Adults with Autistic Spectrum Condition benefit and enjoy learning via social interaction as much as neurotypical adults do

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Abstract

Background: People with Autistic Spectrum Condition (ASC) show poor processing of social signals (i.e. about the social world). But how do they learn via social interaction?

Methods: 68 neurotypicals adults and 60 adults with ASC learned about obscure items (e.g. exotic animals) over zoom i) in live video-call with the teacher, ii) from a recorded learner-teacher interaction video and iii) from a recorded teacher-alone video. Data was analysed via analysis of variance and multi-level regression models.

Results: Live-teaching provided the most optimal learning condition, with no difference between groups. Enjoyment was the strongest predictor of learning: both groups enjoyed significantly more in live interaction and reported similar level of anxiety across conditions.

Limitations: Some of our participants in the ASC group were self-diagnosed – however, further analysis where these participants were excluded showed the same results. Recruiting participants over online platforms may attract people who are generally keen to participate in a social interactive experiments, including a potential bias in our sample. Future work should investigate this question in a sample recruited via diverse sources (e.g. schools).

Conclusions: These findings strongly advocate for a distinction between learning about the social versus learning via the social: models of ASC should be revisited to consider social interaction not just as a puzzle to de-code, rather a medium through which people, including neuro-diverse groups, experience the world around them.

Trail registration: Part of this work has been pre-registered before data collection https://doi.org/10.17605/OSF.IO/5PGA3

Introduction

We live in a world that is more digital by the day. With the rise in online learning, which has seen an impetus since the Covid-19 pandemic, it is important to understand what social contexts best support learning across a wide range of populations. We have recently showed that social interaction boosts learning in neurotypical (NT) adults (De Felice et al., 2021). Here, we ask whether the same live-learning advantage would be replicated in a sample of adults with Autistic Spectrum Condition (ASC).

ASC is a heterogeneous group of neurodevelopmental conditions manifesting in infancy or early childhood (American Psychiatric Association, 2013). While the constellation and severity of symptoms can vary significantly across individuals, the main common feature of people with ASC is disruption of processes crucial in communication and social interaction, including implicit imitation (Edwards, 2014), joint attention (Roos et al., 2008), pragmatic language use (Whitehouse et al., 2007) and affect sharing (Happé & Frith, 2014). Vivanti and Rogers (2014) identified three aspects of social learning, which may be specifically impaired in people with ASC. Namely, social learning is characterised by being 1) implicit (without explicit instructions, e.g. via imitation), 2) intrinsically rewarding and 3) flexible (use social signals adaptively according to the communicative contexts, e.g. Senju et al., 2013). While the implicit aspect of Vivant & Rogers’ definition of social learning may be less relevant here – as we are interested in declarative learning of non-social knowledge (De Felice et al., 2022) –, the rewarding and the flexible nature of social exchange may be part of the interactive-learning advantage (or the lack of it) over less interactive contexts. In fact, clinical and experimental observations found that people with ASC show disrupted processing on both social rewarding (Corbett et al., 2014) and flexible behaviour (Semrud-Clikeman et al., 2010).
The social motivation hypothesis argues that people with ASC engage less in social contexts as they do not find these rewarding (Chevallier et al., 2012; G. Dawson et al., 1998; Mundy & Newell, 2007; Čeponiene et al., 2003). However, a meta-analysis of 13 fMRI studies found disrupted rewarding processes in autistic people for both social and non-social signals (Clements et al., 2018), suggesting that there may be a global deficit in reward processing. Other evidence suggests that people with ASC cannot flexibly adapt their attention to use social signals in social learning contexts (Spengler et al., 2010). Again, this may be due to a general attentional processes and repetitive and restrictive interests, including but not limited to the social world. Sasson et al. (2008) presented NT and autistic children with some complex social and non-social scenes. Autistic children looked at fewer images, fixated each image for longer and were much more detail-oriented, irrespectively of whether stimuli were social or non-social. Similarly, a study on eye-gaze and word-learning found that children with ASC were able to follow the gaze of the instructor as well as NT children, but they use it in qualitatively different ways: while NT children were able to infer the social informativeness of gaze (resulting in higher semantic learning of the object-word), children with ASC used eye-gaze mainly as an associative aid to consolidate phonological feature of the word, and showed significantly less contingent gaze-to-object fixation (Norbury et al., 2010).

Taken together, this evidence predict that people with ASC would fail to show an interactive-learning advantage (either because live interaction is less rewarding or because it may be harder to attend to compared to less interactive situation). However, this conclusion is mainly drawn from evidence on implicit learning of social material (e.g. language, Fitch et al., 2010; Seyfarth & Cheney, 2014). In fact, motor learning, observational learning and imitation (Bandura, 2019) have been extensively studied both in children and adults with ASC (M. Dawson et al., 2007; Pearson, 2004; Webb et al., 2017), and overall results are consistent in finding idiosyncratic processing associated with ASC. What remains unclear is whether acquisition of non-social knowledge benefit from social interaction equally in people with ASC as in NT. To the best of our knowledge, this question remains unexplored empirically.

In this study, we compare learning performance during three different social learning conditions (one live and two recorded), where learning-content is always delivered online by a (human) teacher (similar to De Felice et al., 2021). In all conditions, participants are explicitly instructed to learn facts about obscure items (e.g. exotic animals). In the live condition, participant joins a live video-call where they can interact with the teacher. In the recorded-observant condition, participant learns the material from a pre-recorded video of a previous session (observant a previously recorded student-teacher interaction). In the recorded-alone condition, participant learns the material from a pre-recorded video the teacher alone.

We expect to replicate results from our previous study (De Felice et al., 2021), showing live-learning advantage in NT adults. With regards to people with ASC, according to the literature showing social cognition deficits, one could speculate that no advantage in the live condition would be observed in this group. However, this speculation would be based on studies which mainly looked at implicit learning of social content, in contrast to declarative interactive learning of non-social knowledge. We therefore do not have strong predictions about ASC performance. We first present results from a pilot study and then show findings from a larger pre-registered replication.

1. EXPERIMENT 1

2.1 METHODS

2.1.1 Design

This study aims to investigate whether 1) participating in a live learning session improves learning online compared to recorded videos of either a previous interaction or of a teacher alone and ii) whether these conditions impact learning
differently in adults with ASC compared to neurotypicals. To answer these questions, this study adopted a 2 (group) x 3 (learning condition) x 2 (time) repeated-measures design, with between- and within-subjects factors. The between-subjects factor is group (Autistic Spectrum Condition (ASC) vs neurotypical (NT)), the within-subjects factors are i) learning condition (live vs recorded of another social learning episode vs recorded of the teacher alone), and ii) time of recall (immediate vs delay quiz). Specifically, facts about 15 items were presented with two minutes per item. Five items were assigned to each condition: 1) live condition: participant participated in a live video-call when they learned in interaction with the teacher; 2) recorded-observant condition: participant was shown a pre-recorded video of the teacher presenting the learning material to a student (confederate); 3) recorded alone condition: participant was shown a pre-recorded video of the teacher alone presenting the learning material (Figure 1). Learning score (outcome measure) for each participant was obtained from a multiple-choice quiz (see Materials). Items assigned to each condition and trial order within each condition remained fixed for the whole duration of this experiment. Order of conditions were randomised across participant.

2.1.2 Materials

A selection of 15 items were selected from De Felice et al., (2021), three from the exotic food category (Rambutan, Kiwano, Cherimoya), four from the antiques category (Strigil, Porte-joupe, Scotch Hands, Chatelaine), four from the animals category (Tarsier, Axolotl, Glaucus, Anhinga) and four from the musical instruments category (Kalimba, Caxixi, Agogo, Hulusi). Each condition presented a mixture of objects from these categories, which remained fixed for all participants for this experiment, as follow: 1) live condition [Tarsier, Kalimba, Strigil, Axolotl, Rambutan]; 2) recorded-observant condition [Porte-joupe, Kiwano, Caxixi, Scotch Hands, Glaucus]; 3) recorded-alone condition [Agogo, Cherimoya, Anhinga, Chatelaine, Hulusi]. Learning was tested via the same multiple-choice quiz used in De Felice et al., (2021). Full details of item information and multiple-choice quiz are reported in Appendix Table 1.

2.1.3 Procedure

Participants recruitment

This study was approved by the UCL ethic committee. Participants were recruited via the online platform Prolific (www.prolific.co). The platform retains demographic details as well as information on any disabilities/diagnosis of users, as reported by the users at the time of account registration. Such anonymous information can be used by researchers to create adverts targeting a specific pool. Two separate adverts were published: one targeting neurotypical participants and one targeting people with Autistic Spectrum Disorder (ASC). As a further check, users who responded to our adverts were asked to confirm their diagnosis via a questionnaire on Gorilla Experiment Builder (www.gorilla.sc). To ensure that the experimenter was blind to participants’ diagnosis, recruitment was done by a researcher who was not involved in data collection.

To be eligible, all participants had to i) be fluent in English (speaking English regularly for >5 years); ii) be aged 18-65; iii) give consent to having their camera and microphone on; and iv) give consent to being recorded for the whole duration of the experiment. Participants were paid at the hourly rate of £7.50 for a total of £15 over two hours. An additional £3 were offered for those who completed a 10 min quiz a week later.

Participants who responded to our advert were asked to complete four main parts: 1) background battery (independently online, on Gorilla Experiment Builder), 2) learning session (over a video-call), 3) online learning multiple-choice quiz immediately after the learning session (independently online on Gorilla Experiment Builder), and 4) repeat the quiz a week later.
**Background Battery**

Users who responded to the Prolific adverts were redirected to Gorilla Experiment Builder (www.gorilla.sc) where they received instructions on the study and gave consent for participation. They then completed the Background Battery tasks. This comprises of i) Spot-the-word test, a measure of verbal fluency (Baddeley et al., 1993), ii) matrix reasoning item bank (MaRs-IB), a measure of non-verbal reasoning (Chierchia et al., 2019) and iii) Animated Triangle test, a measure of mentalising (Abell et al., 2000; White et al., 2011).

Upon completion of the Background battery task, an independent researcher sent the participant ID to the experimenter (teacher), who arranged a video-call with the participant (via Prolific chat), while remaining blind to their diagnosis.

**Video-call**

The experimenter greeted the participant and checked that audio and video worked properly. Participant was asked to open the zoom window in full-screen mode and chose the gallery view (i.e. everyone in the call is shown equal size, this ensured that view during live session was comparable to view during pre-recorded video watching). Participants were told that the aim of the study was to investigate how people learned online and whether this differed in people with ASC, and were asked not to disclose any personal information to the teacher, who was blind to their diagnosis. The experimenter then explained that the participant will learn some facts about exotic food, animals, antiques and rare musical instruments over three formats: in live interaction with the teacher (live condition), and through watching of pre-recorded videos showing either the teacher with a previous participant (recorded-observant condition) or the teacher alone (recorded-alone condition). They were instructed to memorize as much information as possible, as at the end of the video-call they will complete a multiple-choice quiz to test their learning. During the live condition, participants were told that they were free to ask questions and interact with the teacher. Before starting the learning sessions, participant’s pre-knowledge was tested. If any item was known, it was excluded from the analysis (but not from the learning session). Learning sessions started with either the live, recorded-alone or recorded-observant condition, in a counterbalanced and semi-randomised order. The whole call lasted approximately 40 minutes (i.e. 10 minutes per condition, with 2 min per item and five items in each condition, plus 10 minutes for instructions).

**Learning quiz**

Immediately after the learning session, participants were redirected to Prolific, where their IDs were included into a ‘white list’, so that a new advert was visible to them only. By replying to that advert, participants were redirected to Gorilla Experiment Builder (www.gorilla.sc), where they reported on the quality of the video call (audio and video), before completing the learning quiz. After the learning quiz, they also completed an ‘enjoyment questionnaire’ and inclusion of other in self questionnaire (Aron et al., 1992). This part lasted approximately 20 minutes and was completed by the participant independently (note that the ‘immediateness’ of the quiz was ensured by the experimenter who terminated the video-call only a few moments later participant initiated the quiz part on Gorilla Experimenter Builder).

Exactly one week after the learning sessions, participants invited through Prolific to the final stage of the experiment, and directed to Gorilla Experimenter Builder to complete the same learning quiz. Additionally, participants filled in a history questionnaire, to check for potential revision of any of the items (e.g. search on Google). This part lasted approximately 10 minutes.

**2.2 RESULTS**

**2.2.1 Sample**
53 participants took part in the study (Table 2). Participants were excluded when reporting 3 or less on a 1 (poor) to 5 (excellent) video-call quality scale (N=3), and being visibly distracted during the video-call (N=1). Of the remaining 49 participants, 46 (N<sub>ASC</sub>=20, male=11, female=4, non-binary=4; N<sub>NT</sub>=26, male=11, female=15) completed the full experiment, including the one-week delay quiz (see 2.1 Design and 2.3 Procedure). We lost demographic data from one participant (ASC group) due to a technical fault.

Participant with ASC either received a diagnosis by a clinician (N=18) or were self-diagnosed (N=2). ASC and NT group did not differ on age (mean<sub>ASC</sub> (sd) = 27.79 (9.22), mean<sub>NT</sub> (sd) = 29.85 (9.90), t<sub>(43)</sub>=.71, p=.48), verbal fluency (Spot the word test, mean<sub>ASC</sub> (sd) = 47.63 (6.71), mean<sub>NT</sub> (sd) = 44.73 (6.23), t<sub>(43)</sub>=-1.48, p=.15) non-verbal reasoning (MaRs-IB, mean<sub>ASC</sub> (sd) = 64.48 (18.57), mean<sub>NT</sub> (sd) = 61.64 (16.98), t<sub>(43)</sub>=-.52, p=.60) and mentalising test (Animated Triangle, mean<sub>ASC</sub> (sd) = 9 (2.54), mean<sub>NT</sub> (sd) = 9.33 (1.92), t<sub>(43)</sub>=.38, p=.71). ASC scored significantly higher on AQ than NT (mean<sub>ASC</sub> (sd) = 33.37 (6.73), mean<sub>NT</sub> (sd) = 19.19 (7.29); t<sub>(43)</sub> = -6.73, p<.0001).

### 2.2.2 Data pre-processing

Single trials were excluded when: i) participants reported that they knew the item; ii) internet connection dropped during the single trial but was good for the rest of the experiment; iii) the experimenter reported incorrect information about the item; iv) participants reported revising information about a given item before the delay quiz (excluded from delay performance only). Performance was calculated for each learning condition separately, as an average over the included trials (score= points collected on all trials / total points available on all included trials).

### 2.2.3 Analysis of Variance

An analysis of variance (ANOVA) was run to test the difference in learning performance between 2 (groups: ASC and NT) x 3 (learning conditions: live, recorded-alone and recorded-observant) x 2 (time of learning quiz: immediate and delay). Means and SD for all conditions are reported in Table 3. Results for main and interaction effects are reported in Table 4 and Figure 2.

**Main effects.** Findings show a main effect of time: unsurprisingly, people remembered more things straight after the learning session (mean (sd) = 4.2(.58) than a week later (Mean=3.8, sd=.73; F<sub>(1,44)</sub>=56.16, p<.001, η<sup>2</sup>=.56, large effect size; Bakeman, 2005). More interestingly, we found a main effect of learning condition (F<sub>(2,43)</sub>=3.86, p=.03, η<sup>2</sup>=.15, medium effect size; Bakeman, 2005). The pairwise comparison revealed a significant learning advantage associated with Live compared to Recorded-alone condition (M<sub>Live</sub> (sd) = 4.1 (.09); M<sub>Recorded-alone</sub> (sd) = 3.9 (.1); t<sub>(44)</sub> = .19 p = .008). No other significant difference between learning conditions were found. No main effect was found for group: in other words, people with ASC showed a NT-equivalent performance (mean<sub>ASC</sub> (sd) = 4.01 (.09); mean<sub>NT</sub> (sd) = 3.99 (.1); t<sub>(44)</sub> =-.01 p=.93).

**Interaction effects.** No significant interaction effects where found between the main factors of interest (group, learning conditions and time). However, visualization of the data (Fig. 1.C) revealed a trend specific to ASC group: while immediate recall showed a similar pattern across conditions between groups, delayed recall dropped specifically for items learned during the Live condition for ASC group. A 2(group) x2(time) was therefore run to test the hypothesis that delay performance was significantly more affected for ASC compared to NT specifically for things learned during Live condition. Results revealed a group*time interaction effect: F<sub>(1,44)</sub>=4.88, p=.03, η<sup>2</sup>=.1): for things learned during Live
condition, a week later people with ASC recalled significantly less things compared to NT (mean_{ASC} (sd) = 3.75 (.18); mean_{NT} (sd) = 3.97 (.16)).

### 2.3 Conclusions from Experiment 1 & Hypothesis for Experiment 2

Experiment 1 found that for both NT and people with ASC, learning during Live session was associated with better recall both immediately after the session and one week later. In addition, it was found that the ASC group exhibits a decline in recall for items learned over Live interaction specifically, to a significantly greater extent than what was observed in the NT group.

Based on these results, a follow-up experiment was pre-registered (https://archive.org/details/osf-registrations-5pga3-v1) to confirm two main hypotheses:

1. Participants from both groups will learn more from live calls (Live condition) compared to pre-recorded video calls (Recorded-alone and Recorded-observant condition).
2. There will be an interaction between learning condition, group and time: while neurotypical adults will show a consistent advantage for interactive learning (Live condition) over time, the ASC group will show better immediate learning for material learnt in Live condition, and better long-term learning for materials learned from pre-recorded videos (Recorded-alone and Recorded-observant condition).

Experiment 2 consisted of two equal sub-experiments, which followed the same methods and procedure as experiment 1. Each sub-experiment was run by a different teacher.

### 3. EXPERIMENT 2

#### 3.1 RESULTS

##### 3.1.1 Sample

86 participants took part in this study (Table 2), split equally between two researchers playing the role of the teacher. Each researcher completed the recruitment for the other, so that each teacher was blind to the diagnosis of the student during data collection. Participants were excluded when reporting 3 or less on a 1 (poor) to 5 (excellent) video-call quality scale (N=4). The final sample included 82 participants (N_{ASC}=41, male=17, female=20, non-binary=4; N_{NT}=41, male=12, female=27, non-binary=2).

Participants in the ASC group either received a diagnosed by a clinician (N=13) or were self-diagnosed (N=28; see section below and appendix for further analysis excluding the self-diagnosed participants). The ASC and NT group did not differ on age (mean_{ASC} (sd) = 27.49 (5.13), mean_{NT} (sd) = 27.63 (4.91), t_{(80)}= .13, p=.89), verbal fluency (Spot the word, mean_{ASC} (sd) = 45.73 (9.83), mean_{NT} (sd) = 44.54 (8.46), t_{(80)}=-.59, p=.56), non-verbal reasoning (MaRs-IB, mean_{ASC} (sd) = 63.08 (18.68), mean_{NT} (sd) = 61.37 (17.26), t_{(80)}=-.43, p=.67) and mentalising test (Animated Triangle, mean_{ASC} (sd) = 9.37 (1.85), mean_{NT} (sd) = 9 (2.20), t_{(43)}=-.81, p=.42). ASC scored significantly higher on AQ than NT (mean_{ASC} (sd) = 28.39, (8.6), mean_{NT} (sd) = 19.98 (6.74); t_{(80)}=-6.73, p<.0001).

##### 3.1.2 Analysis of Variance

An analysis of variance (ANOVA) was run to test the difference in learning performance between 2 (groups: ASC and NT) x 3 (learning conditions: live, recorded-alone and recorded-observant) x 2 (time of learning quiz: immediate and
Main effects. Findings show a main effect of time: unsurprisingly, people remembered more things straight after the learning session (mean (sd) = 4.22 (.6)) than a week later (mean (sd) = 3.83 (.08); F(1,80)=38.56, p<.0001, η²=.32, large effect size; Bakeman, 2005). More interestingly, there was a main effect of learning condition (F(2,80)=13.53, p<.0001, η²=.15, large effect size; Bakeman, 2005). Pairwise comparisons revealed that Live interaction condition was the one associated with the highest learning, while Recorded-observant condition was associated with the worst learning: specifically, there was a significant learning advantage associated with Live compared to Recorded-observant condition (M_Live (sd)= 4.16 (.06); M_Recorded-observant (sd) = 3.86 (.07); t(80)=.29, p<.0001), and an advantage approaching significance level compared to Recorded-alone condition (M_Recorded-alone (sd) = 4.06 (.08); t(80)=.10, p=.08). Recorded-observant condition was associated with significantly worse performance than Recorded-alone condition (t(80)=-.19, p=.001). No main effect was found for group: in other words, people with ASC showed NT-equivalent performance (M_ASC (sd) = 4.12 (.09); M_NT (sd) = 3.93 (.09); t(44)=.19, p=.13).

Interaction effects. No significant interaction effects were found between the main factors of interest (group, learning conditions and time). Data visualisation showed a similar pattern across groups and times, with Recorded-observant condition producing the worst learning performance in both groups.

To summarise, this experiment found support for hypothesis 1, showing that for both NT and people with ASC, learning during Live session was associated with better recall over time. In contrast, hypothesis 2 was not supported: ASC and NT group showed the same pattern of performance over time, with learning over Recorded-observant condition being associated with the worst performance for both groups.

4. COMBINED ANALYSIS

In the previous section we presented results from experiment 1 (N=46) and experiment 2 (N=82). Overall, in both experiments we found that learning in Live video-call was associated with the best performance for both groups. However, while experiment 1 showed a significantly greater decline in recall over time for ASC specifically for things learned in Live condition (as compared to NT), experiment 2 did not confirm this pattern. In this section we present a combined analysis using mixed-linear effect regression model to better understand the effect of social learning online in ASC and NT over time.

4.1 RESULTS

4.1.1 Sample

The combined dataset included a sample of 128 participants (Table 2, NT N= 67; ASC N= 61). For the ASC group, either received a diagnosed by a clinician (N=31) or were self-diagnosed (N=29). All analyses were also run by excluding the self-diagnosed participants in the ASC group, and as results did not differ, here we report the full sample including the self-diagnosed participants (for results considering only participants who were clinically-diagnosed refer to Appendix, Table 2, 3 and 4). The ASC and NT group did not differ on age (mean_ASC (sd) = 27.58 (6.2), mean_NT (sd) = 28.49 (7.27), t(125)=.73, p=.46), verbal fluency (Spot the word, mean_ASC (sd) = 46.33, (8.95), mean_NT (sd) = 44.61 (7.63), t(125)=.64, p=.24) and non-verbal reasoning (MaRs-IB, mean_ASC (sd) = 63.52 (18.50), mean_NT = 61.47 (17.02); t(80)=.65, p=.51) and mentalising test (Animated Triangle, mean_ASC (sd) = 9.27 (2.03), mean_NT (sd) = 9.08 (2.13), t(43)=-.49, p=.62). ASC scored significantly higher on AQ than NT (mean_ASC (sd) = 29.97 (8.33), mean_NT (sd) = 19.67 (6.91),
\( t_{(125)} = -7.61, \ p < .0001 \). We also confirmed that teacher was not a significant factor for learning performance \( (F_{(2,126)} = .55, \ p = .58) \), ensuring the dataset could be combined into one despite being collected by different experimenters.

**Table 0.1 Demographics for dataset from Experiment 1, 2 and combined**

Sample size (N), age, AQ score and performance on background battery tests for neurotypical (NT) and Autistic Spectrum Condition (ASC) group. Note that higher the AQ score, greater the autistic traits. 1. (Baddeley et al., 1993) 2. (Chierchia et al., 2019) 3. (Livingston et al., 2021) 4. (Baron-Cohen et al., 2001).
### Experiment 1 (N=46)

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### 4.1.2 Mixed-linear regression model
We use AQ as a continuous measure of autistic traits to minimise any confound arising from the fact that our ASC group included both self-diagnosed and clinically-diagnosed participants. Models were run in Matlab R2020b using the function `fitlme`. Full outcomes for both models are reported in table 5.

First, we built a model to predict learning performance from learning condition (Live vs Recorded-observant vs Recorded-alone) along with others variables including autistic traits (AQ), mentalising (Animated Triangle test), verbal fluency (Spot the word test) and non-verbal reasoning (MaRs-IB) measures, while controlling for variability coming from the teachers and individual participants:

\[
\text{Learning} \sim \text{Condition} + \text{AQ} + \text{Animated Triangle} + \text{Spot the word} + \text{MaRs-IB} + (1 \mid \text{Participant}) + (1\mid\text{Teacher})
\]

Results confirmed ‘Condition’ as being a significant predictor of learning performance (beta = -.07, \( p = .003 \)). In addition, we found that both verbal fluency (Spot the word test, beta = .02, \( p = .002 \)) and non-verbal reasoning (MaRs-IB, beta = .01, \( p = .0003 \)) were significant predictors of learning performance. This is not surprising: these measures have been linked to fluid cognition and intelligence (Baddeley et al., 1993; Chierchia et al., 2019), which has been robustly associated with learning and academic performance more generally (Primi et al., 2010). With regards to measures of autistic traits (AQ) and mentalising (Animated Triangle), we did not find any significant effect, in line with the previous analysis of variance showing no difference between neurotypical and ASC group.

Second, in addition to the predictors included in Model 1, we included a measure of Enjoyment and a measure of Anxiety, as well their interaction with learning condition.

\[
\text{Learning} \sim \text{Condition} + \text{AQ} + \text{Animated Triangle} + \text{Spot the word} + \text{MaRs-IB Enjoyment} + \text{Enjoyment*Condition} + \text{Anxiety} + \text{Anxiety*Condition} + (1 \mid \text{Participant}) + (1\mid\text{Teacher})
\]

These measures were collected via participant self-report questionnaires after they completed the experiment: Enjoyment measure reflected a score from 1 to 5 for the question ‘How much did you enjoy learning from the experimenter during [the video-call? / the pre-recorded video?]’ (1 = Not at all, 5 = Extremely much); Anxiety measure reflected a score from 1 to 5 for the question ‘How much anxious / uncomfortable did you feel when you learned [live from the experimenter? / from the recorded video of another participant? / from the recorded video of the experimenter only?]’ (1 = Not at all, 5 = Extremely much).

Results show that Enjoyment was a significant predictor of learning for both groups (beta = .23, \( p = .0005 \)), with people enjoying live interaction (M (sd) = 4.58 (0.71)) significantly more than learning from pre-recorded videos (M (sd) = 3.91 (0.95), \( t_{(128)} = 7.52, p<.00001 \)). We also found Enjoyment*Condition interaction effect approaching significance (beta = -.05, \( p = .07 \)), with Enjoyment boosting Learning performance slightly more for the Live Condition than Recorded (Figure 5.A), although this is hard to interpret given that we only have Enjoyment scores for Recorded condition overall (i.e. our questionnaire did not make a distinction between Observing and Teacher-Alone condition). Interestingly, compared to Model 1, Condition was no longer a significant predictor of learning performance (beta = -.07, \( p = .089 \)). Anxiety was not found to be a significant predictor of learning. Neither Enjoyment nor Anxiety scores differ between groups (Figure 5.B and 5.C).

**Table 0.2 Sample size (N), Means and SDs for all conditions for Experiment 1, 2 and combined**

Mean number of items recalled at test (max of 5) for each condition for neurotypical (NT) and Autistic Spectrum Condition (ASC) group for each Experiment and for combined datasets.
### Experiment 1 – Recall scores

<table>
<thead>
<tr>
<th>Neurotypical (NT)</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate: Live</td>
<td>26</td>
<td>4.26</td>
<td>.10</td>
</tr>
<tr>
<td>Immediate: Recorded-observant</td>
<td>26</td>
<td>4.10</td>
<td>.12</td>
</tr>
<tr>
<td>Immediate: Recorded-alone</td>
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<tr>
<td>+1week: Live</td>
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<td>+1week: Recorded-observant</td>
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<td>.16</td>
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<td>+1week: Recorded-alone</td>
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<td>3.71</td>
<td>.14</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Autistic Spectrum Condition (ASC)</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate: Live</td>
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<td>.12</td>
</tr>
<tr>
<td>Immediate: Recorded-observant</td>
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<td>.14</td>
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<tr>
<td>Immediate: Recorded-alone</td>
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<td>4.15</td>
<td>.17</td>
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<tr>
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<td>.18</td>
</tr>
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<td>+1week: Recorded-observant</td>
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<td>+1week: Recorded-alone</td>
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### Experiment 2 – Recall scores

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<th>Mean</th>
<th>SD</th>
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</thead>
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<tr>
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<td>.08</td>
</tr>
<tr>
<td>Immediate: Recorded-observant</td>
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<td>3.93</td>
<td>.10</td>
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<tr>
<td>Immediate: Recorded-alone</td>
<td>42</td>
<td>4.15</td>
<td>.10</td>
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<tr>
<td>+1week: Live</td>
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<td>3.84</td>
<td>.12</td>
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<td>+1week: Recorded-observant</td>
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</tr>
<tr>
<td>+1week: Recorded-alone</td>
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</table>

<table>
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<tr>
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<td>.10</td>
</tr>
<tr>
<td>Immediate: Recorded-alone</td>
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<td>4.33</td>
<td>.10</td>
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<td>+1week: Recorded-observant</td>
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<td>+1week: Recorded-alone</td>
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<td>4</td>
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### Combined – Recall scores

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<th>Mean</th>
<th>SD</th>
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<tr>
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<td>---</td>
<td>------</td>
<td>----</td>
</tr>
<tr>
<td>Immediate: Recorded-observant</td>
<td>68</td>
<td>4</td>
<td>.08</td>
</tr>
<tr>
<td>Immediate: Recorded-alone</td>
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<td>4.13</td>
<td>.08</td>
</tr>
<tr>
<td>+1 week: Live</td>
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<td>3.89</td>
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</tr>
<tr>
<td>+1 week: Recorded-observant</td>
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<td>3.67</td>
<td>.10</td>
</tr>
<tr>
<td>+1 week: Recorded-alone</td>
<td>68</td>
<td>3.75</td>
<td>.10</td>
</tr>
</tbody>
</table>

**Autistic Spectrum Condition (ASC)**

<table>
<thead>
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<th></th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
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<tr>
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<tr>
<td>Immediate: Recorded-alone</td>
<td>60</td>
<td>4.27</td>
<td>.09</td>
</tr>
<tr>
<td>+1 week: Live</td>
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<td>3.93</td>
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</tr>
<tr>
<td>+1 week: Recorded-observant</td>
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<td>+1 week: Recorded-alone</td>
<td>60</td>
<td>3.89</td>
<td>.11</td>
</tr>
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</table>

**Table 4 Results from the linear mixed-effects models**

Outcome of the linear mixed-effects regression models. **Model 1**: Learning ~ Condition + AQ + Animated Triangle + Spot the word + MaRs-IB + (1 | Participant) + (1|Teacher); **Model 2**: Learning ~ Condition + AQ + Animated Triangle + Spot the word + MaRs-IB Enjoyment + Enjoyment*Condition + Anxiety + Anxiety*Condition + (1 | Participant) + (1|Teacher).
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<th>Model</th>
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<th>df</th>
<th>p-value</th>
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<th>Upper bound</th>
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<td>.003</td>
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<tr>
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<td>Verbal fluency (Spot the word)</td>
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<td>.02</td>
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<td>.006</td>
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<td>.002</td>
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<td>Non-verbal reasoning (Matrix reasoning item bank, MaRs-IB)</td>
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<td>.01</td>
<td>.002</td>
<td>.002</td>
<td>750</td>
<td>.0003</td>
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<td></td>
<td>Mentalising (Animated Triangle)</td>
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<td>-.01</td>
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<td>.02</td>
<td>750</td>
<td>.91</td>
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<td></td>
<td>Autistic Quotient (AQ)</td>
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<td>.003</td>
<td>.005</td>
<td>.14</td>
<td>750</td>
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<td>.07</td>
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<td>746</td>
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<tr>
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<td>Enjoyment*Condition</td>
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<td>-</td>
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<td>.02</td>
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<td>746</td>
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### 5. DISCUSSION

Recently, we found evidence for social interaction boosting learning in neurotypical (NT) adults in online contexts (De Felice et al., 2021). Here we asked whether the same interactive-learning advantage would replicate in adults with Autism Spectrum Condition (ASC). Previous literature on ASC has mainly focused on infancy and childhood, and studied social learning (e.g. imitation and observation, Bandura, 2019) of social knowledge (e.g. face perception: M. Dawson et al., 2007; Webb et al., 2017; or language: Norbury et al., 2010; Whitehouse et al., 2007). To the best of our knowledge, this is the first large empirical investigation to test interactive-learning of non-social factual knowledge in adults with ASC. We tested learning over two blinded experiments (one pre-registered) in 128 adults, equally split in NT and ASC group, as they were presented with facts about documentary-like content over zoom in three conditions (figure 1): in a live video-call with the teacher (interactive condition), by watching a recorded video of a previous student-teacher session (recorded-observant condition) and by watching a recorded video of the teacher alone (recorded-alone condition).

We report two main findings: first, overall and across groups, learning in live video-call was significantly greater than learning over pre-recorded videos, in line with our pre-registered hypothesis and replicating results from our previous study (De Felice et al., 2021). Second, the interactive-learning advantage was present in participants with ASC too, in accordance with our pre-registered hypothesis 1: in fact, adults with ASC not only showed NT-equivalent performance overall, but benefitted from learning in live video-call over pre-recorded video as much as NT adults did. With regards to our pre-registered hypothesis 2, the present data does not support it: we found no difference between groups in learning-advantage over time. In other words, pattern observed for learning across condition was similar when tested immediately after the session and one week later.
There are a number of mechanisms (e.g. attention, mutual-understanding) that may be supporting learning in a contingent learner-teacher interaction (De Felice et al., 2022). Our investigation does not allow to disentangle these different mechanisms, nor to interpret NT and ASC group performance with reference to specific cognitive processes. Overall however, the mechanisms identified as possible candidate to explain the interactive-learning benefit – including attention, social motivation and reward, mentalising and arousal – have been found to various degrees to be abnormal in ASC (Abell et al., 2000; Clements et al., 2018; Hamilton & Lind, 2016; Hill, 2004; Klin, 1991; Webb et al., 2017; White, 2013). This would predict poorer learning in ASC in social contexts. However, our results robustly contradict this prediction. If the cognitive processes implicated in social interactive learning are also those typically disrupted in ASC, why do we still find that participants with ASC learned as well as NT in our study? We identified two possible explanations: i) people with ASC showed NT-equivalent performance, but at greater cost (compensatory hypothesis); ii) while people with ASC may struggle to learn about ‘the social’, they benefit from learning via ‘the social’ as much as NT do (about-the-social versus via-the-social hypothesis).

First, let’s consider the possibility that equivalent learning between groups comes at greater cost for people with ASC (compensatory hypothesis). Both hyper- or hypo-arousal during social information processing has been associated with autistic people (Yi et al., 2022). People with ASC also show abnormalities in executive function, sensory processing and emotional regulation (Fernandez-Prieto et al., 2021; Kilroy et al., 2019; Semrud-Clikeman et al., 2010). This may result in the social environment being cognitively demanding for autistic people, and would predict that they may show discomfort and/or less enjoyment during the task, despite overall NT-equivalent performance. Results however reject this interpretation. ASC group enjoyed the experiment as much as NT, and significantly more when learning in the interactive condition compared to the less-interactive ones (pre-recorded videos). Crucially, anxiety level during the task also did not significantly differ between the two groups nor across learning conditions. Instead, we suggest that this data supports the about-the-social vs via-the-social hypothesis. The majority of the past literature has failed disentangle these two mechanisms experimentally: previous experimental work looked at how people with ASC either learn about the social, or – e.g. in imitation studies – make implicit use of social signals to learn. In contrast, the present work disentangled the means through which explicit learning occurs from the object of learning: this may have allowed ASC to benefit from the same interactive mechanisms supporting learning in NT. While the present data does not allow us to identify the specific process, or set of processes, responsible for supporting learning in interactive contexts, it robustly showed how crucial it is to separate the medium through which we learn from the content of learning, and how contingent social interaction in online context can act as a catalyst across a variety of neuro-population, inclusive of ASC groups.

This work has the strength of studying a novel question in a large sample, with findings robustly replicated over two separate experiments and three different blinded teachers. Results are ground-breaking in that they demonstrate, for the first time, that adults with ASC not only benefit but also enjoy learning via live-interaction more than from recorded videos. Some considerations however must be made to place these findings within the appropriate panorama. Participants with ASC who took part in this study were all high-functioning individuals, including a number of self-diagnosed participants (although results did not differ when these participants were excluded), and conclusions may not extend to the entire autism population. Moreover, recruiting participants over online platforms may attract people who are generally keen to participate in a social interactive experiments, while leaving out those people who are less likely to engage in social interaction (either because they struggle more or because they enjoy it less). Future work should investigate this question in a sample recruited via diverse sources (e.g. schools).

Our results predicts that the interactive-learning advantage would also apply to in-person contexts. The present study – despite being online – resembled more the typical in-person situation: participants did not engage with any of the defining characteristics of a typical e-learning experience, e.g. pausing, repeat, forwarding etc. We however
acknowledge that other aspects specific to in-person interaction, e.g. arousal due to physical proximity (Lougheed et al., 2016; McBride et al., 1965), may play a role in learner-teacher interaction, and online versus face-to-face contexts should be directly tested.

In conclusion, we showed that people with high-functioning ASC benefit and enjoy learning in interactive contexts as much as NT people do, and did not report being more anxious in any of our social interactive conditions. The present work has implications for classic cognitive models of social learning, arguing for a distinct separation of the context through which learning occurs from the content of learning. Designing experiments which explicitly separate these two factors is essential to better understand the underlying cognitive mechanisms supporting interactive social learning in both neurotypical as well as neuro-diverse populations. This in turn would help identify specific dysfunctions of social cognition, without making assumptions about a certain condition in relation to one factor (e.g. via-the-social) based solely on the other (e.g. about-the-social). Practical implications for pedagogy include re-thinking about how we deal with education in ASC.

Declarations

Ethics approval and consent to participate

This study was approved by the UCL ethic committee.

Consent for publication

Not applicable

Availability of data and materials

Experiment 1 was not preregistered; the preregistration for Experiment 2 can be accessed at https://osf.io/5pga3. Deidentified data for both experiments are posted at https://osf.io/5az7g/?view_only=27d98b16261f47a6a9e1c9de6c053660. The materials used in these studies available in Supplementary Material uploaded as a separate file with this submission.

Competing interests

The authors declare that they have no competing interests

Funding

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Authors' contributions

S.D.F. Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; A.Hatilova: Investigation, Writing – review &
Acknowledgements

We thank all participants who took part in this study.

References


Figures
Figure 1

Schematics of the three experimental conditions

Learning sessions are represented as appearing to participants. From left to right: Live condition, participant learn about 5 items as they interact with the teacher in a real-time video-call; Recorded-observant condition: participant learn about 5 item from a pre-recorded sessions with a confederate acting as a previous participant; Recorded-Alone condition: participant learn about 5 items from a pre-recorded session of the teacher alone. In each condition, participant learn about 5 different items. Items were assigned to each condition randomly and remained fixed within each experiment, and counterbalanced between experiments.

Figure 2

Results for Experiment 1

Results from dataset of Experiment 1. *p<.05; **p<.001; ***p<.0001  A. Boxplots of the three main factors of interest: Time, Learning condition and Group. B. Violin plots of learning performance immediately after the learning session (top)
and a week later (bottom), for the three learning conditions. Violins are split in half showing the distribution of NT (blue) and ASD (red) sample separately. C. Line plot for learning performance immediately after the learning session (top) and after one week (bottom), plotted separately for NT (blue) and ASD (red). Error bars represent the standard error of the mean.

Figure 3

Results for Experiment 2

Results from dataset of Experiment 2. *p<.05; **p<.001; ***p<.0001 A. Boxplots of the three main factors of interest: Time, Learning condition and Group. B. Violin plots of learning performance immediately after the learning session (top) and a week later (bottom), for the three learning conditions. Violins are split in half showing the distribution of NT (blue) and ASC (red) sample separately.
Figure 4

Results for combined analysis (Experiment 1 and 2)

A. Boxplots of the three main factors of interest across the two experiments: Time, Learning condition and Group. B. Violin plots of learning performance immediately after the learning session (top) and a week later (bottom), for the three learning conditions across the two experiments. Violins are split in half showing the distribution of NT (blue) and ASC (red) sample separately.
Figure 5

Enjoyment and Anxiety level across conditions and groups

A. Scatter plot of learning performance by enjoyment score for both groups, divided by condition (Live and Recorded, note: our questionnaire did not distinguish between the two recorded conditions). B. Box plots of enjoyment score divided by condition (Live and Recorded, note: our questionnaire did not distinguish between the two recorded conditions) and by group. C. Box plots of Anxiety score divided by condition and by group. All data plotted here refers to the combined sample (N=128; NT=67, ASC=61). ** p<.001

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx