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ABSTRACT

Emotions, and emotional expression, have a broad influence on social interactions and are thus a key factor to consider in developing social robots. This study examined the impact of life-like affective facial expressions, in the humanoid robot Zeno, on children's behaviour and attitudes towards the robot. Results indicate that robot expressions have mixed effects depending on participant gender. Male participants interacting with a responsive facially expressive robot showed a positive affective response and indicated greater liking towards the robot, compared to those interacting with the same robot maintaining a neutral expression. Female participants showed no marked difference across the conditions. We discuss the broader implications of these findings in terms of gender differences in human–robot interaction, noting the importance of the gender appearance in robots (in this case, male) and in relation to advancing the understanding of how interactions with expressive robots could lead to task-appropriate symbiotic relationships.

Introduction

A key challenge in human–robot interaction (HRI) is the development of social robots that are able to engage with people successfully. Effective social engagement requires robots to present personalities that promote human–user interaction (Breazeal & Scassellati, 1999) and to maintain user interest through dynamically responding to, and shaping, their interactions to meet user needs (Pitsch et al., 2009).

The Expressive Agents for Symbiotic Education and Learning (EASEL) project seeks to develop a biologically grounded (Vouloutsi et al., 2016) robotic system capable of meeting these requirements in the form of a socially engaging Synthetic Tutoring Assistant (STA; Reidsma et al., 2016). In developing the STA, we aim to further the understanding

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of human–robot symbiotic interaction; symbiosis in this instance is defined as the capacity of the robot, and the person, to mutually influence each other in ways beneficial to the interaction and interaction task outcomes. Examples of symbiosis may include a robot reconfiguring task requirements in response to users' emotions (e.g. simplifying tasks to reduce user anxiety, Agrawal, Liu, & Sarkar, 2008) and users modifying behaviours in collaborative HRI tasks to better signal their intended actions (e.g. Charisi et al., 2015). As such, symbiosis, in a social context, requires that the robot can interpret, and be responsive to, the behaviour and state of the person, and adapt its own actions appropriately. By applying methods from social psychology we aim to uncover key factors in robot personality, behaviour and appearance that can promote symbiosis. We hope that this work will also contribute to a broader theory of human–robot bonding that we are developing through drawing on comparisons with our psychological understanding of human–human, human–animal and human–object bonds (Collins, Millings, & Prescott, 2013).

A key factor in both the perceived experience and the progression of social interaction is the experience of emotions for the individuals involved (Van Kleef, 2009). Emotions provide important information and context to social events, and can dynamically influence how interactions unfold (Hareli & Rafaeli, 2008; Niven, Totterdell, Holman, & Cameron, 2013). Emotions can promote cooperative and collaborative behaviour and can exist as shared experiences, bringing individuals closer together (Kelly & Barsade, 2001). Communication of emotion is considered as a request for others to acknowledge and respond to our concerns and to shape their behaviours to align with our motives (Parkinson, 2005); social emotions are therefore, in essence, a call for symbiosis. Thus emotional expression can be important to dyadic interactions, including HRI (Novikova, Watts, & Bryson, 2014), where there is a need to align goals and behave symbiotically.

Research with a range of robot platforms has demonstrated the willingness of humans to interpret various forms of expressive behaviour in robots as affective communication, including gesture (Tielman, Neerincx, Meyer, & Looije, 2014), posture (Beck et al., 2011) and facial expression (Breazeal & Scassellati, 1999). The extent to which robot expression will promote symbiosis will depend, however, on how well the use of expression is tuned to the ongoing interaction. Van Kleef's (2009) model of social interaction identifies that the social context, within which the interaction takes place, will impact on the influence of expression. In social robotics, the development of effective robotic expressions in the context of interactions with humans requires researchers to consider the individuals engaging in HRI and the social mores surrounding the context in which the interaction occurs (Cameron et al., 2015a). Inappropriate use of affective expression for individuals or for the social context could disrupt communication and be detrimental to symbiosis. Good timing and sending clear signals is obviously important.

Facial expression is a fundamental component of human emotional communication (Buck, Savin, Miller, & Caul, 1972). Emotion expressed through the face is also considered to be especially important as a means for communicating evaluations and appraisals (Parkinson, 1996). Given the importance of facial expressions to the communication of human affect, they should also have significant potential as a communication means for humanoid robots (Nitsch & Popp, 2014). This intuition has led to the development of many robot platforms with the capacity to produce human-like facial expression, ranging from the more iconic/cartoon-like (e.g. Breazeal, 2003; Ros et al., 2011) to the more natural/realistic (e.g. Becker-Asano & Ishiguro, 2011; Mazzei, Lazzeri, Hanson, & De Rossi, 2012).

Given the need to communicate clearly it has been argued that, for facial expression, iconic/cartoon-like expressive robots may be more appropriate for some HRI applications, for instance, where the goal is to communicate/engage with young children (Becker-Asano & Ishiguro, 2011; Ros et al., 2011). Nevertheless, as the technology for constructing robot faces has become more sophisticated, robots are emerging with richly expressive life-like faces (Becker-Asano & Ishiguro, 2011; Hanson et al., 2009; Mazzei et al., 2012), with potential for use in a range of real-world applications including use with children. In the current study, we investigate the effects of robot facial expressions on children's interaction with a robot. Our goal was to evaluate this symbiotic interaction between a potential synthetic tutoring assistant for children.

Whilst it is clear that people can distinguish robot expressions almost as well as human ones (Becker-Asano & Ishiguro, 2011; Mazzei et al., 2012), there is little direct evidence to show a positive benefit of life-like expression on social interaction or bonding. Children playing with an expressive robot are more expressive than those playing alone (Shahid, Krahmer, & Swerts, 2014). However, the presence of other social agents is sufficient to increase the expressivity of individuals (Kraut & Johnston, 1979) and the social context of another agent (human or otherwise) can impact on expression (Hess, Banse, & Kappas, 1995). Therefore, Shahid et al.'s finding could be a result of the robot's mere presence and cannot be attributed solely to its use of expression. A useful step forwards in understanding the effects of robot facial expressions on social interaction would be the controlled use of emotional expression in a setting in which other factors, such as the presence of the robot and its physical and behavioural design, are kept constant.

Current study

In the current study, we investigated the effects of robot facial expressions on children's social interaction with the robot, in a controlled setting, using multiple modes of measurement, including both objective and subjective data. Our primary experimental manipulation was to turn on or off the robot's presentation of appropriate positive and negative facial expressions (congruent with verbal feedback), during a game-playing interaction, with other features such as the nature and duration of the game, and the robot's bodily and verbal expression held constant. Our chosen platform was a Hanson Robokind Zeno R50 (Hanson et al., 2009) which has a realistic silicon rubber ("frubber") face, because this can be reconfigured, by multiple concealed motors, to display a range of reasonably life-like facial expressions in real time (Figure 1).

By recording the physical behaviour of participants (with parental consent), and through questionnaires, we obtained objective measures of proximity, human emotional facial expression and subjectively reported attitudes towards the robot and the interaction. We hypothesised that children would respond to the presence of facial expression by (a) reducing their distance from the robot, (b) showing greater positive facial expression themselves during the interaction and (c) reporting greater enjoyment of the interaction compared to peers who interacted with the same robot but in the absence of facial expression. Previous studies have shown some influence of demographics such as age and gender on HRI (Cameron et al., 2015b; Cameron et al., 2015c; Kanda, Hirano, Eaton, & Ishiguro, 2004; Kuo et al., 2009; Mutlu, Osman, Forlizzi, Hodgins, & Kiesler, 2006; Shahid, Krahmer, Swerts,

Figure 1. The Hanson Robokind Zeno R50 robot with example facial expressions.

& Mubin, 2010; Woods et al., 2007). We accounted for this by treating gender and age as potential moderators in our analyses.

Method

Design

Due to the potential of repeated robot exposure prejudicing participants' affective responses, we employed a between subjects design, such that participants were allocated to either the experimental condition – interaction with a facially expressive robot, or to the control condition of a non-facially expressive robot. Allocation to condition was not random but determined by logistics due to the real-world setting of the research. The study took place as part of a two-day special exhibit demonstrating modern robotics at a museum in the UK. Robot expressiveness was manipulated between the 2 consecutive days, such that visitors who participated in the study on the first day were allocated to the expressive condition, and visitors who participated in the study on the second day were allocated to the non-expressive condition.

Participants

The exhibit was publicly available and mostly attended by family groups. Children visiting the exhibit were invited to participate in the study by playing a game with Zeno. Fifty-nine children took part in the study in total (36 males and 23 females; M age = 7.58, SD = 2.82).

Measures

Our primary dependent variables were interpersonal responses to Zeno measured through two objective measures: affective expressions and interpersonal distance. Additional

measures comprised of children's interaction with other individuals (i.e. parents/carers and experimenters) during the period of HRI, a self-report questionnaire, completed by participating children, with help from their parent/carer if required, and an observer's questionnaire, completed by parents/carers.

Objective measures

Interpersonal distance between the child and the robot over the duration of the game was automatically recorded, using a Microsoft Kinect sensor, and mean interpersonal distance during the game calculated.

Participant facial expressions were recorded throughout the game and automatically coded for seven discrete facial expressions: Neutral, Happy, Sad, Angry, Surprised, Scared and Disgusted, using Noldus FaceReader version 5 (Den Uyl & Van Kuilenburg, 2005). Mean intensity of the seven facial expressions across the duration of the game was calculated. Overall duration of each of the seven facial expressions' "expressive dominance" was also recorded; expressive dominance is determined automatically by FaceReader as being the facial expression with the highest intensity at any given point. FaceReader offers automated coding of expressions at an accuracy comparable to trained raters of expression (Lewinski, den Uyl, & Butler, 2014). On average, 85% of video frames were coded by FaceReader as having a recognisable expression; unrecognisable expressions were accounted for by obscured faces due to rapid movement from the children or children turning away from camera.

Frequency and duration for children turning to look towards their parent/carer was recorded. Similarly, frequency and duration for children turning towards the experimenters was also recorded. Observations were made using the Noldus Observer XT software (Noldus, 1991) across the same portion of video used to code for facial expressions. The layout of the interaction (see procedure) offered clear indication in the videos of instances of children turning towards parents/carers or the experimenters. Children were coded as looking towards parents/carers if they turned their head away from Zeno and fully to their right. They were also coded as looking towards the experimenters by turning away from Zeno either to their left, towards the team's roboticist, or partially to their right (but not sufficient to meet criteria for turning towards parents/carers), towards the team's experimenter.

Last, participants' game performances (final scores) were recorded.

Questionnaires

Participants completed a brief questionnaire on their enjoyment of the game and their beliefs about the extent to which they thought that the robot liked them. Enjoyment of playing Simon Says with Zeno was recorded using a single-item, four-point measure, ranging from "*I definitely did not enjoy it*" to "*I really enjoyed it*". Participants' perceptions of the extent to which Zeno liked them was recorded on a single-item thermometer scale. This thermometer scale, represented as a 10-cm line, serves as a continuous 100-point measure ranging from "*I do not think he liked me very much*" at the 0-point (left) to "*I think he liked me a lot*" at the 100-point (right); participants may mark any point on the line to reflect how closely they agree with either statement. They were also asked if they would like to play the game again. Parents/carers completed a brief questionnaire on their perceptions of their child's enjoyment and engagement with the game on two single-item thermometer scales, ranging from "*Did not enjoy the game at all*" to "*Enjoyed the game very much*" and "*Not at all engaged*" to "*Completely engaged*" respectively.

Procedure

The experiment took place in a publicly accessible lab and prospective participants could view games already underway. Brief information about the experiment was provided to parents/carers and informed consent for participation and optional video recording of the interaction was obtained from parents/carers prior to participation. Ethical approval for this study was obtained prior to any data collection.

Set-up

Children approached Zeno from beyond the furthest point of the designated "*play zone*" boundary marked on the floor. The designated play zone was marked by three-foam .62msq mats. The closest edge of the play zone was 1.80 m from the robot and the play zone extended to 3.66 m away. These limits approximate the "social distance" classification (Burgess, 1983). This range was chosen for two reasons: participants would likely expect the game used in the interaction to occur within social rather than public- or personal dis- tance; this enabled reliable recordings of participant movement by the Kinect sensor. The mean overall interpersonal distance across participants during the study was 2.48 m: well within social distance boundaries. Parents were situated on the children's right at the back of the play zone, approximately 2 m away. To capture unobscured footage of the inter- action, video recordings were taken from a camcorder on tripod situated above and to the left of Zeno; as a result, all videos show children unobscured when looking towards Zeno. The roboticist was positioned to the right of Zeno and the experimenter to the left of the camcorder. As outlined in *objective measures*, if children wished to look towards their parents/carers, the layout required children to orient away from Zeno.

During the game, children were free to position themselves relative to Zeno within the play zone and could leave the game at their choosing. At the end of the game, participants completed the self-report questionnaire, while parents completed the observer's question- naire. Participant–experimenter interaction consistency was maintained over the 2 days by using the same experimenter on all occasions for all tasks.

Human–robot interaction

Interaction with the robot took the form of the widely known Simon Says game (Figure 2). This game was chosen for two reasons: children's familiarity with the game, its uncluttered structure allows autonomous instruction and feedback delivery by Zeno, and its record of successful use in a prior field study (Dautenhahn et al., 2009).

The experiment began with autonomous instructions delivered by Zeno as soon as indi- viduals were detected in the play zone in front of the Kinect sensor. Zeno introduced the game by saying, "*Hello. Are you ready to play with me? Let's play Simon Says. If I say Simon Says you must do the action. Otherwise you must keep still*". The robot would proceed with 10 rounds of the game or play until the child chose to leave the designated play zone. In each round, Zeno gave one of three simple action instructions: "*Wave your hands*", "*Put your hands up*" or "*Jump up and down*". Each instruction was given either with the prefix of "*Simon says*" or no prefix; instructions were delivered in pseudorandom order. Zeno gave relevant actions to accompany each instruction (e.g. waving its arms with the "Wave your hands" instruction). Each instruction delivered was accompanied with Zeno moving its mouth to correspond to the synthesised speech.

Figure 2. A child playing Simon Says with Zeno.

The OpenNI/Kinect skeleton tracking system was used to determine if the child had performed the correct action in 3 s following Zeno's instruction. For the *Wave your hands* action, the system monitored the speed of the hands moving. If, following Zeno's instruction, arm movement was detected and was greater than arm movement at rest, then the movement was counted as a wave. For the *Jump up and down* action, the vertical velocity of the head was monitored, again differentiating between head movement at rest to determine if a jump had taken place. Finally for the *Put your hands up* action, our system monitored the positions of the hands relative to the waist. If the hands were found to be above the waist for more than half of the 3-s period following the instruction then the action was judged to have been executed. The thresholds for the action detection were determined by previous trial and error during pilot testing. The resulting methods of action detection were found to be over 98% accurate in our study. In the rare cases where the child did the correct action and the system judged incorrectly then the experimenters would intervene to say "*Sorry, the robot made a mistake there, you got it right*". No false positives (i.e. the children's actions being erroneously recorded as correct) were observed during the study.

If children correctly followed the action instruction after hearing "Simon says" the robot would say, "*Well done, you got that right*". If the child remained still when the prefix was not given, Zeno would congratulate them on their correct action with "*Well done, I did not say Simon Says and you kept still*". Conversely, if the child did not complete the requested movement when the prefix was given Zeno would say, "*Oh dear, I said Simon Says, you should have* [action required]". If they completed the requested movement in the absence of the prefix, Zeno would inform them of their mistake with, "*Oh dear, I did not say Simon Says, you should have kept still*". Zeno gave children feedback of a running total of their score at the end of each round (the number of correct turns completed).

If the child left the play zone before 10 rounds were played, the robot would say, "*Are you going? You can play up to 10 rounds. Stay on the mat to keep playing*". The system would then wait 3 s before announcing, "*Goodbye. Your final score was* [score]". This short buffer

sequence was to prevent the game ending abruptly if the child accidentally left the play zone for a few seconds.

At the end of the 10 rounds, the robot would say, "*All right, we had 10 goes. I had fun playing with you, but it is time for me to play with someone else now. Goodbye*".

The sole experimental manipulation was presented with Zeno's spoken feedback to the children after each turn. In the expressive robot condition, Zeno responded with appropriate "happiness" or "sadness" expressions, following children's correct or incorrect responses. These expressions were prebuilt animations, provided with the Zeno robot, named "victory" and "disappointment" respectively. These animations were edited to remove arms gestures so only facial expression was present. In contrast, in the non-expressive robot condition, Zeno's expressions remained in a neutral state, regardless of child performance. Other studies indicate that children can recognise these facial expression representations by the Zeno robot with a good degree of accuracy (Cameron et al., 2016; Costa, Soares, & Santos, 2013).

Statistical analysis

Demographic analysis and examination of even distribution of participants across conditions are conducted before main analysis of dependent variables. Demographic analysis, in terms of participants age, is examined using an ANOVA with Condition as the independent variable. Even allocation of genders to condition is determined through a chi-square test.

A series of 2×2 ANOVAs are run with *Condition* (Expressive versus Non-Expressive Robot) and *Gender* (Male versus Female) as independent variables for the above measures of children's interactions with Zeno. Any third variables identified in the preliminary analysis as being of note are added as covariates and any meaningful impact on results reported. Main and interaction effects are examined for the above measures, with follow-up analysis of simple effect tests for any observed interaction effects. The conservative Bonferroni correction is used to account for the effects of multiple statistical tests run.

Where use of ANOVA for the measures described above is not appropriate (i.e. the "count" measure of instances children looked towards adults), Mann–Whitney *U* tests are used to explore main effects of condition and gender.

Results

A preliminary check was run to ensure even distribution of participants to expressive and non-expressive conditions. There were 11 female and 17 male participants in the expressive condition and 12 female and 19 male participants in the non-expressive condition. A chi-square test run before analysis to check for even gender distribution across conditions indicates no significant difference (χ^2 (1, $N = 59$) = .002, $p = .964$).

There was a significant difference between conditions for participants' age F(1, 54) = 14.38, $p < .01$. Participants in the expressive condition were older than those in the non-expressive condition (M = 8.82, SE = .51; M = 6.49, SE = .45, respectively). There was no significant difference in age between gender F(1, 54) = .05, $p = .821$, nor a significant interaction between gender and experimental condition F(1, 54) = 3.15, $p = .08$. Age correlated with only one primary outcome measure (children's perceptions that Zeno liked them, $r = -.30, p = .03$); and the inclusion of age as a covariate for primary outcome measures did not meaningfully impact on results presented unless otherwise stated.

Objective measures

Interpersonal distance

We did not observe any significant main effects of Zeno's expressiveness on objective measures of interpersonal distance between conditions. There was also no significant interaction for experimental condition and child's gender for interpersonal distance $F(1, 53) = 2.90$, $p = .09$, although mean scores for interpersonal distance reflected the observed interaction effects described prior. Interpersonal distance for male participants was smaller for those interacting with the expressive robot than the non-expressive robot (M = 2.36 m, SE = .10 m; M = 2.65 m, SE = .10 m), whereas female participants interacting with the expressive robot tended to stand further away (M = 2.59 m, SE = .12 m) than those interacting with the non-expressive robot (M = 2.45 m, SE = .12 m). Controlling for participant age and game performance made no material difference to the findings for objective measures of interpersonal distance.

Facial expressions

Overall, we did not observe any significant main effects of Zeno's expressiveness on facial expressions between conditions. However, there were significant interaction effects, when gender was included as a variable.

There was a significant interaction of experimental condition and child's gender on average intensity of happiness expressions $F(1, 50) = 5.84$, $p = .02$ (see Figure 3). While male participants showed greater average happiness in the expressive robot condition in comparison to those in the non-expressive condition (16.73%, SE = 2.71% versus 3.94%, SE = 2.88%), female participants did not differ between conditions (7.95%, SE = 3.37% versus 10.12%, SE = 3.37%). Simple effect tests (with Bonferroni correction) indicated that the observed difference between conditions for only male participants was significant ($p = .01$).

Results for the duration of time that happiness was the dominant expression were similar, with a significant interaction of experimental condition and child's gender $F(1, 50) = 8.49$, $p < .01$. Male participants showed greater duration for happiness as the
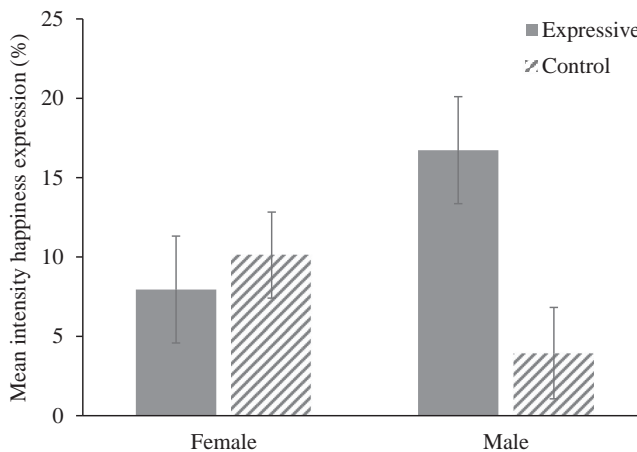

Figure 3. Mean intensity of happiness expression (%) during game (standard errors shown).

dominant expression in the expressive robot condition in comparison to those in the non-expressive condition (M = 24.8 s, SE = 3.70 s versus M = 5.10 s, SE = 3.94 s), female participants did not differ between conditions (M = 12.20 s, SE = 4.60 s versus M = 18.6 s, SE = 4.60 s). Simple effect tests (with Bonferroni correction) indicated that only the observed difference between conditions for male participants was significant ($p < .01$).

To account for possible influence of variation in recording durations between subjects (M = 154.77 s, SE = 2.21 s) as a factor for differences observed in duration of expressive dominance, expression durations were recalculated in terms of percent time recorded. The observed interaction between experimental condition and child's gender on child's duration of happiness as a dominant expression was still maintained $F(1, 50) = 10.45, p < .01$. Furthermore, this interaction is not substantively affected when excluding all video frames in which FaceReader could not register an expression for participants $F(1, 50) = 8.49, p < .01$.

A significant gender interaction was also found for average expressions of surprise $F(1, 50) = 5.60, p = .02$. Male participants in the expressive robot condition showed less surprise than those in the non-expressive condition (6.68%, SE = 3.45% versus 21.22%, SE = 3.67%), whereas female participant expressions for surprise did not differ between conditions (12.72%, SE = 4.29% versus 8.61%, SE = 4.29%). Simple effect tests (with Bonferroni correction) indicated that only the observed difference between conditions for male participants was significant ($p = .01$). This interaction was not seen in terms of duration of surprise as a dominant expression $F(1, 50) = 2.83, p = .10$.

Controlling for participant age and game performance made no material difference to any of the findings for objective measures of children's facial expressions. There were no further significant interactions for the remaining expressions: sadness, anger, disgust or fear for either expression intensity or duration of expression dominance. Values for mean intensity and duration of expressive dominance for all expressions are presented in Table 1.

Gaze direction

There was a significant main effect of Zeno's expressions on objective measures of children's looking towards the experimenters rather than the robot and significant main effects of gender for children's looking towards their parent/carer rather than the robot. There were no significant interaction effects for these secondary objective measures. Children in the non-expressive condition looked towards the experimenters for a significantly longer time in total during the interaction than those in the expressive condition $U(54) = 229.00, Z = 2.35, p = .019$. Median total looking duration for those in the non-expressive condition was 5.72 s while median total looking duration for those in the expressive condition was 1.82 s. There was no significant effect observed for the number of instances children turned to look towards the experimenters across conditions $U(54) = 253, Z = 1.94, p > .05$. Median counts for children looking towards the experimenters in the non-expressive condition and expressive condition were 4 and 2 instances during the interaction respectively.

Across both conditions girls tended to look towards their parents/carers more often $U(54) = 231.50, Z = 2.14, p = .03$ and for a longer total duration $U(54) = 228, Z = 2.20, p = .03$ during the interactions than boys did. Median counts for girls looking towards their parents/carers were 3.5 instances, while median counts for boys were 2 instances during the

Table 1. Mean intensity and duration of expressive dominance for all observed expressions.

	Mean intensity (%)				Primary expression (s)				Primary expression (% duration) – *Unknown expression* frames removed			
	Expressive		Non-expressive		Expressive		Non-expressive		Expressive		Non-expressive	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Happy	16.73[a] (2.71)	7.95 (3.37)	3.94[a] (2.88)	10.12 (3.37)	24.8[c] (3.70)	12.2 (4.60)	5.10[c] (3.94)	18.56 (4.60)	22.22[e] (3.39)	9.61 (4.21)	3.84[e] (3.61)	13.80 (4.21)
Sad	4.35 (1.01)	4.28 (1.26)	3.82 (1.08)	4.09 (1.26)	2.58 (1.44)	0.84 (1.78)	0.53 (1.53)	4.09 (1.26)	1.84 (1.00)	0.77 (1.24)	0.35 (1.06)	1.24 (1.24)
Anger	0.93 (0.32)	0.89 (0.40)	1.90 (0.34)	1.29 (0.40)	2.58 (1.44)	0.84 (1.78)	0.53 (1.53)	1.72 (1.78)	0.00 (0.40)	0.22 (0.49)	0.92 (0.42)	0.00 (0.49)
Scared	1.18 (0.59)	0.59 (0.73)	1.60 (0.62)	1.62 (0.73)	1.06 (0.99)	0.25 (1.23)	1.67 (1.05)	1.19 (1.23)	0.76 (0.71)	0.27 (0.88)	1.21 (0.76)	0.81 (0.88)
Disgust	0.02 (0.12)	0.08 (0.15)	0.54 (0.13)	0.04 (0.15)	0.00 (0.38)	0.19 (0.47)	0.99 (0.41)	0.00 (0.47)	0.00 (0.29)	0.20 (0.36)	0.76 (0.31)	0.00 (0.36)
Surprise	6.68[b] (3.45)	12.72 (4.29)	21.23[b] (3.67)	8.61 (4.29)	4.31 (5.65)	9.66 (7.02)	26.17 (6.01)	9.83 (7.02)	4.13 (4.21)	7.50 (5.24)	19.16 (4.49)	7.52 (5.24)
Neutral	50.76 (4.85)	60.63 (6.03)	63.93 (5.17)	55.12 (6.03)	97.15 (8.66)	105.45 (10.77)	99.08 (9.22)	99.3 (10.77)	71.06 (5.44)	81.43 (6.76)	73.77 (5.79)	76.64 (6.76)
Unknown	–	–	–	–	22.40 (3.29)	31.77[d] (4.09)	22.78 (3.50)	17.08[d] (4.09)	–	–	–	–

Standard errors shown in parentheses. Significant differences between values marked with matching superscripts. *Note*: While Primary Expression (% duration) columns sum to 100%, mean intensity is independent across emotions so columns can sum to values other than 100%.

interaction. Median total looking duration for girls was 6.16 s, while median total looking duration boys was 2.34 s during the interaction.

Game performance
Participants near universally completed all 10 trials in the game (93% fully completed); 4 participants completed less than the full game; game completion did not meaningfully impact on results presented. There were no significant gender differences in game performance, $F(1, 54) = .64$, $p = .43$ between boys (M = 7.83 correct responses, SE = .52) and girls (M = 8.35, SE = .33). There was a significant difference in game performance between conditions $F(1, 54) = 6.38$, $p = .02$; children in the expressive condition performed better in the game than those in the non-expressive condition (M = 8.89, SE = .31; M = 7.23, SE = .55, respectively), however, when controlling for age, this result was not significant $F(1, 54) = .32$, $p = .57$. There was no significant interaction between gender and condition, $F(1, 54) = .02$, $p = .89$. Game performance did not significantly correlate with any of the primary outcome measures and its inclusion as a covariate did not meaningfully impact on results presented unless otherwise stated.

Questionnaires

No significant main effects of condition or gender were seen for self-reported measures or observer reported measures. However, there were significant interaction effects of gender and experimental condition.

There was a significant interaction for gender and experimental condition on children's beliefs about the extent to which the robot liked them $F(1, 48) = 4.11$, $p = .05$. Male participants interacting with the expressive Zeno reported that Zeno like them to a greater
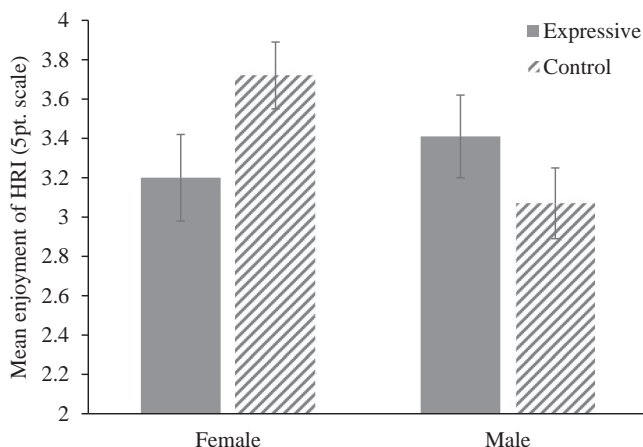
Figure 4. Mean enjoyment of interacting with Zeno (standard errors shown).

extent than those who interacted with the non-expressive Zeno ($M = 4.08$, SE $= .39$ versus $M = 3.49$, SE $= .41$), whereas female participants interacting with the expressive Zeno reported that Zeno liked them to a lesser extent than those interacting with the non-expressive Zeno ($M = 2.48$, SE $= .50$ versus $M = 3.70$, SE $= .48$). However, simple effect tests did not indicate that the difference found between conditions was significant for either male participants ($p > .10$) or female participants ($p > .10$).

We also observed a significant interaction of gender and experimental condition for participants' enjoyment in interacting with Zeno $F(1, 49) = 5.16$, $p = .03$. Results are presented in Figure 4. Male participants interacting with the expressive Zeno reported greater enjoyment of the interaction than those who interacted with the non-expressive Zeno ($M = 3.41$, SE $= .17$ versus $M = 3.07$, SE $= .18$), whereas female participants interacting with the expressive Zeno reported less enjoyment than those interacting with the non-expressive Zeno ($M = 3.20$, SE $= .22$ versus $M = 3.73$, SE $= .21$). Simple effect tests (with Bonferroni correction) indicated that the only observed difference between conditions for female participants was significant ($p = .01$).

Results from the observer reports generated by the participants' parents or carers showed the same trends as those from the self-report results but did not show significant main or interaction effects. Controlling for participant age and success/failure in the game made no material difference any of the questionnaire findings except the interaction effect on children's beliefs of the robot liking them (after controlling $p = .15$).

Discussion

Our study was the first to investigate the role of robot facial expressions on children's interaction with a robot, using multiple modes of measurement, comprising objective and subjective data. Our results provide new evidence that the presence of life-like facial expressions in humanoid robots impact on children's interaction experience and enjoyment of HRI. Moreover, our results are consistent across different modalities, including facial expression, interpersonal distance and self-reported enjoyment.

Our hypotheses were that children in the expressive robot condition would (a) show shorter interpersonal distance from the robot; (b) show greater positive facial expressions during the interaction and (c) report greater enjoyment of the interaction, compared to children in the non-expressive robot condition. We found partial support for some of our hypotheses, and many of our findings were moderated by gender. By way of summary, in relation to hypothesis (a), we found that boys in the expressive robot condition stood closer to the robot than boys in the non-expressive robot condition, and the opposite patterns of results were found for girls. However, this finding was not statistically significant, and so we make no attempt to interpret it theoretically. In relation to hypothesis (b), we found that males interacting with the expressive robot showed greater happiness and less surprise than did males interacting with the non-expressive robot, offering partial support for our hypothesis. Hypothesis (c), that children in the expressive robot condition would report greater enjoyment of the interaction, was also partially supported, with males interacting with the expressive robot reported greater enjoyment and perception that the robot liked them than did males interacting with the non-expressive robot, but females showed the opposite pattern. Additionally, overall, we found that: (i) children interacting with the expressive robot looked at the experimenters less and (ii) females looked towards their parents during the game more than males did. We discuss each set of findings in relation to existing literature and implications for future research.

Our finding that children in the expressive group look towards the experimenters less may indicate that the robot's expressions are supplementing its verbal feedback. Expressions are considered to be useful tools in directing or instructing others (Parkinson, 2005) and presence of the robot's expressions may reduce children's need to seek feedback from other sources (i.e. the experimenters). However, the robot's presentation of expressions in this study, and thus potentially greater feedback, does not affect game performance, when children's age is taken into account; this may be due to older children across conditions reaching ceiling performance in the game. Future work could disentangle these findings, perhaps by identifying a way of directly measuring engagement, while simultaneously assessing gaze direction and performance.

Perhaps most notable of our findings are the gender interactions indicating that responses towards the robot were not universal across participants. Boys in the expressive robot group showed more positive behaviours and views than boys in the non-expressive robot group, whereas girls tended to show the opposite pattern. We outline potential explanations for these findings.

Shyness

The current study took place in a publically accessible space, with participants in the company of museum visitors, other volunteers, and the children's parents/carers. Our finding that girls looked towards their parents during the game more than boys did could relate to gender-driven behavioural tendencies (e.g. differences in public and explorative play, Gonzalez, 2013; Kim, Arnold, Fisher, & Zeljo, 2005). Children's turning to look towards their parents/carer throughout the interaction is indicative of proximity seeking behaviour in parent–child relationships in response to threat (Maccoby, 1980). Girls may have felt more uncomfortable than boys when in front of their parents whilst engaging in explorative play

with strange people (experimenters) and an unfamiliar object (the robot). Indeed, research has found that in mid-childhood, girls tend to experience greater shyness than boys (Cozier, 1995). That we found girls in the expressive robot condition enjoyed the interaction less than girls in the non-expressive robot condition may result from the robot expressions serving to emphasise the social (and public) context of the interaction, thus increasing feelings of shyness and awkwardness.

To better explore the gender differences observed in our study, we must take into consideration existing observed behavioural patterns in children engaging in explorative play around their parents. Replication in a familiar environment without an audience or the presence of the children's parents would be a more stringent examination of the origins of these gender differences.

Same gender preferences

Boys in the expressive robot condition showed greater happiness and less surprise, and greater enjoyment and perception that the robot liked them than did males interacting with the non-expressive robot. The social cues afforded by the facial expression, together with same sex preference in children (Martin & Fabes, 2001), may go some way to explaining these results. Robots with human-like faces and behaviour may prompt users to expect the social complexities of human–human interaction and behave towards such robots accordingly. Indeed, boys in the expressive robot condition showed less surprise than boys in the non-expressive robot condition, which supports the idea that the facial expressions served to normalise Zeno as an interaction partner. The facial expressions that may cue users to treat Zeno as human-like may also trigger the application of commonly used behavioural tendencies. One such common tendency in the age group of our participants is the preference for same gender friends and playmates (Martin & Fabes, 2001). Zeno is a "boy" robot, both nominally (Bar-Cohen, Marom, & Hanson, 2009, p. 36) and in children's opinion (Cameron et al., 2016); the presence of life-like facial expressions may encourage participants to view Zeno as more human-like. As a result, the children in our sample may have been differentially cued in the expressive versus non-expressive conditions to utilise their usual same gender preference towards a prospective playmate. If this is the case, a replication of the current study with a "girl" robot counterpart (e.g. Robokind Alice R50) should produce results that directly contrast the current findings[1] (Hoffmann & Powlishta, 2001; Lindsey, 2014).

Additionally, it would be worthwhile to narrow the target of interaction to solely Zeno's face. Younger participants (35% of participants were aged 6 or under) may still hold naïve theories of animacy (e.g. Carey, 1985), and so could be particularly influenced by physical cues such as movement of limbs. By limiting the robot's autonomy, movements and responsiveness (as these other cues may create a ceiling effect for animacy for many), the impact of solely facial expressions on children's perceptions of Zeno as a boy can be more thoroughly observed.

Limitations

The current study is a field experiment, based in the UK. As such cultural differences (e.g. Shahid et al., 2014) in children's interactions with robots are not explored; further work may

illuminate if the observed gender differences in this study are seen in HRI of different cultures and contexts. As with the nature of field studies, maintaining an exacting control over experimental conditions is prohibitively difficult. Possible confounds from the public testing space include prospective participants observing others interacting with the robot, and noise in the room serving as a distraction, potentially drawing children's gaze and attention away from the robot. The public testing space shaped study design such that the primary experimenter knew the condition each child was assigned to; despite best efforts in maintaining impartiality, the current study design cannot rule out potential unconscious experimenter influence on children's behaviours. In studies concerning emotion and expression, potential contagion effects of expression and emotion (Hatfield, Cacioppo, & Rapson, 1994) could impact on participant's expressions and reported emotions. The current results therefore offer a strong indication of the areas to be further explored under stricter experimental conditions.

Implications for future research

The gender differences in interaction with facially expressive robots during HRI that we have observed could have profound implications for the design and development of future robots. It is therefore important that these findings are replicated, and further research should explore this topic in more depth in order to identify why these findings arose. In particular, future research needs to employ lab settings that afford greater experimental control over the environment to eliminate potential confounds from having an audience present, and from participants watching others interact with the robot prior to their own interaction. The potential for emotional contagion needs to be eliminated as far as is possible. As participant gender is observed to impact on HRI, it is worth considering potential influence of experimenter gender on children's HRI experience (this study was conducted by a mixed sex team; single sex teams might influence interaction differently). New ways of disentangling engagement from enjoyment would also be useful, in order to further examine the effects of expressions on performance. Finally, and crucially, future studies also need to source and utilise a "girl" robot to fully test our ideas about same sex preferences accounting for differences in the behaviour of girls and boys towards Zeno.

In our own future research, we aim to repeat the current study in a more controlled, but familiar, experimental environment. Children (of a more homogenous age group than in the current study) will complete the same Simon Says game in their school, this time without an audience, in a study protocol that allows true randomisation to condition, conducted by an experimenter naïve to conditions. By repeating the current study under these stricter conditions, we will have the opportunity to further examine the interactive effects of gender and robot expressions on children's enjoyment of HRI.

Conclusion

This paper offers further steps towards developing a theoretical understanding of symbiotic interactions between humans and robots. The production of emulated emotional communication through facial expression by robots is identified as a central factor in shaping human attitudes and behaviours during HRI. Multi-modal findings, from both self-report and objective measurement of behaviour, point towards possible gender differences in

responses to facially expressive robots. Further research to explore this is essential, as these findings highlight important considerations for the future development of socially engaging robots.

Note

1. Unfortunately, the availability of girl robots is extremely limited because the "Alice" counterpart of Zeno is no longer in production. The lack of visibility of "female" in robots, especially for potential use in schools, has important implications for the inclusion and encouragement of girls in STEM subjects, but a full discussion of this issue is beyond the scope of this paper.

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