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RESEARCH ARTICLE

# Comparing internal representations of facial expression kinematics between autistic and non-autistic adults

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## Abstract

Recent developments suggest that autistic individuals require dynamic angry expressions to have a higher speed in order for them to be successfully identified. Therefore, it is plausible that autistic individuals do not have a 'deficit' in angry expression recognition, but rather their internal representation of these expressions is characterised by very high-speed movement. In this study, matched groups of autistic and non-autistic adults completed a novel emotion-based task which employed dynamic displays of happy, angry and sad point light facial (PLF) expressions. On each trial, participants moved a slider to manipulate the speed of a PLF stimulus until it moved at a speed that, in their 'mind's eye', was typical of happy, angry or sad expressions. Participants were shown three different types of PLFs—those showing the full-face, only the eye region, and only the mouth region, wherein the latter two were included to test whether differences in facial information sampling underpinned any dissimilarities in speed attributions. Across both groups, participants attributed the highest speeds to angry, then happy, then sad, facial motion. Participants increased the speed of angry and happy expressions by 41% and 27% respectively and decreased the speed of sad expressions by 18%. This suggests that participants have 'caricatured' internal representations of emotion, wherein emotion-related kinematic cues are over-emphasised. There were no differences between autistic and non-autistic individuals in the speeds attributed to full-face and partial-face angry, happy and sad expressions respectively. Consequently, we find no evidence that autistic adults possess atypically fast internal representations of anger.

KEYWORDS
autism, emotion recognition, emotion representations, facial expression, kinematics

## INTRODUCTION

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterised by difficulties in social communication and restricted and repetitive interests (American Psychiatric Association, 2013). The question of whether autistic individuals ('condition-first' terminology is used throughout this manuscript in line with the preferences of the majority of the autistic community [Kenny et al., 2016]) exhibit atypical facial emotion recognition has been debated for over 30 years (see Harms et al., 2010; Keating & Cook, 2020; Uljarevic & Hamilton, 2013 for reviews). However, to date this literature has largely focused on the recognition of emotion from *static* face stimuli. This bias in the literature potentially reflects a broader bias across the entirety of the emotion perception literature. Indeed, it is well established that the spatial features of facial expressions (i.e., the configuration of facial features relative to one another) are important for emotion recognition and thus that emotion can be recognised from static snapshots of faces (Bassili, 1979; Ekman & Friesen, 1978; Frank et al., 1993; Wegrzyn et al., 2017). In contrast, a limited number of studies have investigated the influence of *dynamic* (changing over time) emotion cues such as the *temporal* order of face actions within a sequence (see Chen et al., 2021; Delis et al., 2016; Jack et al., 2014; Jack & Schyns, 2015), and facial movement *kinematics*, where kinematic information concerns all properties of movement except force and in the context of facial movement typically refers to speed, acceleration, and jerk (change in acceleration; see Sowden et al., 2021).

Recent developments in the facial emotion literature have started to tip this balance (e.g., Delis et al., 2016; Dobs et al., 2018; Jack et al., 2014; Jack & Schyns, 2015; Sowden et al., 2021). Consequently, dynamic information is increasingly considered a valuable source of cues with respect to emotion recognition. For instance, in a series of experiments with non-autistic participants, Sowden et al. (2021) demonstrated that facial movement kinematics (in this instance, speed) comprise important cues for emotion recognition. More specifically, these authors showed that across different facial actions (i.e., eyebrow widening, nose lengthening, lip raising, mouth widening and mouth opening) and emotional expression contexts (i.e., posed, spontaneous and communicative), happy and angry expressions were typically fastest, and sad expressions were slowest (Sowden et al., 2021). Importantly, Sowden et al. (2021) also demonstrated that kinematic cues play a causal role in facial emotion judgements. Their paradigm employed point-light displays (a series of dots that convey biological motion) of the face (point light faces; PLFs) that had been manipulated to achieve three spatial levels, ranging from reduced to increased spatial movement (50% spatial; 100%; 150%), and three kinematic levels, ranging from reduced to increased speed (50% speed; 100%; 150%). Sowden et al. (2021) demonstrated that speeding-up facial expressions promoted anger and happiness judgements and slowing-down expressions encouraged sadness judgments, thus the speed of movement of internal facial features influences observers' judgements of emotion.

In order to redress the bias towards the use of static stimuli in the ASD emotion recognition literature, our most recent work employed the paradigm developed by Sowden and colleagues to investigate emotion recognition from facial motion cues in ASD (Keating et al., 2021). There were two key findings from our recent study. First, autistic adults (relative to non-autistic adults who were matched on age, gender, non-verbal reasoning [NVR] and alexithymia) had significantly lower emotion recognition accuracy for angry, but not happy or sad, facial motion when PLFs were unmanipulated (i.e., when they were played at their normal (100%) speed and with normal (100%) degree of spatial movement across frames; Keating et al., 2021). Second, whilst for controls, recognition accuracy increased when angry facial motion was sped up from 50% to 100% speed and from 100% to 150% speed, the recognition accuracy of autistic participants only increased from 100% to 150% (and not from 50% to 100%; Keating et al., 2021). Note that since our groups were matched in terms of alexithymia (a subclinical condition, characterised by difficulties identifying and expressing emotions [Nemiah et al., 1976]) differences between our groups were related to autistic, not alexithymic, characteristics (for further discussion of this issue see Bird & Cook, 2013; Cook, Brewer, et al., 2013). In sum, we observed that autistic adults exhibited typical anger recognition for high speed (150%) PLFs, but reduced accuracy (relative to non-autistic adults) at a lower speed (100%).

Our recent findings therefore illustrate differences between autistic and non-autistic adults in emotion recognition from facial *kinematic* information (Keating et al., 2021). However, these differences are specifically restricted to anger and do not extend to happiness and sadness (Keating et al., 2021). Interestingly, this anger-specific difficulty is also mirrored in the static emotion recognition literature. A number of empirical studies indicate that the recognition of anger is particularly challenging for autistic individuals (Ashwin et al., 2006; Bal et al., 2010; Brewer et al., 2016; Leung et al., 2019; Song & Hakoda, 2018). Indeed, a meta-analysis of this literature suggests that there are greater differences between autistic and non-autistic individuals in the recognition of angry than happy and sad facial expressions (Lozier et al., 2014). Further to this, Song and Hakoda demonstrated that autistic children (relative to non-autistic children) require angry, but not happy or sad, expressions to have higher emotional intensity in order for them to be correctly identified (Song & Hakoda, 2018). More specifically, to estimate 'identification thresholds' (the intensity at which an expression is identified correctly on two consecutive trials) Song and Hakoda used static photographic stimuli at varying expressive intensities (constructed by repeatedly morphing a full expression with a neutral expression to result in nine intensity levels for each emotion) and asked participants to select which emotion most effectively described the emotion shown (out of six possible options). They found that, compared to their non-autistic counterparts, autistic children had significantly higher identification thresholds for angry expressions, meaning that a higher intensity was necessary before an expression could be reliably identified as angry. Importantly, there were no significant differences between the groups in identification thresholds for happiness or sadness (Song & Hakoda, 2018). These findings suggest that autistic individuals require a higher intensity of emotion before a *static* facial expression can be reliably identified as angry. At present there is no equivalent study for *dynamic* facial expressions.

Our recent results (Keating et al., 2021) raise the hypothesis that autistic adults may require a higher intensity of emotion before a *dynamic* facial expression can be reliably identified as angry. That is, our results clearly illustrated that autistic adults did not have a categorical 'deficit' in the recognition of anger (Keating et al., 2021). Rather, relative to controls, autistic participants required a higher speed before they could accurately identify angry expressions (Keating et al., 2021). It is therefore plausible that autistic adults do not have a 'deficit' in the recognition of angry expressions, but rather their internal representation of angry facial expressions (i.e., the speeds at which they would visualise these emotions in their 'mind's eye') is characterised by very high-speed movements (Keating et al., 2021).

Atypical internal representations of facial expressions could influence the accuracy of emotion recognition via multiple potential mechanistic pathways. For example, according to 'template matching' models of emotion labelling (see Brewer et al., 2016; Scherer et al., 2019), when trying to interpret an expression, one compares the physical features of the observed expression to one's own internal representations or expression 'templates' and 'reads off' the corresponding emotion label (Brewer et al., 2016). Consequently, correct labelling of the observed expression is more likely if the 'sender' and 'receiver' have matching internal representations of emotions (see Brewer et al., 2016; Cook, Blakemore, & Press, 2013). Thus, individuals with internal representations of emotion that are very common within the general population are more likely, on average, to correctly label observed expressions. Whereas correct emotion labelling may be reduced in individuals with uncommon internal representations. In this case, an abnormally high-speed representation of anger may lead to reduced accuracy in recognising 'normal speed' angry stimuli because only high-speed angry expressions match the observer's internal representation of anger. In addition, internal representations of facial expressions provide predictive information based on previous experience, that is, 'priors' (Jack et al., 2009, 2012; Jack & Schyns, 2015). Consequently, an abnormally high-speed representation of anger may lead to reduced accuracy in recognising 'normal speed' angry stimuli by acting as an atypical prior which biases subsequent perception of incoming face stimuli (Pellicano & Burr, 2012).

The question of why differences in autistic facial emotion recognition are specific to anger is a difficult one. If autistic individuals have internal representations of anger that are characterised by atypically high-speed movement, why would this be selective to anger, why is this not also the case for emotions such as happiness? One potential explanation relates to differences in facial information sampling. There is evidence to suggest that autistic individuals tend to avoid looking at the eye region of the face, and instead preferentially look at the mouth region (Klin et al., 2002; Riby et al., 2009; Rutherford et al., 2007; though also see Bird et al. (2011) for a debate concerning the role of alexithymia in explaining differences in autistic facial information sampling). Some researchers believe that this is a strategy that autistic individuals adopt to modulate amygdala activation (Kliemann et al., 2010; Perlman et al., 2011; Tottenham et al., 2014), which is often atypical in ASD in response to faces (Ashwin et al., 2007; Bookheimer et al., 2008; Corbett et al., 2009; Dalton et al., 2005; Hadjikhani et al., 2007; Monk et al., 2010; Nomi & Uddin, 2015; Weng et al., 2011), as the amygdala is highly responsive to the eye region of emotional facial expressions (Gamer & Büchel, 2009). Given that for anger the majority of expressive information is thought to be conveyed in the upper half of the face, around the eye region (Calder et al., 2000; Smith et al., 2005), autistic participants may require greater 'signal' (i.e., faster movement) when recognising anger because they are focusing on an information-poor part of the face (i.e., the mouth). This would not be the case for happy and sad because, for these emotions, the mouth comprises a more information rich part of the face (Du et al., 2014; Ekman & Friesen, 1978).

To investigate whether, compared to non-autistic adults, autistic adults have different internal representations of anger that are characterised by higher mean speed, the current study employed a novel emotion-based task which we refer to as the 'PLF slider task'. Using a method of adjustment design, participants were required to manipulate a sliding scale in order to speed-up or slow-down PLF stimuli until the stimuli matched their internal representation of anger, happiness and sadness. PLF stimuli were employed to facilitate comparisons between the current study and our previous study (Keating et al., 2021), to draw participants' attention to facial motion cues as opposed to static cues such as texture, luminance, and contrast, and because the use of point lights to represent particular facial landmarks simplifies the task of modulating facial speed in real time. This method estimates, for each participant, an index of mean percentage speed attribution. We hypothesised that, relative to control participants, autistic adults would attribute higher mean speeds to angry, but not happy or sad, stimuli. Furthermore, we reasoned that, if higher speed thresholds for anger, are driven by a focus on the mouth region—an information-poor part of the face with respect to anger recognition—differences between the ASD and control groups should disappear if participants are required to focus on information-rich parts of the face (i.e., the eye region). To test this hypothesis, we included a partial face condition, in which participants saw only the upper or lower face of the face on each trial.

# METHODS

See https://osf.io/sgxum for the pre-registration relating to this report.

## Participants

A total of 25 autistic and 25 non-autistic participants were recruited from the Birmingham Psychology Autism

Research Team database and Prolific. The pre-registered sample size was based on an a priori power analysis conducted using G*Power (Faul et al., 2007), which focuses on replicating the group-difference (Keating et al., 2021) in recognition accuracy (between ASD and control individuals) for angry videos at the normal spatial and speed level. Using data from our previous study (Keating et al., 2021), 25 participants are required in each group in order to have 80% power to detect an effect size of 0.719 (Cohen's *d*) at alpha level 0.05 for this group-difference in accuracy.

All participants in the ASD group had previously received a clinical diagnosis of ASD from an independent clinician. The level of autistic traits of 21 individuals in the ASD group was assessed using the Autism Diagnostic Observation Schedule (version 2; Lord et al., 2012). Of those who did complete the ADOS assessment, 16 met criteria for ASD (5 autism, 11 autism spectrum; mean ADOS-2 score = 9.62). Although, five individuals in the ASD group did not meet criteria for diagnosis according to the ADOS, they had previously received a clinical diagnosis of ASD and thus still participated in the study. Unfortunately, it was not possible to complete observational assessments on four ASD participants due to restrictions on face-to-face testing during the COVID-19 pandemic. The participants in the ASD group had significantly higher autism quotient (AQ) scores (Baron-Cohen et al., 2001) than those in the non-autistic group (see Table 1).

## Procedure

Participants completed our group-matching measures followed by the PLF slider task, both of which were administered online via Qualtrics and Gorilla.sc.

### Group-matching measures

To facilitate group-matching, participants provided information on age and gender, and completed the Toronto Alexithymia Scale (TAS; Bagby et al., 1994) and the Matrix Reasoning Item Bank (MaRs-IB; Chierchia et al., 2019), an 8-min assessment of NVR ability. The AQ (Baron-Cohen et al., 2001) was also completed to ensure that the autistic group were significantly higher in autistic traits. All of these measures were completed online.

### PLF slider task

The PLF slider task is a novel tool for the estimation of the mean speed of a participant's internal representation of emotional expressions. In this task, on each trial, participants are presented with a PLF stimulus video (on average, ~6 s in length) which was looped such that when the stimulus reached the end it played again from the beginning. Participants were instructed to 'move the slider to change the speed of this video until it matches the speed of a typical ANGRY/HAPPY/SAD expression' (note that participants were only asked to change the speed of the expression to match the emotion that was displayed in the stimulus video, i.e., on a trial where an angry facial expression was presented, participants were only asked to manipulate the speed of the video so that it matched the speed of a typical angry expression). Consequently, participants were matching the speed of the displayed PLF to their internal representation of that expression. Participants can change the speed of the video by moving a slider to the left (decrease speed) or right (increase speed) on a visual analogue scale ranging from 25% to 200% of the recorded speed. Once participants were satisfied that the speed of the video matched that of a typical angry/happy/sad expression, they could press the spacebar to continue. There was no time limit for participants to respond on each trial. This task indexes the percentage speed attributed, by participants, to each of the PLF stimulus videos (e.g., 125% speed).

The PLF stimulus videos (taken from Sowden et al., 2021 and Keating et al., 2021) were originally created by taking video recordings of four actors (two male, two female) verbalising sentences whilst posing the three target emotions (angry, happy and sad). These recordings were then fed into OpenFace (Baltrusaitis et al., 2018) from which the x and y coordinates of 68 facial landmarks were extracted at 25 frames per second. To create the PLF stimuli, Sowden et al. (2021) displayed successive frames of these coordinates as white dots on a black

**TABLE 1** Means, standard deviations (SDs) and group differences of participant characteristics

| | Control ($n = 25$) | ASD ($n = 25$) | Significance |
|---|---|---|---|
| Gender | 9 Female, 15 Male, 1 Other | 11 Female, 13 Male, 1 Other | $p = 0.842$ |
| Age | 27.57 (9.70) | 31.98 (9.88) | $p = 0.118$ |
| NVR | 63. 31 (15.75) | 55.59 (17.81) | $p = 0.111$ |
| TAS | 56.00 (12.97) | 57.96 (12.03) | $p = 0.582$ |
| AQ | 20.04 (7.17) | 34.60 (9.40) | $p < 0.001$ |

*Note*: In the central columns, means are followed by SDs in parentheses. Note that age is in years.
Abbreviations: NVR, Non-verbal reasoning; TAS, Toronto Alexithymia Scale; AQ, Autism Quotient.

background (using Cogent graphics for MATLAB) and saved these displays as video files. This resulted in four videos per emotion (i.e., one for each actor).

There were two main sections of the PLF slider task. In the first part of the task (the full-face condition), participants were shown full PLF stimuli made up of 68 white dots on a black background (see Supporting Information A). In the second part of the task (partial face condition), participants were shown partial PLF stimuli comprising 32 dots on a black background displaying either the eye or mouth region (see Supporting Information A). In the first part of this task (the full condition), participants were shown four repetitions of *full-face* PLF stimuli for each of the four actors, however, each repetition had a different starting speed (80%, 90%, 100% and 110% speed). The starting speed manipulation ensured that the point on the scale relating to the normal recorded (100%) speed was not always in the same spatial location. This resulted in 16 *full-face* videos per emotion (4 actors × 4 starting speeds × 3 emotions = 48 trial in total). Participants completed three practice trials (one for each emotion at 100% starting speed) and then the 48 randomly ordered experimental trials across three blocks. In the second part of the task (the partial face condition), participants were shown two repetitions of eye PLF stimuli, and two repetitions of mouth PLF stimuli, for each actor. The starting speeds for these repetitions were 80% and 100% speed respectively. This resulted in eight eye and eight mouth PLF stimulus videos per emotion. Participants completed 48 randomly ordered experimental trials (4 actors × 2 face areas × 2 starting speeds × 3 emotions = 48 trials in total) across three blocks.

## Score calculations

### Group-matching measures

Scores on the AQ and TAS were calculated as a sum of participants' responses whereby, in line with published standards for each questionnaire, some questions were reverse scored. Higher scores on the AQ (maximum score: 50) and TAS (maximum score: 100) reflect higher levels of autistic and alexithymic traits respectively. Scores on the MaRs-IB (NVR) were calculated as the percentage of correct responses within 8 minutes.

### PLF slider task

Before calculating percentage speed change and attributed speed (see below), we adjusted for the PLF starting speed. To do so, we multiplied the percentage speed attributed to the videos moving at 80% speed by 0.8, 90% speed by 0.9, and 110% speed by 1.1 (if a participant attributed 125% speed to a video with 80% starting speed, they actually attributed 100% speed to the video; $125 \times 0.8 = 100$; that is, they adjusted the speed of the video such that it played back at 100% of the speed at which it was recorded). This gave us 'adjusted percentage speed attributions'.

*Percentage speed change*

In order to index whether participants' internal representations of emotion were faster or slower than the 100% (natural) speed of the stimulus videos, we calculated percentage speed change. This index was calculated by subtracting 100 from all of the adjusted percentage speed attributions made by participants (e.g., if a participant attributed 73% speed to a video (after adjusting for starting speed), the percentage speed change would be −27%). Therefore, this index of percentage speed change reflects how much participants changed the speed of the PLF stimulus video relative to the speed it was recorded at (since we had already corrected for starting speed).

*Attributed speed*

In order to answer the question of whether autistic and non-autistic individuals have differing internal representations of angry, happy and sad dynamic facial motion in terms of speed, we needed to calculate the speed (in pixels per frame) that participants attributed to each of these emotions. We did this via three steps; (1) calculating the recorded speed in pixels per frame for each PLF stimulus; (2) calculating an attribution multiplier based on the participants' responses (i.e., based on percentage speed change) and finally (3) calculating attributed speed by multiplying the recorded speed of the PLFs with this attribution multiplier.

For step one, we followed procedures outlined in Sowden et al. (2021). The 12 different PLF videos (4 actors × 3 emotions) were fed into the open-source software OpenFace (Baltrusaitis et al., 2018) to identify the x and y coordinates (in pixels) of 68 facial landmarks, sampled at a rate of 25 Hz. Subsequently, key points (e.g., inner eyebrow) were identified and distances between these key points were calculated as the square root of the sum of squared differentials of the x and y co-ordinates of each key point. Next, these face distances were summed to create five face 'actions' (as in Zane et al., 2019 and Sowden et al., 2021) including inner eyebrow widening, nose lengthening, lip raising, mouth widening and mouth opening. Speed was calculated as the absolute value of the average change in distance between relevant points on the face for each face action across the whole video clip, and thus represents the absolute mean speed (pixels/frame) for each facial action, within the whole recording window. These speed vectors were low pass filtered at 10 Hz to include human movement signal and exclude noise associated with the MATLAB diff function. Since our speed measure concerns the movement of face actions (such as eyebrow widening) it represents the speed of movement of the internal features of the face, not the speed of rigid-body head movement. We focus on the internal features because we know that their movement speed is important in emotion recognition (Sowden et al., 2021). For the full-face videos, we calculated mean speed by taking an average for each video across all five facial actions. For videos in the partial face condition, we took an average of speed across the relevant facial action regions (e.g., averaging across eyebrow widening and nose lengthening for PLFs displaying the eyes, and averaging across lip raising, mouth widening and mouth opening for PLFs displaying the mouth).

Next, we transformed participants' responses to each of the full-face and partial face emotional videos into 'attribution multipliers' by dividing percentage speed change by 100 and then adding 1 to all the values (e.g., for a trial in which a participant has increased the speed of a video relative to the speed at which it was recorded by 40%, the attribution multiplier would be 1.4. For a trial in which a participant decreases the speed by 27%, the attribution multiplier would be 0.73). Following this, we calculated attributed speed by multiplying the 'attribution multiplier' by the mean speeds that we calculated (see above) for each of the full-face/partial-face emotional videos. Finally, we calculated the mean speeds attributed to the angry, happy and sad videos by taking an average across the videos for each emotion respectively.

## Statistical analyses

All frequentist analyses were conducted using SPSS (version 26) and all Bayesian analyses were conducted using JASP (version 0.11.1). Data, analysis files and preregistration are available online at https://osf.io/xa23h/. For all analyses, we used a $p = 0.05$ significance threshold to determine whether to accept or reject the null hypothesis. The frequentist approach was also supplemented with the calculation of Bayes Factors, which quantify the relative evidence for one theory or model over another. For all Bayesian analyses, we followed the classification scheme used in JASP (Lee & Wagenmakers, 2014), in which $BF_{10}$ values between one and three are considered weak evidence, between 3 and 10 as moderate evidence and greater than 10 as strong evidence for the alternative hypothesis. In addition, $BF_{10}$ values between 1 and $\frac{1}{3}$ are considered weak evidence, between $\frac{1}{3}$ and $\frac{1}{10}$ as moderate evidence, and smaller than $\frac{1}{10}$ as strong evidence for the null hypothesis respectively (Lee & Wagenmakers, 2014).

### Group demographics

Independent samples *t* tests were used to assess possible group differences in age, NVR, TAS and AQ. A chi-squared test was used to test for group differences in gender.

### PLF slider task

To test our first hypothesis, we conducted two mixed $2 \times 3$ analysis of variance (ANOVA), with the between-subjects factor *group* (ASD, control) and the within-subjects factor *emotion* (angry, happy, sad). In the first of these ANOVAs, we used percentage speed change as our dependent variable (DV), and in the second we used mean attributed speed as our DV. To test our second hypothesis, we conducted two mixed $2 \times 2 \times 3$ ANOVAs with the between-subjects factor *group* (ASD, control), and the within-subjects factors *face area* (eyes, mouth) and *emotion* (angry, happy, sad). As before, in the first of these ANOVAs, we used percentage speed change as our DV, and in the second we used mean attributed speed.

# RESULTS

## Group demographics

Participants were matched on age, gender, NVR and alexithymia. The ASD group were significantly higher in autistic traits. In order to ensure that there were no outliers in survey scores, we verified that each of the participants' scores on the AQ, TAS and MaRs-IB were no more than three SDs away from their group mean. Descriptive statistics for each of these groups, in addition to group comparison statistics are presented in Table 1. Information about participants' ethnicities is reported in Table 2.

## PLF slider task

### Percentage speed change analyses

In order to compare the extent to which autistic and non-autistic individuals increased/decreased speed of emotional expression PLFs, we conducted a mixed $2 \times 3$ ANOVA with the between-subjects factor *group* (ASD, control) and the within-subjects factor *emotion* (angry, happy, sad), and with percentage speed change as the DV. This analysis revealed a main effect of *emotion* ($F(2,96) = 84.78$, $p < 0.001$, $\eta_P^2 = 0.64$, $BF_{10} = 2.58e^{25}$; Figure 1), with participants speeding up angry expressions the most (mean (SE of the mean (SEM)) = +41.10% (3.33)), followed by happy expressions (mean (SEM) = +26.78% (2,47)), and slowing down sad expressions (mean(SEM) = −17.64% (3.37)). Importantly, we identified no main effect of *group* ($t(48) = 0.67$, $p = 0.669$, mean difference = 1.26%, $BF_{10} = 0.20$) and, contrary to our hypothesis, no *emotion* × *group* interaction ($F(2,96) = 2.14$, $p = 0.135$, $\eta_P^2 = 0.04$, $BF_{10} = 0.90$; Figure 1). Since our $BF_{10}$ value only provided weak evidence to support the null hypothesis, we proceeded to unpack this interaction. This showed that there were no

**TABLE 2** Ethnicity data for autistic and non-autistic participants

| Ethnic group | Autistic ($N = 25$) | Non-autistic ($N = 25$) |
|---|---|---|
| White English/Welsh/Scottish/Northern Irish/British | 21 | 3 |
| White Hungarian/Greek | 1 | 0 |
| White European | 1 | 2 |
| Mixed/Multiple Ethnic Groups—White and Black Caribbean | 1 | 0 |
| White Polish | 0 | 6 |
| White Italian | 0 | 3 |
| White Portuguese | 0 | 2 |
| White/Caucasian | 0 | 2 |
| White Slavic | 0 | 1 |
| White Albanian | 0 | 1 |
| Black African | 0 | 1 |
| Asian Pakistani | 0 | 1 |
| Asian Indian | 0 | 1 |
| Mixed/Multiple Ethnic Groups—White and Asian | 0 | 1 |
| Mixed/Multiple Ethnic Groups—Other | 0 | 1 |
| Prefer not to say | 1 | 0 |

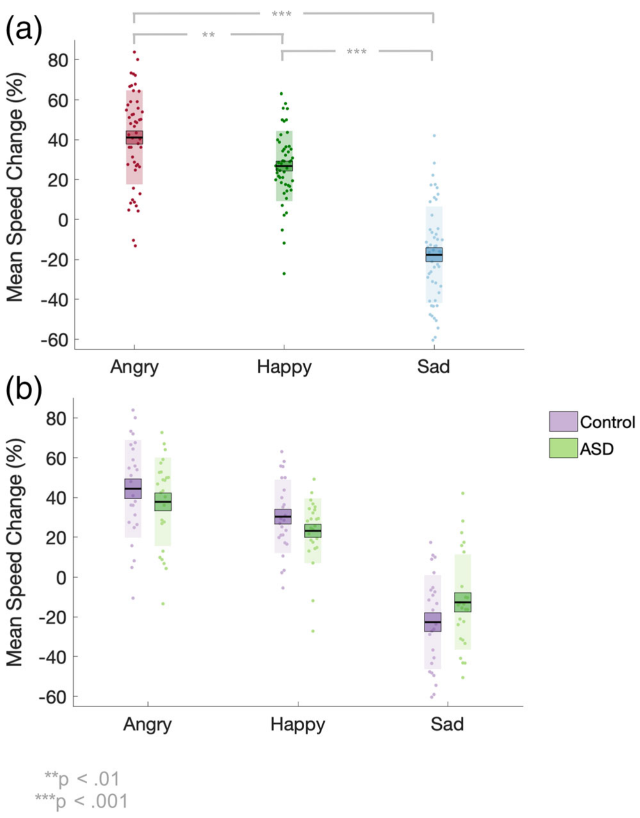


**FIGURE 1** (a) Mean percentage speed change attributed to each target emotion for all participants. (b) Mean percentage speed change attributed to each target emotion for control (lilac) and autistic (green) participants respectively. In both graphs, the black line represents the mean, the shaded region represents one SD. The coloured box represents one SE around the mean and the dots represent individual datapoints

significant differences between the groups in the percentage speed change (even before Bonferroni-correction) for angry ($t(48) = 0.99$, $p = 0.326$, mean difference = 6.60%, $BF_{10} = 0.42$), happy ($t(48) = 1.45$, $p = 0.154$, mean difference = 7.15%, $BF_{10} = 0.67$) or sad ($t(48) = -1.48$, $p = 0.145$, mean difference = −9.99%, $BF_{10} = 0.69$) facial motion. Notably, in conflict with our hypothesis, percentage speed change for anger was numerically higher in the non-autistic relative to autistic participants (non-autistic mean (SEM) = +44.40% (4.70%); autistic mean (SEM) = +37.79% (4.70%)).

In the following additional analyses, the DV (percentage speed change) is calculated only from the trials in the partial face condition. To analyse this data, we conducted a mixed 2 × 2 × 3 ANOVA with the between-subjects factor *group* (ASD, control), and the within-subjects factors *face area* (eyes, mouth) and *emotion* (angry, happy, sad) in order to compare the percentage speed change for the eye and mouth regions of the emotional expressions across groups. Once again we identified a main effect of *emotion* ($F(2,96) = 75.464$, $p < 0.001$, $\eta_P^2 = 0.61$, $BF_{10} = 2.65e^{46}$), with participants speeding up the eye and mouth regions most for angry (mean (SEM) = +31.84% (3.61)), followed by happy expressions (mean (SEM) = +20.97% (2.54)), and slowing down these regions for sad expressions (mean (SEM) = −23.77% (3.61)). In addition, this analysis found no main effect of *group* ($t(48) = 0.56$, $p = 0.575$, mean difference = 2.01%, $BF_{10} = 0.17$), or *face area* ($F(1,48) = 3.75$, $p = 0.059$, $\eta_P^2 = 0.07$, $BF_{10} = 0.14$), no *face area* × *group* interaction ($F(1,48) = 0.02$, $p = 0.900$, $\eta_P^2 = 0.00$, $BF_{10} = 0.17$), or *face area* × *emotion interaction* ($F(2,96) = 1.34$, $p = 0.266$, $\eta_P^2 = 0.03$, $BF_{10} = 0.07$), and finally no *face area* × *emotion* × *group* interaction ($F(2,96) = 0.27$, $p = 0.270$, $\eta_P^2 = 0.01$, $BF_{10} = 0.12$). Our analysis also revealed that the *emotion* × *group* interaction was not significant ($F(2,96) = 1.81$, $p = 0.178$, $\eta_P^2 = 0.04$, $BF_{10} = 2.43$) however since Bayesian statistics provide weak evidence for the presence of an emotion × group interaction, we ran post-hoc independent samples *t* tests. This identified that there were no significant differences between autistic and control participants in percentage speed change (before Bonferroni-correction) for angry ($t(48) = 1.28$, $p = 0.205$, mean difference = 9.27%, $BF_{10} = 0.55$), happy ($t(48) = 0.99$, $p = 0.330$, mean difference = 5.00%, $BF_{10} = 0.42$), or sad ($t(48) = -1.14$, $p = 0.260$, mean difference = −8.24%, $BF_{10} = 0.48$; see Figure 2) displays when the eyes and mouth were grouped together (as would be the case in the emotion × group interaction). Once again, contrary to our hypothesis, percentage speed change for anger was numerically higher in non-autistic relative to autistic participants (non-autistic mean (SEM) = +36.48% (5.11%); autistic mean (SEM) = +27.21% (5.11%)).

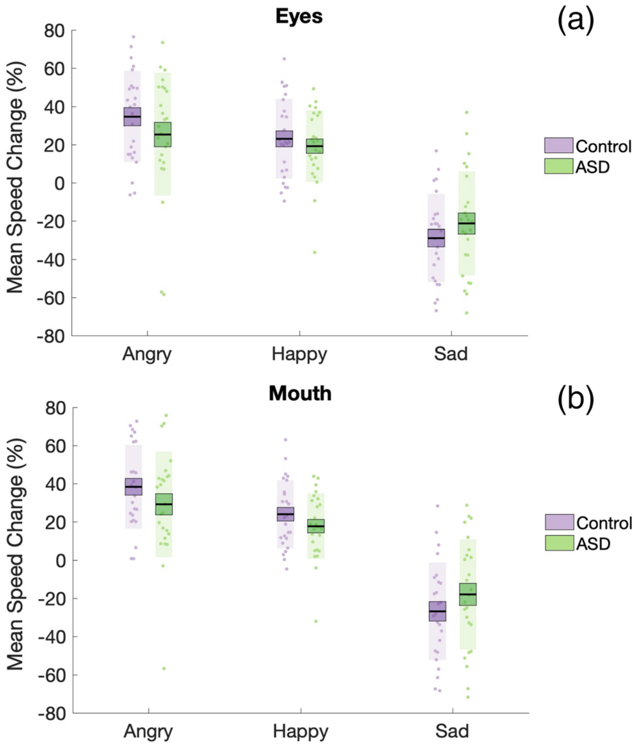


**FIGURE 2** Mean percentage speed change attributed to each target emotion for the eyes (panel a) and mouth (panel b) for control (lilac) and autistic (green) participants. In both graphs, the black line represents the mean, the shaded region represents one SD. The coloured box represents one SE around the mean and the dots represent individual datapoints

## Attributed speed analyses

In order to compare the mean speed attributed to the emotional expressions by autistic and non-autistic individuals, we conducted a mixed 2 × 3 ANOVA with the between-subjects factor *group* (ASD, control) and the within-subjects factor *emotion* (angry, happy, sad), and with mean attributed speed as the DV. This analysis revealed a main effect of *emotion* ($F(2, 96) = 254.61$, $p < 0.001$, $\eta_P^2 = 0.84$, $BF_{10} = 5.46e^{49}$), with participants attributing the highest speeds to angry (mean (SEM) = 3.18(0.08) pixels/frame), followed by happy (mean (SEM) = 2.21(0.04) pixels/frame), and finally sad (mean (SEM) = 1.18(0.05) pixels/frame) expressions. Importantly, we identified no main effect of *group* ($t(48) = 0.721$, $p = 0.475$, mean difference = 0.04 pixels/frame, $BF_{10} = 0.20$) and, contrary to our hypothesis, no *emotion × group interaction* ($F(2,96) = 1.74$, $p = 0.189$, $\eta_P^2 = 0.04$, $BF_{10} = 0.60$). Since our Bayes Factor only provided weak evidence to support the null hypothesis, we proceeded to unpack this interaction. This showed that there were no significant differences between the groups in the speeds attributed to angry ($t(48) = 0.97$, $p = 0.337$, mean difference = 0.15 pixels/frame, $BF_{10} = 0.42$), happy ($t(48) = 1.38$, $p = 0.172$, mean difference = 0.122 pixels/frame, $BF_{10} = 0.61$) or sad ($t(48) = -1.55$, $p = 0.128$, mean difference = −0.15 pixels/frame, $BF_{10} = 0.75$) facial motion (note that the stats shown are before Bonferroni-correction). Notably, in conflict with our hypothesis, autistic participants attributed numerically lower speeds to angry facial motion than their non-autistic counterparts (autistic mean (SEM) = 3.11 pixels/frame(0.11 pixels/frame); non-autistic mean (SEM) = 3.26 pixels/frame(0.11 pixels/frame)).

In the following additional analyses, the DV is calculated only from the trials in the partial face condition. To analyse this data, we conducted a mixed 2 × 2 × 3 ANOVA with the between-subjects factor *group* (ASD, control), and the within-subjects factors *face area* (eyes, mouth) and *emotion* (angry, happy, sad) in order to compare the mean speed attributed to the eye and mouth regions of the emotional expressions across groups. Once again we identified a main effect of *emotion* ($F(2,96) = 221.54$, $p < 0.001$, $\eta_P^2 = 0.82$, $BF_{10} = 9.60e^{17}$), with participants attributing the highest speed to angry (mean (SEM) = 2.70 (0.07) pixels/frame), followed by happy (mean (SEM) = 1.96 (0.04) pixels/frame), and finally sad (mean (SEM) = 1.01 (0.05) pixels/frame) expressions. In addition, this analysis identified a main effect of *face area* ($F(1,48) = 3732.59$, $p < 0.001$, $\eta_P^2 = 0.99$, $BF_{10} = 1.25e^{46}$), with the highest speeds attributed to the mouth region (mean (SEM) = 2.85 (0.04) pixels/frame), and the slowest speeds attributed to the eye region (mean (SEM) = 0.93 (0.02) pixels/frame). We also found a significant *emotion × face area* interaction ($F(2, 96) = 262.38$, $p < 0.001$, $\eta_P^2 = 0.85$, $BF_{10} = 4.99e^{41}$), which suggested that there was a larger effect of face area for happy ($F(1,48) = 1922.89$, $p < 0.001$, $\eta_P^2 = 0.98$, $BF_{10} = 4.17e^{52}$) and angry ($F(1,48) = 1266.40$, $p < 0.001$, $\eta_P^2 = 0.96$, $BF_{10} = 7.56e^{46}$) than sad ($F(1,48) = 331.58$, $p < 0.001$, $\eta_P^2 = 0.87$, $BF_{10} = 1.42e^{23}$) facial motion. Taken together, higher speeds were attributed to the mouth than eye region across all emotions, but this difference was greater for happy and angry than sad facial motion (see Figure 3). There was no main effect of group ($t(48) = 0.98$, $p = 0.334$, mean difference = 0.06 pixels/frame, $BF_{10} = 0.16$), no *emotion × group* interaction ($F(2,96) = 1.75$, $p = 0.188$, $\eta_P^2 = 0.04$, $BF_{10} = 0.09$) or *face area × group* interaction ($F(1,48) = 1.70$, $p = 0.199$, $\eta_P^2 = 0.03$, $BF_{10} = 0.18$), and finally no *face area × emotion × group* interaction ($F(2,96) = 1.71$, $p = 0.196$, $\eta_P^2 = 0.03$, $BF_{10} = 0.24$).

# DISCUSSION

The current study used a novel PLF slider task to investigate whether autistic and non-autistic individuals have differing internal representations of angry, happy and sad dynamic facial motion in terms of speed. In doing so, we identified that the participants, as a whole, attributed the highest speeds to angry, followed by happy, followed by sad expressions for both full-face and partial-face (eye and mouth) PLFs. More specifically, we found that on average, participants *increased* the speed of full angry expressions by 41%, *increased* the speed of full happy expressions by 27%, and finally *decreased* the speed of full sad expressions by 18%.

Our primary concern, however, was whether autistic and non-autistic individuals possess *differing* internal representations of the speeds of dynamic emotional expressions. We hypothesised that the ASD and non-autistic control group would attribute different mean speeds to full-face angry (and not happy or sad) expressions, that is we predicted an interaction between group and emotion. Our frequentist analyses showed that there was no significant group by emotion interaction in both the percentage speed change and attributed speed analyses. However, Bayesian analyses indicated that our data only provided anecdotal evidence in support of the null hypothesis (that there is *no* group × emotion interaction). To explore whether there was a trend towards a difference between the groups in the speeds attributed to angry expressions we unpacked the interaction. This revealed that there were no group differences in the speeds attributed to full-face happy, sad and, importantly, angry facial motion in both the frequentist and Bayesian analyses. Contrary to our hypothesis, for angry expressions thresholds were numerically higher for the non-autistic than for the autistic group. Thus, the evidence suggests that autistic and non-autistic individuals do not differ in their internal representations of the speed of angry facial motion.

In addition, in the partial-face condition (when participants either saw the mouth or eyes alone), our frequentist analyses identified that there was no group × emotion interaction. However, our Bayesian analyses indicated that our data provided anecdotal evidence for the presence of this interaction in the percentage speed change analysis. Importantly, unpacking this interaction demonstrated, once again, that there were no group differences in how much participants increased or decreased the speed of partial-face angry, happy and sad facial motion (in both frequentist and Bayesian analyses). Notably, in conflict with our hypothesis, percentage speed change for anger was numerically higher in the non-autistic relative to autistic participants. In addition, in our attributed speed analysis, our data provided strong evidence for the absence of a group × emotion interaction ($BF_{10} = 0.09$) in the partial-face condition. As such, it was apparent that when we accounted for the recorded speed of the eye and mouth expressions, the group × emotion interaction disappeared. Taken together, there were no group differences in how much participants increased or decreased the speed of partial-face angry, happy and sad facial motion, nor were there group differences in the speeds attributed to these partial-face expressions.

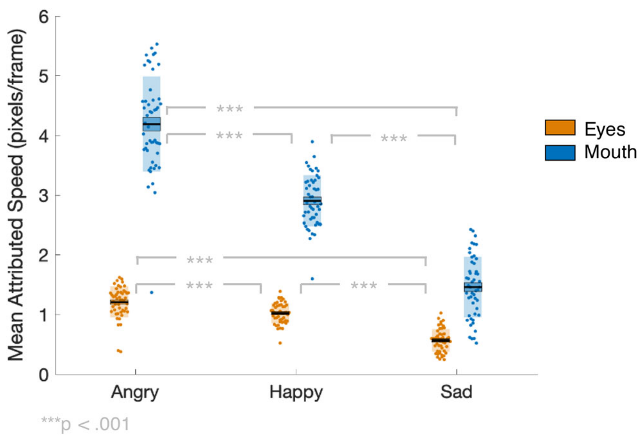


**FIGURE 3** Mean speed (pixels/frame) attributed to each target emotion for the eyes (orange) and mouth (blue). For each condition, the black line represents the mean and the shaded region represents one SD. The coloured box represents one SE around the mean and the dots represent individual datapoints

Our secondary concern was whether there would be significant group differences in the speeds attributed to the mouth, and not the eye, region for angry facial motion. We reasoned that if higher speed thresholds for anger were driven by a focus on the mouth region—an information-poor part of the face with respect to anger recognition—differences between the autistic and non-autistic participants should disappear if participants are required to focus on information-rich parts of the face (i.e., the eye region). Our results demonstrate that autistic and non-autistic participants attributed comparable speeds for all emotional expressions, irrespective of whether they saw information from the eye region, or mouth region alone. Indeed, our Bayesian analyses provide moderate evidence to support the null hypothesis, as shown by the Bayes Factors for the face area × emotion × group interaction in both the percentage speed change ($BF_{10} = 0.12$) and attributed speed ($BF_{10} = 0.24$) analyses. Therefore, we found no evidence to support our hypothesis that autistic and non-autistic participants would attribute different speeds for angry expressions in the mouth, but not eye, partial face condition.

One may query whether the current study would have observed significant differences between the groups if we had recruited an ASD sample that scored more highly in terms of autistic traits. We do not believe this to be the case for several reasons. First, the mean AQ score in this study was comparable to that in a large-scale study with over 800 autistic participants (34.60 in the present study and 33.73 in Abu-Akel et al., 2019) and therefore, our sample is representative of the broader population in terms of autistic traits. Second, there was no correlation between autistic traits (as measured by the AQ) and mean percentage speed change ($p = 0.287$, $BF_{10} = 0.31$) or attributed speed ($p = 0.247$, $BF_{10} = 0.34$) within our sample. Therefore, even if we recruited participants who scored more highly in terms of autistic traits, it is unlikely that larger group differences would emerge. Finally, our autistic participants have comparable AQ, and ADOS scores to those in other studies (e.g., Ashwin et al., 2006; Corden et al., 2008; Keating et al., 2021) in which significant group differences in facial emotion recognition have been found.

Taken together, our results suggest that autistic and non-autistic individuals do not significantly differ in their internal representations of full and partial (eye or mouth region) angry, happy, and sad facial motion in terms of speed (though see Brewer et al., 2016 for discussion of alternative potential differences in internal representations of emotion in autism). Importantly, these results suggest that the finding from our previous study wherein autistic participants were less accurate (relative to alexithymia-matched non-autistic participants) in recognising angry expressions when stimuli were played at 100% of their recorded speed (but not if they were played at 150% of recorded speed), is unlikely due to differing internal representations in the speed domain. Consequently, these results force us to question other processes which may be contributing to differences in the recognition of anger in autistic samples.

One potential explanation is that whilst autistic and non-autistic individuals do not differ in their internal representations (at least in the speed domain), autistic people may be *less affected/guided* by these internal representations, and thus may exhibit differences in emotion recognition. As discussed above, template matching models of emotion recognition emphasise that, to label an expression, one must compare the incoming sensory stimulus (i.e., the facial expression) to one's internal representations of emotion and 'read off' the corresponding emotion label. However, such explanations overlook the effect that prior expectations have on the perception of incoming sensory information. For example, if one expects to observe a happy expression one will attend more to features that generally signal happiness and less to features that tend to signal sadness (Calder & Young, 2005). According to Bayesian accounts, autistic people may be less affected by their priors than neurotypical people (Cook et al., 2012; Pellicano & Burr, 2012) and place greater emphasis on incoming sensory information (see Lawson et al., 2014). Thus, for non-autistic people, expectations can bias the perception of expressions (i.e., incoming sensory stimuli) such that they better match internal representations of expected emotions. For autistic people the perception of expressions may be less affected by prior expectations. In cases where non-autistic people have informative priors (which faithfully represent statistically regularities in the environment), this process should improve emotion recognition. Thus, autistic individuals would exhibit a comparative reduction in the accuracy of emotion recognition. That is, although autistic and non-autistic people may have comparable internal representations, for non-autistic people only, expectations may bias the perception of expressions to bring them 'closer' to their internal templates. For comparable emotion recognition, autistic people may require the incoming stimulus itself to be closer to their internal representation. In line with this, in our previous work (Keating et al., 2021), we observed that autistic individuals had difficulty recognising normal speed (100%) angry expressions, which are further away from the average internal representation speed (137.79%), but not those with a higher speed (150%), which are closer to the average internal representation speed for anger. Emotion recognition difficulties would be more likely for anger because, for both happy and sad expressions, there is less of discrepancy between the normal (100%) speed that expressions were displayed at and the average internal representation speed (happy = 123.19%; sad = 87.35%; Keating et al., 2021).

Another possible explanation for why autistic individuals have a particular difficulty recognising angry expressions relates to movement production. In our previous study (Keating et al., 2021), we used PLF videos that were created by filming four *non-autistic participants* posing different emotions. Given that autistic and non-autistic individuals may produce different facial expressions of emotion (Brewer et al., 2016; Keating & Cook, 2020), and that one's own movement patterns influence the interpretation of the movement of others (Cook, 2016; Eddy & Cook, 2018; Edey et al., 2017; Happé et al., 2017) the autistic participants in our previous study might have exhibited reduced emotion recognition accuracy because the non-autistic expressions were dissimilar to expressions that autistic individuals would adopt themselves. That is, in addition to the process (outlined above) of matching visual expression stimuli to internal templates, participants may motorically simulate observed expressions and 'read off' the corresponding emotion label (Goldman & Sripada, 2005; Ipser & Cook, 2016; Niedenthal et al., 2010; though note that this process is not essential for emotion recognition; see Vannuscorps et al., 2020). If the motoric simulation is associated with an unsuitable emotion label emotion recognition accuracy would be reduced. Since internal visual representations and motor programs are formed through different experiences (primarily the experience of observing others' expressions, and the experience of executing and refining actions until they achieve the desired goal) and one has relatively little experience of observing (and therefore forming visual representations based upon) one's own facial expressions, it is possible that autistic individuals could have internal motor programs for angry expressions that differ from those in the general population, without have differing internal visual representations. If a mismatch in the production of facial expressions is to explain autistic individuals' difficulty recognising angry expressions, one would expect to see that these groups differ more in their production of angry relative to happy and sad expressions. This seems plausible since Faso et al. (2015) identified that the angry expressions posed by autistic, relative to non-autistic, individuals were rated (by non-autistic raters) as more intense (and there were no group differences in the intensity of posed happy and sad expressions). Therefore, it could be the case that autistic angry expressions are *more intense* (e.g., are faster or jerkier), and therefore this group struggle to read the *less intense* non-autistic expressions. Further research is necessary to a) characterise the expressive differences of autistic and non-autistic individuals, and b) ascertain whether these differences underpin an emotion-specific difficulty with angry expressions. In addition, this line of investigation requires further work to determine the direction of causality. It could be the case that autistic and non-autistic individuals produce different facial expressions and this leads to bidirectional emotion recognition difficulties, but it is also possible that difficulties with perceiving and labelling emotional facial expressions impacts on the production of emotional expressions.

In addition to the implications for the autism literature, we believe that our results have important implications for the study of emotion recognition more generally. Previous research has demonstrated that when *experimenters* speed-up PLF expressions, observers are more accurate in anger and happiness judgements and, when *experimenters* slow-down PLFs, observers are more accurate in their judgments of sadness (Sowden et al., 2021). To date, however, no research has investigated the speed of *observers'* internal representations of dynamic emotional expressions. Our findings, that participants increased speed (relative to the natural speed at which actors executed these expressions) for happy and angry, and decreased speed for sad expressions, suggest that people may have 'caricatured' internal representations of emotion. In these caricatures, emotion-related kinematic cues are over-emphasised such that sad expressions appear extremely slow, and angry expressions appear extremely fast. Our results build on findings from the static emotion recognition literature wherein exaggerated internal representations of *static* expressions are common (Jack et al., 2012). Our results also suggest a possible psychological mechanism for Sowden et al.'s (2021) observation that participants are more accurate in their recognition of slowed sad expressions and speeded happy and angry expressions: slowed sad expressions and speeded happy/angry expressions may comprise a better match to participants' internal representations of these emotions, thus facilitating emotion recognition.

## LIMITATIONS

The results of the current study are informative with respect to understanding emotion representations from facial motion cues alone. However, since many features of expressions are implicated in emotion processing, such as shading/depth (Wang et al., 2017) and pigmentation/colouring (Yasuda, 2007), one should be cautious to assume that our findings generalise to full dynamic emotional expressions (e.g., video recordings of facial expressions). It could be, for instance, that autistic and non-autistic individuals differ in the speeds they attribute to full emotional expressions but not point-light displays. However, given that our study was motivated by the observation of group differences in emotion recognition *from facial motion cues* (as isolated by PLF stimuli; Keating et al., 2021), it was crucial to our overall research question that we used PLF stimuli in the current study. It is also important to note that autistic and non-autistic groups could in principle differ in their internal representations of facial expressions in the spatial (i.e., the configuration of facial features relative to one another) but not speed dimension. In line with this, Song and Hakoda (2018) demonstrated that autistic individuals required a higher intensity of static angry, but not happy or sad, expressions in order for them to be correctly identified. Our choice to focus on the speed, rather than spatial, domain was driven by our empirically grounded a priori hypothesis that representations of anger would be characterised by higher speed movement (see Keating et al., 2021).

With respect to the current study, it is also important to note that whilst we tested adults, the study by Song and Hakoda (2018), focused on children (mean age was $\sim$11.5 years). It is possible that there are developmental effects such that internal representations of emotion differ between autistic and non-autistic children but not between autistic and non-autistic adults. This is plausible since autistic children show less attention to faces than non-autistic children (as shown by a lack of an attentional bias to faces, less distraction by faces in visual search tasks, and lower fixation times; Kikuchi et al., 2009; Riby et al., 2012; Rice et al., 2012) and spend less time looking at heads/faces in a social scene than autistic adults (Kaliukhovich et al., 2020). Consequently, one may speculate that autistic children have atypical internal representations of emotion (at least in part due to reduced attention to faces), however, by the time they reach adulthood, they have gathered enough information about faces to have 'typical' emotion representations. At present, we cannot say whether we would have found group differences if our sample was made-up of children. Since the current study was motivated by our previous work with adult autistic participants (Keating et al., 2021) our focus on an adult sample was necessary. To establish whether there are developmental changes in internal representations of emotional expressions, further work, which compares the development of autistic and non-autistic children, is necessary.

## CONCLUSIONS

The current study aimed to estimate the speeds that autistic and non-autistic individuals attribute to angry, happy and sad dynamic facial motion. Whilst we found no group differences in the speeds attributed to happy and sad expressions (thus supporting our hypothesis), we also found no group difference for angry expressions (in conflict with our hypothesis). Consequently, we find no evidence to support the idea that particular difficulties with expression recognition from angry facial motion (Keating et al., 2021) are due to atypically fast (or slow) internal representations of anger. Future research is necessary to further unpack why autistic individuals display difficulties that are specific to angry expressions.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## ETHICS STATEMENT

The study was approved by the Science, Technology, Engineering and Mathematics (STEM) ethics committee at the University of Birmingham (ERN_16-0281AP9B) and was conducted in accordance with the principles of the revised Helsinki Declaration.

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