. Across five trials, if an individual randomly chose squares, by chance they would be expected to successfully identify the target square on one in every four trials. As such, to pass level 1 a participant had to successfully identify the target square at least twice (in five trials) to perform above chance on this level. The number of distractor squares increased as levels got harder. At level two there were 8 distractors, at level three there were 15 distractors, at level four there were 24 distractors, at level five there were 35 distractors and at level six there were 48 distractors.

Task difficulty was also manipulated by varying the degree of similarity between the movement of the target square and the movements of the distractor squares. The vector movements of the distractor squares could be varied between 0° to 360° relative to the target square. If the movements of the distractor squares varied by 0° degrees from the target square all the squares would move the same, and so the task would be impossible. In contrast, if the movement of the distractor squares varied by 360° the distractor squares could move in any direction relative to the

movement of the target square. If participants successfully completed levels 1 to 6 with the distractor squares set at a movement arc of 360° they moved onto level 7, which was the same as level 1 (i.e., one target and three distractor squares), but the movements of the distractor squares were contained to an 180° movement arc. Levels 8, 9, 10, 11, and 12 were the same as levels 2, 3, 4 5, and 6, respectively, expect that the movements of the distractor squares were also contained to a 180° arc. If participants completed these levels successfully they moved onto level 13, which again was the same as level 1 but with the movements of the distractor squares contained to a 90° arc. Again levels 14, 15, 16, 17, and 18 were the same as levels 2, 3, 4 5, and 6 respectively, except that the movement of the distractor squares was now restricted to 90°. Table 2 summarises each level of the task.

Participants always completed the Self condition of the task first. In this condition participants moved the mouse and were instructed to press the spacebar once they thought they had identified that target square. Once the spacebar was pressed all squares on the screen froze and did not move when the mouse was moved, allowing participants to then click on the square they thought was the target square. The next trial began immediately after participants clicked on a square. If participants did not press the spacebar within 30s the trial ended and participants moved onto the next trial. This was considered an incorrect trial. Before participants completed the experimental trials, they were shown a demonstration of the task. The experimenter demonstrated two trials at level 1, explaining to the participant 'I think I know which square I am controlling so I am going to press the spacebar. Then I can indicate which square I think I was controlling by clicking on it'. Participants then completed two practice trials at level 1 followed by the experimental trials. On all trials the mouse was placed inside a cardboard box, which could be reached through openings at both ends of the box. This obscured vision of both the mouse and the participant's hand and was used to ensure that participants did not succeed at the task simply by matching their hand movements with the movements of the square on the screen. If participants did

not successfully complete enough trials for their performance to be better than chance at a particular level a 'Game Over' screen appeared, signalling the end of that condition.

After completing the Self condition participants then completed the Other condition of the task. This condition was identical to the Self condition except that as well as the participant placing their hand on the mouse, the experimenter took hold of the mouse from the opposite end and gripped the top of the mouse with their index and thumb fingers. This allowed the experimenter to control the movements of the mouse. The participant was instructed to allow the experimenter to control the movements of the mouse, and not to try and move the mouse themselves. During each trial the experimenter continuously moved the mouse, first up and down and then left and right. The same mouse movements were standardised across all participants and trials. Once the participant thought they had identified the target square they were instructed to press the spacebar. Like before, all squares on the screen froze and the participant were then able to control the movements of the mouse, and click on the square they thought was the target square. As before, the experimenter demonstrated the task and participants then completed two practise trials at level one, before beginning the experimental trials.

Scoring

For the enactment effect memory task participants' recall performance was calculated as the proportion of actions individuals correctly recalled, both for enacted actions and observed actions. As a measure of recognition performance two separate corrected hit rates were calculated[1]. Corrected hit rates were calculated using the formula H-FA, where H represents hit rate (the proportion of old items participants *correctly* identifying as 'old') and FA represents false alarm rate (the proportion of new actions participants *incorrectly* identifying 'old'). Two corrected hit rate scores were calculated, using separate hit rates for enacted and observed actions. A single false alarm rate was used to calculate both corrected hit rates, since false alarm rates were derived from

performance on distractor items which by definition were neither enacted nor observed. Source monitoring performance was calculated as the proportion of action phrases participants made correct source attributions for (i.e. correctly identified performed actions as 'performed', and observed actions as 'observed'), for both enacted and observed action phrases.

During both conditions of the action monitoring task the computer automatically recorded which squares participants clicked on during each trial, and whether this was the correct target square. For each participant the total number of successfully completed trials (from a maximum of 90 trials) and the total number of successfully completed levels (from a maximum of 18 levels) in both the Self and Other condition was calculated.

Results

Enactment Task

Free Recall. Table 3 shows the average proportion of actions that individuals in the ASD and TD group recalled correctly, for both enacted and observed actions. A 2 (Group: ASD/TD) × 2 (Condition: Enacted/Observed) ANOVA was conducted on the proportion of actions correctly recalled. A significant main effect of Condition was found, F (1, 32)= 28.42, $p < .001$, $\eta_p^2 = .47$, reflecting the fact that across groups individuals recalled significantly more actions that they had performed, compared to actions they had observed. There was no significant main effect of Group, F (1, 32) = 1.31, $p = .261$, $\eta_p^2 = .04$, and no significant interaction between Group and Condition F (1, 32) = .01, $p = .906$, $\eta_p^2 < .01$. This reflected the fact that participants in both groups showed the same pattern of performance on the recall task, and recalled significantly more enacted actions than observed actions (showing a statistically significant enactment effect).

Recognition. Corrected hit rates for enacted and observed actions among ASD and comparison participants are reported in Table 3[1]. A 2 (Group: ASD/TD) × 2 (Condition:

Enacted/Observed) mixed ANOVA was conducted on these data. A significant main effect of Condition was found, F (1, 32) = 58.96, p < .001, η_p^2 = .65, reflecting superior recognition of enacted items than observed items. There was no significant main effect of Group, F (1, 32) = 0.004, p = .952, η_p^2< .01, and no significant interaction between Group and condition F (1, 32) = 2.09, p = .158, η_p^2 = .06. This reflected the fact that both groups showed a similar pattern of recognition performance, demonstrating better recognition discrimination for enacted actions compared to actions they had observed.

Source Monitoring. Table 3 also shows the average proportion of actions that participants in the ASD and TD group made correct source memory judgements for, for both enacted and observed actions. A 2 (Group: ASD/TD) × 2 (Condition enacted/observed) mixed ANOVA was conducted. A significant main effect of Condition was found, F (1,32) = 25.9, p <.001, η_p^2 = .45, reflecting the fact that, across groups, individuals made more correct source judgements for enacted actions compared to actions they had observed. There was no significant main effect of Group, F (1, 32) = 0.04, p = .844, η_p^2< .01, and no significant interaction between Group and condition F (1, 32) = .01, p = .944, η_p^2< .01. This reflected the fact that both groups made more correct source monitoring judgments for enacted actions compared to observed action.

A series of one sample *t*-tests was carried out, to establish whether performance on the enactment task was at floor or ceiling level, for any of the memory measures. These *t*-tests indicated that, in both the ASD and TD groups, performance on the recall, recognition, and source monitoring tasks significantly differed from floor or ceiling level performance, all *t*s > 2.38, all *p*s < .030.

To summarise, on all three tests of memory (recall, recognition, and source monitoring) participants in *both* the ASD and TD groups showed better memory for actions that they had enacted compared to actions they had observed. This pattern of memory performance did not differ between ASD participants and TD participants on any measure, as indicated by *no* significant interactions between participants' diagnostic group and their memory for enacted/observed action

Squares Task

Table 4 shows the mean number of levels and trials completed in both the Self and Other conditions of the task, for both ASD and TD participants. Firstly a 2 × 2 mixed ANOVA was carried out, with the number of *trials* completed in each condition (Self/Other) entered as a within-subjects variable and diagnostic group (ASD/TD) entered as a between subject variable. There was a significant main effect of condition on the number of trials completed, F (1, 32) = 75.66, p < .001, η_p^2= .70. This reflected superior performance in the Self condition compared to the Other condition. There was no significant main effect of group, F (1, 32) = 0.46, p = .503, η_p^2= .01, indicating, across both conditions, that participants in the ASD group showed similar performance to comparisons participants. There was also no significant interaction between group and condition, F (1, 32) = 1.45, p = .237, η_p^2= .04.

Another 2 × 2 mixed design ANOVA was carried out, with the number of *levels* participants successfully completed in each Condition (Self/Other) entered as a within-subjects variable, and Group (ASD/TD) entered as a between subjects variable. Again, there was a significant main effect of condition on the number of levels successfully completed, F (1, 32) = 87.23, p < .001, η_p^2= .73. There was no main effect of Group, F (1, 32) =1.54, p = .223, η_p^2= .05. However, the interaction between Group and Condition was marginally significant, F (1, 32) = 3.95, p = .056, η_p^2= .11. To investigate this interaction further a series of independent sample t-tests was carried out. These indicated that within the Self condition there was no significant group difference in the number of levels successfully completed, t (32) = 1.67, p = .105, d = 0.57. This was also the case in the Other condition, t (32) = 1.63, p = .112, d = 0.56. Paired-samples t-tests showed there was a significant difference between the number of levels completed in the Self condition, compared to the Other condition, in both the ASD group, t (16) = 4.83, p <.001, d = 2.87, and the TD group , t (16) = 8.73, p <.001, d = 1.75. The significant interaction between Group

and Condition appeared to be driven by the relatively larger difference between performance on the Self and Other conditions of the task shown by ASD participants compared to TD participants. On average individual in the TD group completed 7.29 (6.22) more levels on the Self condition of the task compared to the Other condition, whereas individuals in the ASD group completed on average 11.24 (5.31) more levels on the Self condition compared to the Other condition. Figures 2 and 3 show the number of participants in each group that successfully completed each level of the task, in both the Self and Other conditions.

Relations between action monitoring ability on the Enactment task and the Squares task

On the Squares task, the size of the effect of action monitoring was calculated by subtracting the number of successful trials participants made in the Other condition from the number of successful trials participants made in the Self condition of the task. This difference score represented the size of the advantage of action monitoring on the Squares task. The greater the score, the more sensitive action monitoring ability was on the task.

On the Enactment task, the size of the enactment effect participants showed was calculated by subtracting participants' memory scores for observed actions from their memory scores for enacted actions. Three separate difference scores were calculated for 1) recall memory, 2) recognition memory and 3), source monitoring memory. For all three scores the greater the score, the greater the memory advantage for enacting actions compared to observing them.

To investigate the relation between the effect of action monitoring on the Squares task and extent to which participants showed an enactment effect on the Enactment task, a series of Pearson's correlations was conducted. There was no significant relation between the size of the effect of action monitoring (on the Squares task) and the extent to which participants showed enactment effects on the recall, recognition and source monitoring tests (on the Enactment task), among either ASD or comparison participants, all rs < .28, all ps > .279.

Discussion

Individuals with ASD showed no evidence of action monitoring impairments in this study. Results from the Squares task indicated that the ASD group were *as* able as comparison individuals to detect which square was controlled by their own actions. Importantly, both groups of participants also found it significantly easier to identify the target square when it was controlled by their own intentional movements, compared to when the movement of the target square was controlled by the experimenter. Thus, individuals with ASD were able to monitor their own motor commands and benefit from the feelings of agency that were unique to the Self condition of the task. Indeed, there was some evidence that individuals with ASD were somewhat more sensitive to their agency than comparison participants; when the number of successful *levels* completed on the Squares task was taken as the dependent measure of performance. These results are in keeping with previous suggestions that individuals with ASD may in fact make *more* efficient use of non-visual, motor cues than typically developing individuals, and rely relatively less on visual cues (Frith & Hermelin, 1969). This suggests that, far from being impaired, individuals with ASD might show heightened physical self-awareness. Regardless of whether this is the case, the results from this study certainly do not suggest that individuals with ASD are impaired at online action monitoring.

During the enactment task, as predicted, adults with ASD showed better memory for actions they had enacted, compared to actions they had observed, on *all three* memory tests. On the recall, recognition, and source monitoring tests, memory performance was both qualitatively and quantitatively similar in the ASD and TD groups; individuals with ASD showed enactment effects of a closely similar magnitude to those shown by typically developing individuals. This is in keeping with many previous studies that have reported finding typical enactment effects in individuals with ASD (e.g., Hare, Mellor, & Azmi, 2007; Lind & Bowler, 2009b; Maras, Memon, Lambrechts, & Bowler, 2012; Summers & Craik, 1994; Williams & Happé, 2009a), and also in

keeping with many studies in the broader action monitoring literature (e.g., Blakemore et al., 2006; David et al., 2008). Indeed, with respect to the recognition and source memory tasks, our results replicate those of Zalla et al. (2010); in both our study and in Zalla et al.'s study, typical enactment effects for recognition and source memory were observed among individuals with ASD. Nonetheless, in their discussion of their data, Zalla et al. mainly focussed on the only difference they observed between the groups, which was in free recall only. It was in this respect we were *not* able to replicate Zalla et al.'s results.

In the introduction we argued that only two studies (Russell & Jarrold, 1999; Zalla, et al., 2010) have reported finding that individuals with ASD do not show a typical enactment effect, using samples we know are well matched. Russell and Jarrold's study could not be replicated by Williams and Happé (2009a). Similarly, in this paper, the only finding we failed to replicate was atypical memory performance in individuals with ASD on the recall test (the only results in the paper that in any way indicated action monitoring is impaired in ASD). As such, it is argued that this study, and the enactment effect literature in general, provides support for theories that suggest action monitoring should remain unimpaired in individuals with ASD (e.g., Lind, 2010; Williams, 2010).

A number of studies have now explored whether individuals with ASD demonstrate typical enactment effects. A summary of the results from these studies is shown in Table 5. This table shows that, in fact, the majority of these studies are in keeping with the results of this study, and report similar performance in ASD and comparison participants (with both groups either showing an enactment effect of similar magnitude, or both groups showing no enactment effect). Across these studies, when you look at the average size of the memory advantage individuals demonstrate for self-performed items compared to other-performed items, there is no significant difference between ASD and TD participants, t (38) = .40, p = .692, d =0.11. On average, across all studies looking at the enactment effect, ASD participants remembered 10% more actions that they

performed compared to actions they observed. Comparably, on average, TD participants remembered 11% more actions when they enacted them. This lends more support to the view that action monitoring (and physical self-awareness, more generally) is undiminished in ASD.

Potential reasons for why both Russell & Jarrold (1999) and Zalla et al., (2010) found discrepant results, compared to other studies of the enactment effect in individuals with ASD, should be considered. One potential reason for discrepancies between studies could be differences in the developmental ability of participants in different studies. It is possible that problems with action monitoring may be evident in individuals with ASD who have low verbal mental ages. The average verbal mental age (VMA) of the children with ASD in Russell & Jarrold's study (VMA= 7.13 years) was lower than the level among children with ASD in Williams & Happé (2009a) study (VMA= 8.44 years), potentially explaining why only Williams and Happé observed an enactment effect among their sample of ASD participants. However, the developmental level (i.e., VMA) of participants is unlikely to be the sole explanation for differences across studies, because other studies have reported a typical enactment effect among children with ASD whose VMAs were on average *lower* than participants in Russell & Jarrold's study. For example, Lind and Bowler (2009b) found that a sample of children with ASD with an average VMA of 6.66 years showed typical enactment effects compared to comparison participants. An alternative explanation for Russell and Jarrold's failure to observe an enactment effect among individuals with ASD may be to do with the verbal intelligence, rather than developmental level, of participants. That is, problems with action monitoring may be evident only among intellectually low-functioning in individuals with ASD. In Russell and Jarrold's study, participants with ASD had a mean VIQ of only approximately 53.89[2], which is notably low, relative to other relevant studies. However, it is also notable that a large proportion of the individuals with ASD in Williams and Happé's sample would still be considered relatively intellectually low-functioning (the mean VIQ among participants with ASD was 73.50), but nonetheless showed typical enactment effects'. Moreover, reference to VIQ does not explain

why adults in Zalla et al's study (mean VIQ =114.2) did not show an enactment effect on the recall task. As such, developmental differences in VMA/ VIQ cannot fully explain discrepancies between each study's findings.

Within the literature, three studies (the current study; Williams and Happé 2009a; Russell & Hill, 2001) have now used the Squares task (or a variation of it) to investigate action monitoring ability in individuals with ASD. All three of these studies find convergent results, indicating undiminished task performance among adults and children with ASD. That being said, the current study did not find a significant correlation between the effect of action monitoring on the Squares task and the extent to which participants showed an enactment effect on the action memory task , in either the ASD or the TD group. In this respect, we did not replicate Williams and Happé's findings (2009a). The enactment tasks that we used was based as closely as possible on the method used in Zalla et al., (2010) and thus was not the same task as the task used by Williams & Happé. As such, it may be the case that the enactment task we used in the current study measured distinct aspects of action monitoring to that used in Williams and Happé. Furthermore, this study assessed action monitoring ability in adults, whereas Williams & Happé assessed action monitoring ability in children. Any of these differences between the study designs/methods could explain the discrepancy between the results in terms of this specific finding. However, in our view, what is more notable is the high consistency of findings across these two studies. Despite the differences in methods used, the results from the two studies converge in most respects.

In terms of the broader literature concerning self-awareness in ASD, the majority of evidence (including the results from both tasks in this study) suggests that physical self-awareness is undiminished in ASD. In contrast, studies have indicated that autobiographical (episodic) memory (Crane & Goddard, 2008; Crane, Pring, Jukes, & Goddard, 2012), and episodic future thinking, is impaired in ASD (e.g., Lind & Bowler, 2010; Lind, Williams, Bowler, & Peel, in press), and arguments have been put forward to suggest that such impairments may (partially) result

from impairments in self-awareness (see Lind, 2010). However, diminished memory for personally experienced events, and the diminished ability to imagine events in the future, is likely to rely on an awareness of a psychological, temporally-extended self. Thus, it appears that individuals with ASD may demonstrate selective impairments only in psychological self-awareness.

Theoretically, the results of this study can also inform cognitive theories surrounding the sense of agency. Within the literature debate exists concerning how different aspects of social cognition, such as agency, imitation and mentalising relate to one and other. Arguably, if a sense of agency acts as a precursor to mentalising ability (Russell, 1996), then stereotypical mentalising deficits in individuals with ASD (e.g., Baron-Cohen, Leslie, & Frith, 1985; Yirmiya, Erel, Shaked, & Solomonica-Levi, 1998) should be associated with similar deficits in action monitoring. Our results, alongside results from several other studies (e.g., David, et al., 2008; Hamilton, et al., 2007; Sebanz, Knoblich, Stumpf, & Prinz, 2005) suggests that a dissociation may exist between the sense of agency and mentalising ability, which is stereotypically impaired in individuals with ASD. Instead, our results support suggestions (e.g., David, et al., 2008) that social-cognitive deficits associated ASD occur at a higher-level than that needed for a sense of agency.

As well as having theoretical implications, establishing the extent of action monitoring abilities in ASD has practical importance. It is well established that typically developing individuals show better memory for information they have enacted. On the basis that individuals with ASD also benefit from self-enactment then strategies aimed at improving learning and memory in ASD should focus on encouraging approaches that capitalise on this particular memory strength (i.e., encouraging motor participation in the learning process). More generally, it may be possible to improve everyday functioning in individuals with ASD if memory can be enhanced by physical self-enactment. Additionally, establishing whether individuals with ASD show an intact ability to accurately determine the source of actions gives rise to potential forensic implications. For example, being able to accurately recall an event one was involved in, and distinguish between actions carried

out by oneself and others, influences the reliability of eyewitness testimonies (see Maras, et al., 2012). This study indicates that action monitoring is a relative strength in ASD, something that should be taken into account in future research.

Table 1: Participant characteristics

	Group				
	ASD (*n* = 17)	TD (*n* = 17)	*t*	*p*	Cohen's *d*
Age	29.11 (10.55)	29.43 (14.95)	0.07	.944	0.02
VIQ	113.06 (13.83)	111.00 (10.77)	0.48	.632	0.17
PIQ	110.71 (15.58)	113.24 (11.20)	0.54	.591	0.19
FSIQ	114.53 (14.51)	113.59 (10.94)	0.21	.832	0.07
AQ Total Score	33.71 (9.23)	12.65 (5.22)	8.19	<.001	2.81
ADOS Total Score*	11.13 (3.58)				

AQ: Autism-spectrum Quotient; ADOS: Autism Diagnostic Observation Schedule

*Based on 15/17 participants

Table 2: Stimulus characteristics for each level of the Action Monitoring task.

Level	No. of distractor squares	Minimum no. of trials required to move onto next level (out of 5)	Distractor movement arc (°)
1	3	2	360
2	8	1	360
3	15	1	360
4	24	1	360
5	35	1	360
6	48	1	360
7	3	2	180
8	8	1	180
9	15	1	180
10	24	1	180
11	35	1	180
12	48	1	180
13	3	2	90
14	8	1	90
15	15	1	90
16	24	1	90
17	35	1	90
18	48	1	90

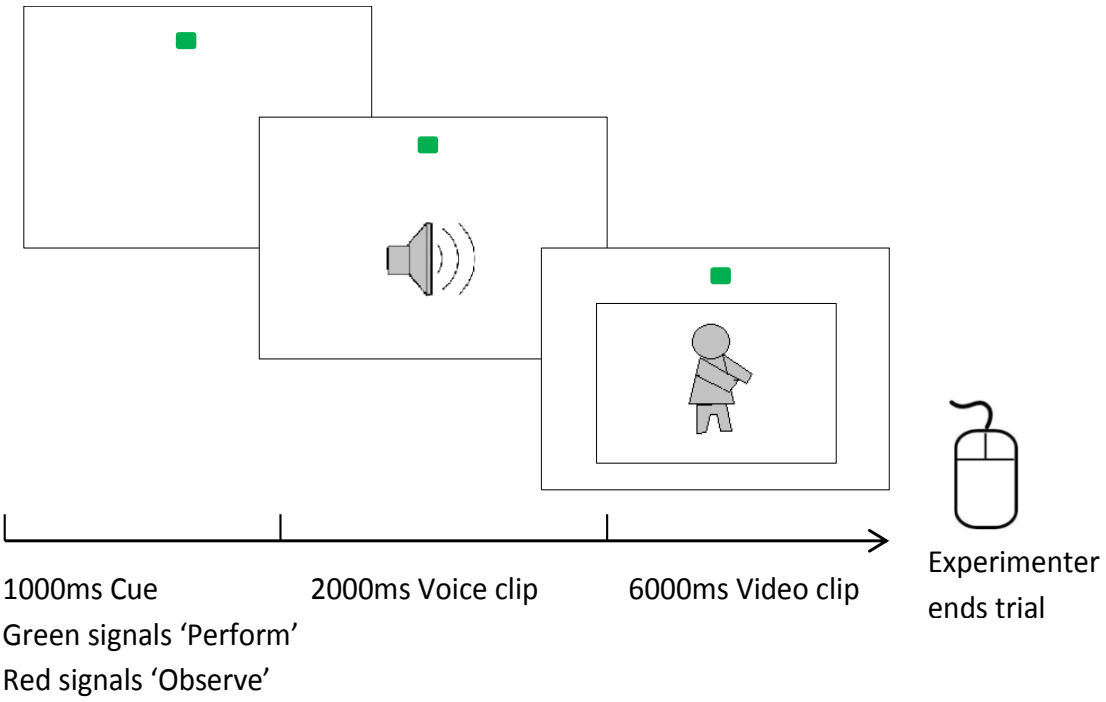

Figure 1: Graphical representation of the procedure used during the study phase of the Enactment Task.

Table 3: Memory performance on the recall, recognition, and source monitoring tasks for enacted and observed action phrases in the ASD and TD groups.

		Group	
		ASD	TD
Recall performance	Enacted	.63 (.13)	.62 (.14)
	Observed	.37 (.13)	.38 (.14)
Recognition performance	Enacted	.95 (.09)	.97 (.05)
	Observed	.83 (.14)	.81 (.13)
Source monitoring performance	Enacted	.95 (.06)	.96 (.07)
	Observed	.80 (.20)	.81 (.11)

Table 4: Mean (standard deviation) number of levels and trials completed in the Self and Other condition, by both the ASD and TD group.

		Group	
		ASD	TD
Trials Completed	Self	40.59 (20.77)	33.53 (22.43)
	Other	3.59 (2.98)	5.53 (4.00)
Levels Completed	Self	12.59 (5.42)	9.41 (5.69)
	Other	1.35 (1.11)	2.12 (1.58)

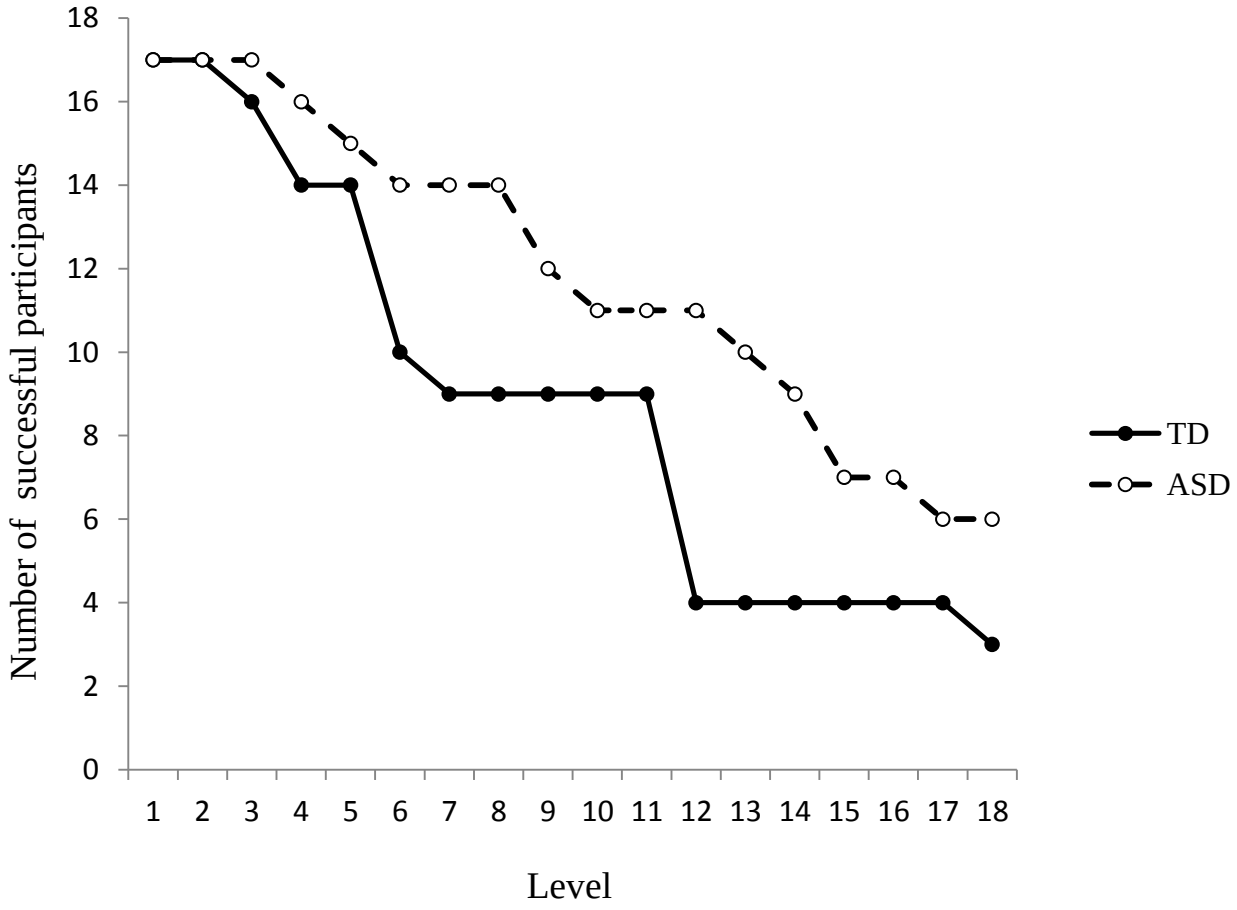

Figure 2: Number of participants in each group who successfully completed each level in the Self condition of the action monitoring task.

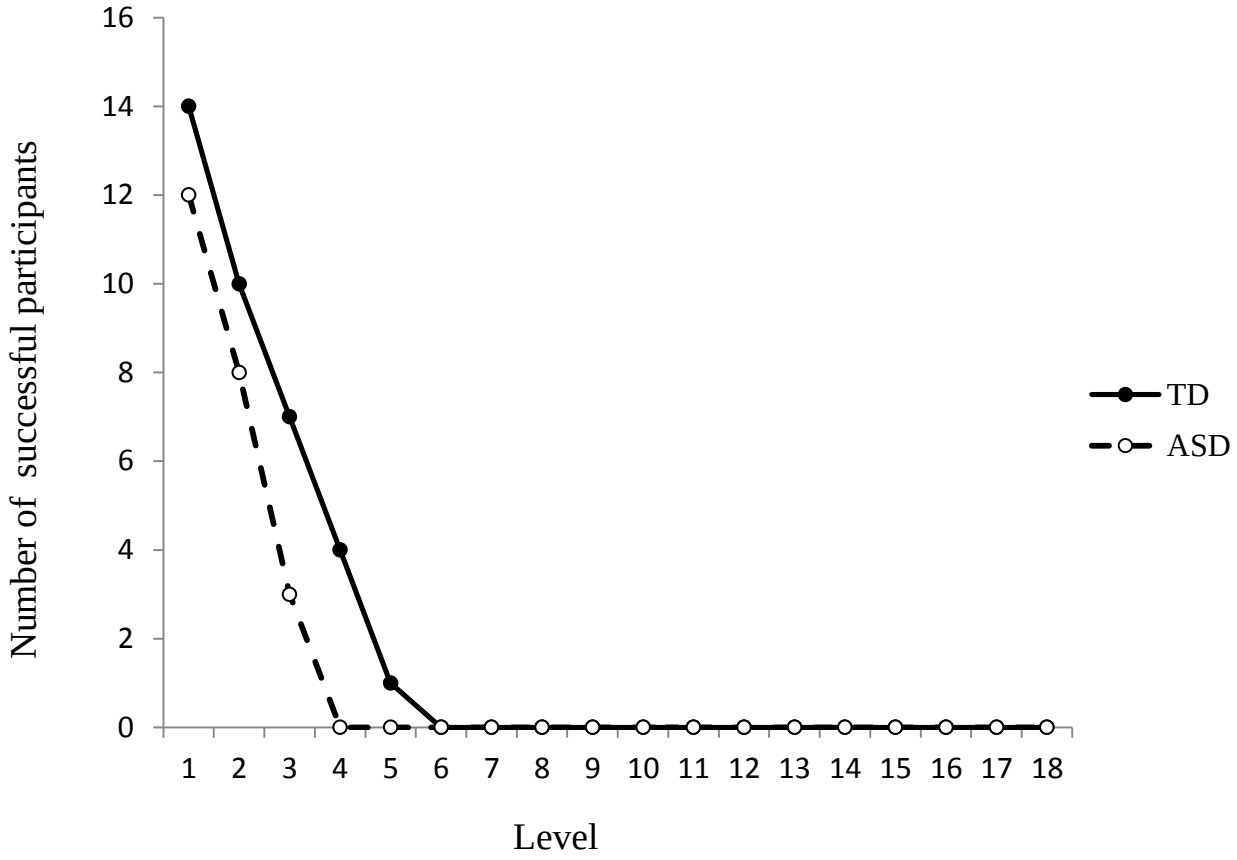

Figure 3: Number of participants in each group who successfully completed each level of the Other condition of the action monitoring task.

Table 5: Summary of studies reporting memory for self-performed items in individuals with ASD and typically developing comparison participants. This table reports the group size for each study, and the average difference in memory performance between the proportion of self-performed items remembered compared to the proportion of other-performed items remembered.

	Memory Test	**Report a significant difference in the size of the enactment effect shown by ASD and TD participants**	**Proportion change across conditions (Self-Other)**		***n***	
			ASD	**TD**	**ASD**	**TD**
Summers & Craik (1994)[a]	Free Recall	No	.20	.05	8	8
	Recognition	No	.17	.24	8	8
Farrant, Boucher & Blades (1998)	Source memory	No	-.18	-.06	15	15
Russell & Jarrold (1999)[b]	Source memory	Yes	-.03	.02	22	22
Millward, Powell, Messer & Jordan (2000)[c]	Recall	Yes	/	/	12	12
Hill & Russell (2002)	Source memory	No	.06	.01	20	20
Hala, Rasmussen & Henderson (2005)	Source memory	No	.16	.05	13	13
Hare, Mellor & Azmi (2007)	Free recall	No	.06	.12	12	14
	Cued Recall	No	.17	.23	12	14
Williams & Happé (2009a)[b]	Source memory	No	.04	-.01	16	16
Lind & Bowler (2009b)	Recognition	No	.19	.22	53	50
	Source memory	No	.12	.07	53	50
Zalla, Daprati, Sav, Chaste, Nico & Leboyer	Free Recall	Yes	.08	.24	18	18
(2010)	Recognition	No	.10	.14	18	18
	Source memory	No	.09	.13	18	18
Wojcik, Allen, Brown & Souchay (2011)	Free Recall	Yes	.00	.03	16	16
Maras, Memon, Lambrects & Bowler (2012)	Free recall	No	.25	.20	18	18
	Cued Recall	No	.02	.05	18	18
Grainger, Williams & Lind (current study)	Free Recall	No	.26	.24	17	17
	Recognition	No	.12	.16	17	17
	Source memory	No	.15	.15	17	17
		Average across all studies (SD):	.10 (.10)	.11(.09)	18.46 (11.02)	18.38 (10.15)
		Total no. of participants in all studies:			240	239

a In this study there was no other-performed condition, but instead self-performed items were compared to verbally presented items.
b For both Russell & Jarrold (1999) and Williams & Happé (2009a) the statistics reported here refer to differences in memory for cards turned over by participants themselves (on behalf of themself and their doll) compared to cards turned by another (on behalf of the experimenter and the experimenter's doll). In the case of Russell & Jarrold (1999) the statistics refer to proportion change across both conditions (expected/unexpected) of the task.
c Millward et al., (2000) do not report means and standard deviations for their results, making it not possible to calculate effect sizes and proportion differences between the Self and Other condition.

Footnote

[1] It should be highlighted that Zalla et al., (2010) used the nonparametric measures of A' and B''_D to assess participants recognition discrimination. However, when A' scores were calculated for recognition performance in this study, one sample *t*-tests indicated that scores did not significantly differ from ceiling level accuracy (100% discrimination accuracy) for enacted actions in both in the TD group, t (16) = 1.97, p = .06, and ASD group, t (16) = 1.87, p = .08. As such, to maximise the rigour of our statistical analysis, corrected hit rates were used as an alternative measure of recognition performance on the task.

[2]The average VIQ for participants in the ASD group is not reported in Russell and Jarrold (1999). However, Russell and Jarrold (1999) reports the average VMA (7.13 years) and the average chronological age (CA; 13.23) for participants in the ASD group. These were used to estimate the average VIQ of the ASD group, using the formula VIQ = VMA/CA × 100.

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Authors Note

Catherine Grainger, School of Psychology, University of Kent; David M. Williams, School of Psychology, University of Kent; Sophie E. Lind, Department of Psychology, City University London.

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Correspondence concerning this article should be addressed to Catherine Grainger, School of Psychology, Keynes College, University of Kent, Canterbury, CT2 7NP. Email: cg341@kent.ac.uk