*Manuscript

**Children with autism do not overimitate**

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Copying the behaviour of others is important for forming social bonds with other people and for learning about the world [1]. After seeing an actor demonstrate actions on a novel object, typically developing (TD) children faithfully copy both necessary and visibly unnecessary actions [2]. This 'overimitation' is commonly described in terms of learning about the object, but may also reflect a social process such as the child's motivation to affiliate with the demonstrator [3] or to conform to perceived norms [4]. Previous studies of overimitation do not separate object learning and social imitation because they use novel objects. Even though researchers consider these objects to be causally transparent in their mechanism, young children's causal reasoning about novel objects is unclear [4]. The present study measures the social component of overimitation by using familiar objects, which preclude the learning component of the task. Here we report a significant reduction in overimitation in children with autism spectrum conditions (ASC). This is coherent with reports that these children have profound difficulties with social engagement [5] and do not spontaneously imitate action style [6] (see also [7]).

We tested 31 children with ASC, 30 TD children matched for verbal mental age and 30 TD children matched for chronological age on an overimitation task using familiar objects. All children were assessed for verbal mental age, overimitation and understanding of action rationality (see Supplementary Information). On each of five trials, the child was asked to watch carefully as a demonstrator showed how to retrieve a toy from a box or build a simple object. Critically, each demonstration included two necessary actions (e.g. unclipping and removing the box lid) and one unnecessary action (e.g. tapping the top of the box twice). The apparatus was then reset behind a screen and handed to the child, who was instructed "get/make the toy as fast as you can". These instructions emphasise the goal, and copying was never mentioned. This means any overimitation is spontaneous and socially motivated. All trials were videotaped for analysis, and completion of the unnecessary action was coded as overimitation. After all overimitation trials, children watched the demonstrator complete individual actions from each sequence, and rated each action on a five point scale from 'sensible' to 'silly'. Rationality discrimination was calculated as the difference between a child's rating of the unnecessary action and the necessary action from the same sequence, with high scores indicating good judgement of which action is more rational.

All TD children were able to complete all tasks and retrieve or build the toy on every trial; children with ASC completed the tasks on 97% of trials (see Supplementary Information). However, we found a striking difference between autistic and TD children in both overimitation and rationality discrimination. TD children copied 43-57% of the unnecessary actions but children with autism copied only 22% (Figure 1A). All groups performed significantly above chance in the rationality discrimination task, but children with autism performed worse than the TD children (Figure 1B). These results have several implications.

First, TD children show substantial overimitation of unnecessary actions on familiar objects, despite understanding that these actions are 'silly'. These results lend support for the position that overimitation in typical children is a social phenomenon rather than being driven by the child's causal learning about the objects. This social overimitation may index a child's motivation [5] to affiliate [3] or to conform to perceived norms [4].

Second, children with autism show significantly less overimitation of the demonstrator's actions. This is not driven by weak motor skill because all the unnecessary actions were familiar simple actions (e.g. tapping a box) and all children were able to complete the more complex goal-directed actions in the sequence. It is also not driven by superior causal reasoning, because the children with ASC also performed worse on the rationality discrimination task. The data go beyond previous studies which showed reduced imitation of action style [6] and reduced spontaneous imitation [8] where differences in behaviour could be driven by the children with autism failing to adopt the same goal as the demonstrator. In our task, children are instructed that the goal is to make/retrieve the toy, and all are able to do so. The failure of children with autism to spontaneously copy unnecessary actions can best be explained in terms of reduced social motivation in these children, with less desire or ability to affiliate with or conform to the perceived norm.

Previous studies have examined social attention in autism using eye-tracking tasks [9], and have examined social motivation using brain-imaging of high functioning adults with ASC [reviewed in 5], but simple methods for measuring social motivation in children did not exist. The ease of implementing our task, and the close links between overimitation and social mimicry in adults [3], mean that this approach can provide a powerful and general tool for examining social motivation in child and adult participants. There is an important contrast between our results and a recent study in which children with autism saw unnecessary actions on novel objects and showed the same rate of overimitation as typical children [10]. One possible interpretation of this difference is that the study using novel objects [10] tapped imitation-to-learn which may be intact in autism, while social imitation, as tested with our simple familiar objects, is atypical. Such a distinction is congruent with previous theories that posit normal goal-directed imitation and abnormal social imitation in autism [7] but further testing of the circumstances that drive children with autism to imitate would be valuable.

Overall, our paper leads to two important conclusions. First, studies of social interaction can examine the social component of imitation behaviour independent of the object-learning component, and this can best be done using familiar objects. Second, children with autism do not show overimitation of actions on familiar objects. This specific difference in a behaviour linked to social affiliation and norm conformity is compatible with claims of abnormal social motivation in autism.

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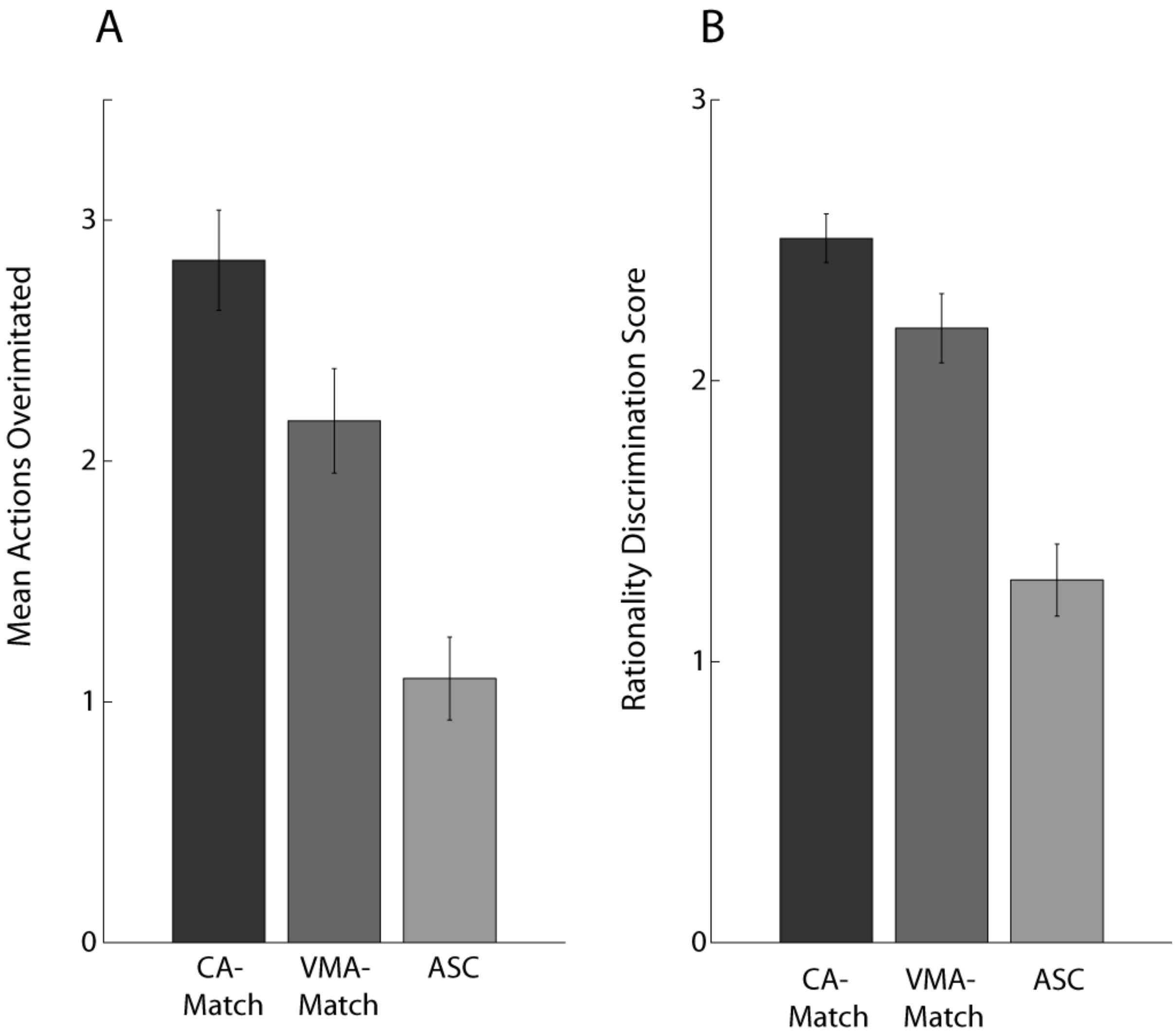


**Figure 1A:** Number of trials where the unnecessary action was copied (maximum 5) in TD and ASC participants. There was a significant reduction in overimitation behaviour in ASC participants compared to CA-match ($F(1,58)=12.84$, $p<0.001$) and VMA-match ($F(1,58) = 7.01$, $p=0.01$) TD controls. Error bars represent +/- 1 standard error.

**Figure 1B:** Mean rationality discrimination score (ranging from -4 to 4) in TD and ASC participants. All three groups performed significantly above chance (zero) (CA-match: $t(29)=16.1$, $p<0.001$; VMA-match: $t(29)=10.2$, $p<0.001$; ASC: $t(30)=5.9$, $p<0.001$). Children with ASC were significantly worse at judging the rationality of actions, when compared to CA-matched ($F(1,58)=19.62$, $p<0.001$) and VMA-matched ($F(1,58)=9.29$, $p=0.003$) groups. Error bars represent +/- 1 standard error. See also Figure S1.

**Supplemental Information: Children with autism do not overimitate**

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## Supplemental Experimental Procedures

*Participants*

Participants were 31 children with autism (ASC), 30 typically developing children matched for chronological age (CA-match) and 30 typically developing children matched for verbal mental age (VMA-match). Table S1 describes the profile of each group.

All children in the autism group had a diagnosis of autism, autism spectrum condition or Asperger's syndrome from an independent clinician or paediatrician. This diagnosis was confirmed using parent reports of the social communication questionnaire lifetime edition (SCQ, [S1]) in 27 participants. Additionally, one participant scored just below the recommended cut-off for autism on this measure and three parents failed to complete it. These four participants were all recruited through specialist schools for autism or through an autism unit at a mainstream school so we are confident of their diagnoses. However, to ensure that these participants did not alter our results, all analyses were performed with and without these participants (see supplementary results). Parents of all children completed the Social Aptitudes Scale (SAS, [S2]), a measure of their child's current social abilities. As expected, children with ASC scored significantly lower on this measure than children in the CA-match and VMA-match groups (CA: $t(53)=14.5$, $p<0.001$, VMA: $t(55)=12.8$, $p<0.001$). Two children with autism scored just outside of the recommended cut-off for autism on this measure, although they both met criteria for autism on the SCQ and had a clinical diagnosis. No children in either of the typically developing groups met the recommended criteria for autism on the SAS and parents of these children reported no developmental disorder.

Children with autism were recruited from schools in the Nottingham area. Typically developing children took part in the study as part of the Summer Scientists week event where children complete a number of cognitive tasks over half a day at the University of Nottingham. The parents of all children gave written informed consent before testing began.

**Table S1:** Participant characteristics for chronological age (CA) matched, verbal mental age (VMA) matched and autism spectrum condition (ASC) groups. Figures reported are group mean ± standard deviation and (range).

| Group | **CA- match** | **VMA- match** | **ASC** |
|---|---|---|---|
| n | 30 | 30 | 31 |
| Age | 8.66 ± 2.0 (4.9 - 12.7) | 6.0 ± 1.3 (4.2 - 8.6) | 9.4 ± 2.3 (5.2 - 13.6) |
| BPVS raw | 94.5 ± 19.9 (57 - 137) | 65.9 ± 20.6 (35 - 122) | 66.7 ± 21.5 (33 - 119) |
| SAS | 27.6 ± 4.7 (10 - 39) | 24.1 ± 4.1 (17 - 32) | 9.2 ± 4.6 (0 - 19) |
| Overimitation | 2.6 ± 1.9 (0 - 5) | 2.2 ± 2.1 (0 - 5) | 1.1 ± 1.6 (0 - 5) |
| Rationality Discrimination | 2.5 ± 0.8 (0 - 3.4) | 2.2 ± 1.2 (-0.8 - 4) | 1.3 ± 1.2 (-1.2 - 4) |
| Theory of Mind (%) | not collected | not collected | 57.7 ± 28.7 (0 - 100) |
| SCQ scores | not collected | not collected | 25.5 ± 4.9 (15-33) |

Abbreviations: CA- chronological age; VMA- verbal mental age; ASC- autism spectrum conditions; BPVS- British Picture Vocabulary Scale; SAS-Social Aptitudes Scale; SCQ- Social Communication Questionnaire. There was no difference in chronological age between the ASC and the CA-match participants ($t(59)=1.39$, $p=0.17$) and no difference in verbal mental age (assessed by the British Picture Vocabulary Scale- BPVS, [S3]) between the ASC and VMA-match participants ($t(59)=0.15$, $p=0.88$).

*Procedure*

Participants were introduced to the experimenter (E) and the demonstrator (D) in an empty classroom. Participants were told that they would watch D play with some toys and when she was finished, they would get a chance to play too. Throughout the experiment, E interacted with the participant and gave them instructions, while D showed the participant how to use the objects but did not interact with them in any other way. Participants were given two warm-up trials and five experimental trials. Warm-up trials contained a sequence of three actions but did not contain an unnecessary action. Experimental trials contained two necessary actions and one unnecessary action (see Table S2 for a description of the actions in each trial).

During each trial, E showed the participant a picture of D with the completed goal and said '*Look at Lauren, she has a [toy elephant]. Lauren is going to show you how she [got the elephant out of the box]. Watch her carefully and then you will get a turn'.* Words in [ ] were altered to be appropriate to each trial. At this point, D entered the testing area and sat opposite the participant with the apparatus on the table in front of her. She demonstrated the sequence of necessary and unnecessary actions to complete the action goal (as described in Table S2). Once complete, D looked at the participant and smiled before putting up a screen and resetting the apparatus. Once reset, E gave the instructions *'Can you [get the elephant out]? Do it as quickly as you can.'* D then removed the screen and walked out of the testing area while the participant completed the task. The instruction to complete the task 'as quickly as you can' differs from the 'your turn' instruction used in many previous overimitation tasks. Our instructions emphasised speed and the goal of the action in order to maximise the goal-directed nature of the task. Previous tests of different instructions [S4] suggest that typical children continue to overimitate when the task instructions are changed or when competition is emphasised.

The current study also explored the role of ostensive signals in overimitation. Previous studies have shown that ostensive cueing provides important information when children decide what to imitate [S5, S6]. We hypothesised that in the typically developing children, a clear ostensive signal such as eye contact, immediately prior to the performance of an unnecessary action might increase the propensity to imitate that action. Therefore, each trial included one eye contact event in which D paused during her demonstration and looked directly at the child for approximately one second before looking down and continuing with the demonstration. The timing of eye contact was counterbalanced between the different action types, apparatus types and conditions. Eye contact did not influence overimitation in either TD or ASC participants (CA-match: $t(141)=1.24$, $p=0.22$; VMA-match: $t(137)=0.21$, $p=0.84$; ASC: $t(148)=0.76$, $p=0.45$), so all other analyses reported in this paper are collapsed across eye contact condition.

Following the five experimental trials, participants were then given a rationality discrimination task. The major motivation for including this task was to test for the possibility that children with autism have *better* causal reasoning than typical children, and to test if better casual reasoning might drive lower overimitation. In this task, children were asked to rate one necessary and one unnecessary action from each sequence. They were first shown a scale with the numbers from one to five along the bottom with a picture of a man in a suit above the number one and a picture of a clown above the number five. The scale was explained to them as ranging from 'very sensible' (E points at the suited man) to 'very silly' (E points at the clown) or somewhere in between (E points at the numbers two to four). D then came and demonstrated the actions one at a time and the participant was asked to rate it as sensible or silly by pointing at the scale. E recorded the response and gave praise on every trial.

In addition to the tests of overimitation and rationality discrimination, participants completed the British Picture Vocabulary Scale (BPVS-II, [S3]) for VMA-matching. In order to explore the relationship between overimitation and theory of mind ability, ASC participants also completed a standard theory of mind battery, including six false belief questions and six trials of a penny hiding task as used in [S7].

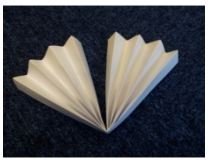
*Data Coding and Analysis*

The entire testing session was video recorded and coding was completed retrospectively. All participants correctly completed the warm-up trials. Correct goal achievement was recorded if the participant was able to open the box or build the object. Performance was 100% for the TD children on all tasks. One child with ASC failed to retrieve the duck or build the block tower due to increased sensory interest in the objects, and two children with ASC failed to make the fan, instead folding the paper in the wrong way. For these participants, their imitation score was computed as a proportion of the number of trials that they did complete. Overall performance for the ASC group was 97%. Overimitation was scored from the videos. On each trial, a participant was given a score of 1 if he/she completed the unnecessary action and a score of 0 if he/she did not. Scores were summed to give a participant overimitation score range from 5 to 0. All coding was completed by two independent researchers and reliability between coding was good (Cohen's kappa = 0.95).

A rationality discrimination score was calculated for each trial by subtracting the participant's rating of the necessary action in the sequence from his/her rating of the unnecessary action. This score therefore ranges from -4 to 4 and indicates the degree to which the participant is able to discriminate necessary and unnecessary actions, with higher scores indicating good discrimination and zero scores indicating chance performance. Each participant's mean rationality discrimination score was calculated for further analysis.

Analysis of overimitation and rationality discrimination was conducted using separate univariate ANCOVAs for comparisons between the each of the TD groups and the ASC group. Group membership (TD or ASC) was entered as a between-subjects variable in each model. When comparing the VMA-matched group to the ASC group, raw BPVS score was added as a covariate and when comparing the CA-matched group to the ASC group, age was entered as a covariate. Main effects of group are presented in the main text of this article. No effects of age, BPVS or interactions between these and group membership were found.

**Table S2:** Description of rational (R) and irrational (IR) actions on each trial.

| **Goal** | **Action 1** | **Action 2** | **Action 3** |
|---|---|---|---|
| **Warm-Up trials** | | | |
| Make a pattern with beads on the rack | Place bead 1 onto a peg | Place bead 2 on top of bead 1 | Place bead 3 on top of bead 2 |
| Put doll into a container | Remove lid from container | Put doll into the container | Put lid back on container |
| **Experimental trials** | | | |
| Retrieve toy duck  | Unclip fastenings of box (R) | Tap the top of the box twice with index finger (IR) | Remove the lid of the box and retrieve duck (R) |
| Retrieve toy elephant  | Remove elastic band (R) | Slide box along the table and back again (IR) | Remove the lid of the box and retrieve elephant (R) |
| Retrieve toy lion  | Pull box towards you (R) | Stroke the top of the box twice with index finger (IR) | Remove the end of the box and retrieve lion (R) |
| Build tower of blocks  | Place block 1 in centre of table (R) | Turn block 2 360° in your hands (IR) | Place block 2 on top of block 1 and place block 3 on top of block 2 (R) |
| Make a paper fan  | Gather up concertina paper (R) | Tap paper on the table twice (IR) | Fold the paper in half to produce a fan (R) |

**Supplemental Results**

*Overimitation*

As reported in the main text, children with ASC showed less overimitation than the CA-matched or VMA-matched typically developing children. To ensure that the four children without a confirmed diagnosis on the SCQ are not driving this difference, we performed the analyses again with these children excluded. The results remain unchanged (CA-match v. ASC subgroup: $F(1,53)=12.9$, $p=0.004$) and VMA-match v. ASC subgroup: ($F(1,53)=6.2$, $p<0.01$)). Furthermore, following the exclusion of these four participants the groups remain matched for chronological age (CA-match: $t(55)=0.66$, $p=0.51$) and verbal mental age (VMA-match: $t(55)=0.70$, $p=0.49$).

The number of children who failed to overimitate on any trial varied between groups. In the chronological age-matched group 7 children did not overimitate at all, this is compared to 12 children in the VMA-matched group and 17 in the ASC group.

*Rationality Discrimination Score*

The rationality discrimination score was calculated by subtracting the ratings of the necessary actions from the ratings of the unnecessary actions. As reported in the main text, both CA-matched and VMA-matched typically developing groups were better at discriminating action rationality than the ASC group. These results remain unchanged when the four ASC children without SCQ diagnosis are excluded from the sample (CA-match v. ASC subgroup: $F(1,53)=22.8$, $p<0.001$) and VMA-match v. ASC subgroup: ($F(1,53)=10.6$, $p=0.002$). Despite the poorer performance of the ASC group, all three groups performed significantly above chance on the rationality discrimination score. Histograms of the ratings given by each group are presented in Figure S1. Both groups of TD children rated almost all the necessary actions as 1 and rated the unnecessary actions as 4 or 5. Children with ASC are performing this task in a similar way, with the majority of responses falling at the extremes of the scale. However, they are also making more errors than the TD children, scoring more necessary actions as 5 and unnecessary actions as 1. This can account for the reduced rationality discrimination scores found in the ASC group. As children with ASC are performing significantly above chance on this measure, we conclude that they do understand the rating scale and are able to make judgements about the rationality of actions, yet they do not discriminate rational and irrational actions as clearly as TD children. There is no evidence that reduced overimitation in autism is driven by better detection of action rationality or by better casual reasoning.

In order to control for the effects of rationality discrimination ability on overimitation, all analyses were repeated with rationality discrimination score included as a covariate. The group difference between the typically developing groups and the ASC group remains unchanged (CA-match: F(1,57)=6.19, p=0.02 ; VMA-match: F(1,57)=4.74, p=0.03). Furthermore, the effect of rationality discrimination score on overimitation was not significant (CA-match: F(1,57)=1.42, p=0.24; VMA-match: F(1,57)=0.46, p=0.50). This suggests that overimitation is independent of a child's ability to discriminate which actions are necessary or unnecessary in a sequence. This finding is compatible with a social explanation of overimitation behaviour rather than an object learning or casual reasoning explanation.

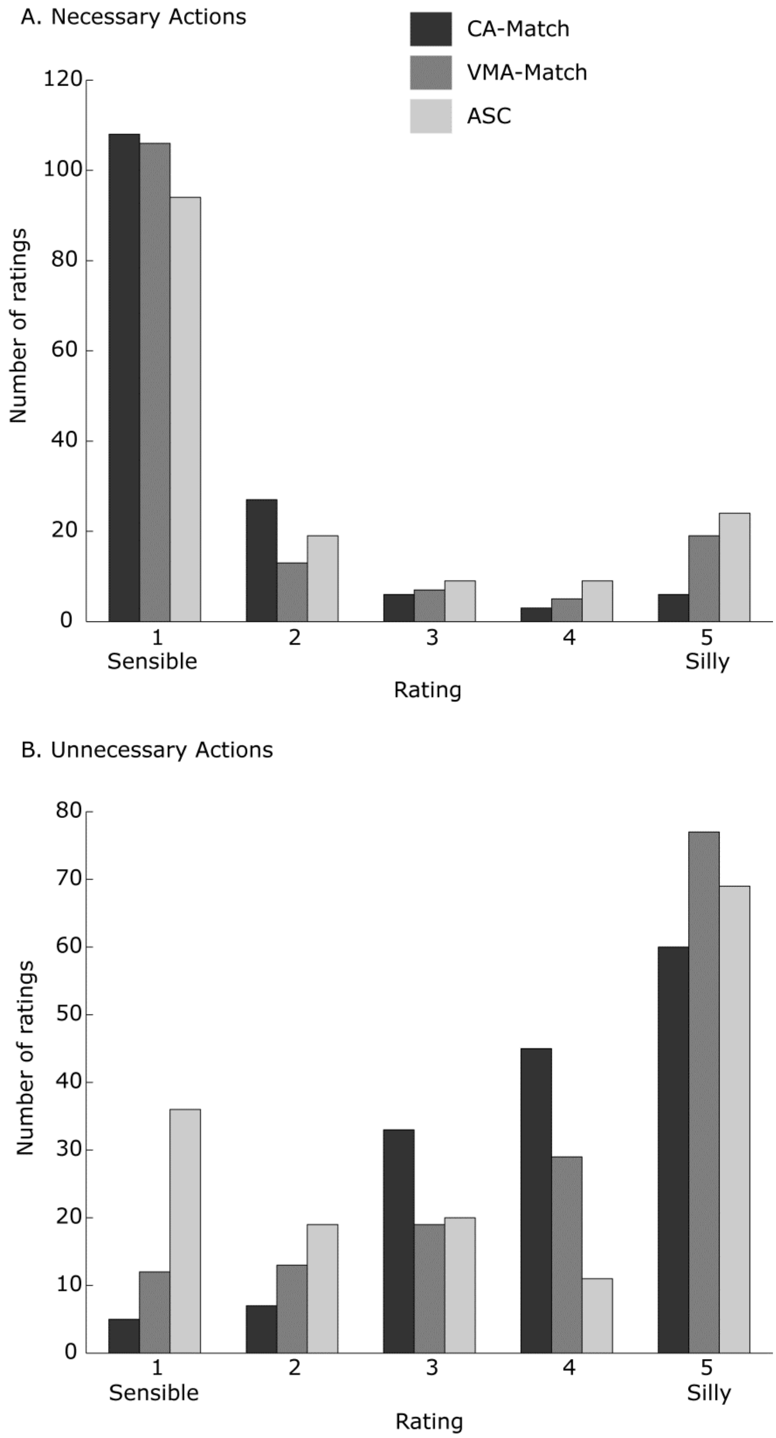



**Figure S1**, (related to Figure 1). Histograms of rationality ratings for necessary (panel A) and unnecessary (panel B) actions as given by CA-matched TD participants (dark grey bars), VMA-matched participants (mid-grey bars) and ASC participants (light grey bars).

*Predictors of imitation*

We also investigated what factors predict a child's overimitation score. Children with autism completed a battery of theory of mind tasks [S7] and their parents completed the lifetime version of the SCQ. These measures were not available for the typically developing children due to time constraints. A composite theory of mind score was generated for each child, averaging performance on the false belief tasks and the penny hiding tasks. We used linear regression to test if overimitation performance in children with autism was predicted by their age, BVPS score, ToM score, SAS score or SCQ score. In total this model accounted for a significant proportion of the variance in overimitation scores ($R^2$=0.44, p=0.02). However, no single variable was a significant predictor (age: t=0.41, p=0.68; bpvs: t=1.93, p=0.07; theory of mind: t=0.67, p=0.51; sas: t=0.02, p=0.99; SCQ: t=1.30, p=0.21). Note that our sample size of 31 is small for this type of analysis, and further study of the relationship between overimitation and other measures of social cognition would be valuable.

**Supplemental Discussion**

Overimitation is considered by some as a form of learning about objects that might have a role in cultural transmission of knowledge [S8] and in dealing with the problem of learning about causally opaque objects by means of pedagogy [S9]. However, these accounts are hard to apply to the simple, familiar, causally transparent objects used in our study. More recently, there has been a focus on the social nature of overimitation [S10]. There is increasing evidence for parallels between childhood overimitation behaviour and adult mimicry behaviour [S11]. Mimicry in adults leads to increased liking [S12] and is commonly believed to be driven by a motivation to affiliate with others [S13]. There is less direct evidence that the same motivation to affiliate drives overimitation in children, but this is highly plausible [S10, S14]. An alternative social reason for overimitation could be the child's desire to conform to the group norm [S15].

Our overimitation task uses familiar, causally transparent objects and children were instructed to behave in a goal-directed fashion. Ostensive and communicative cues were carefully controlled and all children understood that the unnecessary actions were 'silly'. This means that it is hard to explain the typically developing children's overimitation in terms of object learning. A social account is much more plausible. However, the data in our task and many previous studies do not distinguish between a motivation to affiliate with others and a motivation to conform to a group norm.

The results from the present study contrast with those recently reported in [S16] who show high rates of overimitation in children with ASC. This is despite both studies aiming to test the same hypothesis in children with autism with similar ability profiles. There are several possible reasons for this difference. First, the types of objects used in the two studies are very different. The present study used simple, familiar objects that were transparent in both their causal mechanism and their physical appearance. Furthermore, we directly test whether the children understood the causal nature of the actions demonstrated. In contrast, Nielsen et al. used objects that were causally opaque in their mechanism and provide no check for participants' understanding. It is possible therefore, that the overimitation reported by Nielsen et al. reflects object learning as well as social imitation and it is the object learning that drives imitation in ASC children. A second difference between the studies is that the unnecessary actions in the present study were simple hand actions, whereas the unnecessary actions in the Nielsen et al. study involved the use of a tool. There is little previous research directly investigating the use of tools in overimitation compared to the use of unnecessary hand actions. The simple hand actions used in our study remove the need for object learning and causal reasoning about actions, and provide a cleaner measure of social imitation.

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