Exploring Interpersonal Synchrony in Neurotypical and Autistic Children Using Humanoid Robots

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Thesis Summary

Interpersonal synchrony is the tendency for social partners to temporally coordinate their behaviour with one another. Among non-autistic individuals, interpersonal synchrony has been demonstrated to have prosocial benefits and influence their understanding of others' relationships. These social effects are thought to arise through a combination of motor, perceptual, and social skills. However, autistic individuals' interpersonal synchrony is thought to be reduced in its accuracy and frequency, and they are thought to be less sensitive to its social effects. There is also conflicting evidence regarding whether interpersonal synchrony in human-robot dyads produces similar social effects, as robots often have a limited social presence.

To effectively use robots in studies with autistic children, Chapter 2 tested familiarisation techniques for introducing autistic children to robots in a way that promoted participant comfort. Techniques were evaluated in a mixed-methods study by interviewing autistic children's parents, followed by a laboratory visit in which autistic children were introduced to robots using the familiarisation techniques.

To investigate how autistic and non-autistic children compare in the underlying factors that contribute to synchrony, Chapter 3 compared groups' motor production and synchrony perception skills in the absence of a social context. The study found that groups performed similarly in the motor and perception tasks, indicating that autistic and non-autistic experiential differences with interpersonal synchrony are unlikely to be caused by fundamental differences in how accurately the groups can produce and perceive synchrony.

Chapter 4 compared how sensitive autistic and non-autistic children were to the social effects of synchrony when witnessing it in others and experiencing it themselves. Because robots can provide a limited and controlled social presence, synchrony in human-robot pairs was also examined. Results showed that non-autistic children were sensitive to the social effects of synchrony when witnessing human-human and human-robot pairs, while autistic children were not. However, autistic children were sensitive to the social effects of synchronising with a robot themselves, but non-autistic children were not. In summary, this thesis compared the ways in which autistic and non-autistic individuals experience factors

underlying interpersonal synchrony and investigated whether the social effects of interpersonal synchrony can also be found when witnessing or interacting with robots.

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List of Abbreviations

ADHD	attention deficit hyperactivity disorder
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
ASDQ	Autism Symptom Dimensions Questionnaire
EEG	electroencephalogram
ERP	event-related potential
GLMM	generalised linear mixed model
HRI	human-robot interaction
ISI	interstimulus interval
KMO	Kaiser-Meyer-Olkin
MBAC-2	The Movement Assessment Battery for Children: 2nd Edition
MR	mixed reality
MRI	magnetic resonance imaging
ms	milliseconds
PCA	Principal Components Analysis
SD	standard deviation
SJ	simultaneity judgement
SOA	stimulus onset asynchrony
SWAN	Strengths and Weaknesses of Attention-Deficit/Hyperactivity Symptoms and Normal Behavior Scale
ToJ	temporal order judgement
WASI-II	Wechsler Abbreviated Scale of Intelligence – Second Edition

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Publications

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Chapter 1

General Introduction

1.1 Overview

Interpersonal synchrony refers to social partners' inclination towards temporally coordinating their behaviour with one another (Bowsher-Murray et al., 2022). This can occur intentionally (i.e., shaking hands; dancing together) or spontaneously (i.e., walking in step; mirroring postures). Engaging in interpersonal synchrony, whether intentionally or spontaneously, is believed to have a number of prosocial benefits (Bloch et al., 2019), such as increased rapport between synchronous partners (LaFrance, 1979; Vacharkulksemsuk & Fredrickson, 2012) and improved cooperation (Knoblich et al., 2011; Sebanz et al., 2006; Valdesolo et al., 2010). It has also been shown to foster perceived similarity and closeness (Mazzurega et al., 2011) and a sense of affiliation (Hove & Risen, 2009; Tunçgenç et al., 2015). As such, interpersonal synchrony is thought to promote the development of interpersonal relationships.

Because autistic individuals often experience difficulties with nonverbal communication and developing/maintaining relationships (American Psychiatric Association & American Psychiatric Association, 2013), researchers have taken a particular interest in how autistic individuals experience interpersonal synchrony. Research has indicated that autistic people indeed experience this phenomenon differently than their non-autistic peers (Bowsher-Murray et al., 2022). Studies have shown that autistic people engage in interpersonal synchrony less frequently and less accurately than non-autistic people (Fitzpatrick et al., 2016, 2017a; Kaur et al., 2018; Marsh et al., 2013). The social effects of interpersonal synchrony are also thought to be reduced among autistic individuals (Koehne et al., 2016).

There are many factors that could impact how autistic individuals engage in interpersonal synchrony. Differences in how autistic individuals temporally process stimuli (de Boer-Schellekens et al., 2013; Kwakye et al., 2011) and the motor difficulties that autistic people often experience (Hilton et al., 2012) could make engaging in synchrony more difficult. Differences may also be caused by attentional factors, as researchers have found that autistic individuals find it more difficult to attend to social stimuli when perceptual load is increased. For example, in virtual reality (VR) environments, autistic individuals have reduced social attention when viewing a multisensory videosphere compared to when viewing a silent still photosphere (Haskins et al., 2022). The ability to attend to social stimuli is thought to predict imitative capabilities (Vivanti et al., 2014), so the multiple attentional demands of social interactions and environments could make synchrony more difficult for autistic individuals.

One possible situation in which autistic individuals could more successfully achieve interpersonal synchrony is via interacting with humanoid robots. Robots serve as a conceptual midpoint between a social partner and an inanimate object. As such, researchers have become interested in how people synchronise with robots and whether this has similar social effects to interacting with humans. Some autistic children find robots easier to interact with than humans if they are overwhelmed by the social stimuli they encounter when interacting with other people (Huijnen et al., 2018), which in turn might facilitate interpersonal synchrony. However, the effects of synchronising with a robot are not yet understood, as there is conflicting evidence regarding whether synchrony influences these interactions or not (Henschel & Cross, 2020; Lehmann et al., 2015; Sweezy, 2023). As such, this thesis will investigate how synchrony impacts human-robot interactions, and whether this differs between autistic and non-autistic people. However, many social and non-social factors can influence autistic children's experiences with synchrony. Therefore, it is also necessary for us to understand participants' abilities to perceive and produce synchrony in the absence of confounds that are thought to impact autistic children's performance, such as complex motor movements (Whyatt & Craig, 2012), multisensory stimuli (Taylor et al., 2010), and attention to social cues (Bowsher-Murray et al., 2022).

To successfully study synchrony in human-robot interactions with autistic children, it is first vital to ensure the children's comfort during research studies, especially when meeting a robot. Previous research has highlighted that autistic children may feel uncomfortable or distressed when meeting a novel robot in an experimental setting, which can lead to participant withdrawal (Huijnen et al., 2021; Short et al., 2017). While there are general guidelines for how researchers can make research participation more accessible and comfortable for autistic people (e.g., Ashworth et al., 2021; Gowen et al., 2019; McKinney et al., 2021; Pellicano et al., 2017; Tager-Flusberg et al., 2016), these recommendations do not specifically describe support for participants who are encountering unfamiliar equipment. As such, there remains a need for guidance for studies that include human-robot interactions.

While there is no standardised protocol for facilitating the introduction of robots to autistic children, researchers have developed many techniques for helping children feel more comfortable in these situations (Wallbridge et al., 2024). However, it is unknown which of these approaches are the most effective in alleviating children's anxiety and discomfort. It is therefore first necessary to evaluate the various techniques used by researchers to determine which are the best in promoting participant wellbeing, and which methods are preferred by autistic children and their parents.

In the first part of this chapter, I will discuss the effects and components of interpersonal synchrony, and how these present differently in autistic individuals. I will then discuss the ways in which humans interact with robots, and the evidence surrounding how interpersonal synchrony can be used to develop human-robot relationships. I will then provide a summary of the research that exists on how to best support autistic children when meeting unfamiliar robots.

1.2 Interpersonal synchrony

Interpersonal synchrony can be conceptualised in two categories: intentional synchrony and spontaneous synchrony. Intentional synchrony occurs as a result of conscious effort between synchronous partners, where the explicit goal is acting in synchrony (McNaughton & Redcay, 2020). Examples of this include when people dance together, shake hands, or high-five (Bowsher-Murray et al., 2022). This is compared to spontaneous synchrony, in which synchronous behaviours arise without conscious effort or the explicit goal to synchronise (McNaughton & Redcay, 2020). This can occur, for example, when people walk in step (Zivotofsky & Hausdorff, 2007), align their postures (Shockley et al., 2007), or entrain their facial expressions (Louwerse et al., 2012).

Synchrony that has a rhythmic element (e.g., walking, using a rocking chair) is often interpreted through the lens of “in-phase” and “anti-phase” synchrony. In-phase movements are characterised by identical behaviours occurring at the same time (e.g., two people in rocking chairs leaning forward simultaneously), while anti-phase movements are characterised by opposite movements occurring at the same time (e.g., one person in a rocking chair leans forward while the other person simultaneously leans back) (Hu et al., 2022; Reddish et al., 2013). Both are considered to indicate temporal entrainment, but in-phase synchrony is considered to be more stable (Kelso, 1995).

The presence and strength of synchrony can be measured both subjectively and objectively (Hove & Risen, 2009). To measure synchrony subjectively, some researchers have used Likert scales to ask participants whether their partner had temporally aligned with them (e.g., Koehne et al., 2016). Methods to objectively calculate synchrony include measuring participants’ mean response latency (the average interval between the participants’ movements; e.g., Cacioppo et al., 2014) and determining the percentage of actions that occurred “together” (as defined by co-occurring in a pre-defined temporal window; e.g., Hove & Risen, 2009).

1.3 Social effects of interpersonal synchrony

Engaging in interpersonal synchrony has been shown to influence typically developing individuals’ relationships in a number of ways. Research has found that interpersonal synchrony improves people’s cooperation (Knoblich et al., 2011; Sebanz et al., 2006; Valdesolo et al., 2010), helps synchronous partners develop a feeling of affiliation (Hove & Risen, 2009; Tunçgenç et al., 2015), and increases partners’ perceived trustworthiness (Launay et al., 2013). There are also a number of intrapersonal benefits, including reduced emotional and cognitive irritation (Göritz & Rennung, 2019), improved self-esteem (Lumsden et al., 2014), and greater self-agency and extended other-agency (Reddish et al., 2020).

Due to these effects, interpersonal synchrony has been shown to be one of the ways in which people develop and strengthen social bonds. Even in infancy in typically developing individuals, there is evidence suggesting that interpersonal synchrony encourages prosocial behaviour from infants that is specifically directed towards their social partner (Cirelli, Einarson, et al., 2014; Cirelli, Wan, et al., 2014). This is demonstrated by infants' increased helping behaviour towards individuals who moved synchronously with them (Cirelli, Einarson, et al., 2014; Cirelli, Wan, et al., 2014). Furthermore, infants' prosocial behaviour has also been found to extend to anyone who is a member of the partner's social group, as evidenced by infants' also demonstrating increased helping behaviour toward the synchronous partner's affiliates (Cirelli et al., 2016). Indeed, interpersonal synchrony is so integral to the formation of early relationships that one of the goals of infant-mother psychotherapy, also known as parent-infant therapy, is to help parents and infants have more synchronous behaviour as a means of promoting a healthier relationship (Leclère et al., 2014; Tyano et al., 2010).

As typically developing children get older, interpersonal synchrony remains important. In childhood, synchronous movements are often a key feature of physical play with peers (Powell et al., 2016; Timmons et al., 2007). A study investigating pro-social behaviours between children aged four to six years old found that children who engaged in synchronous play subsequently exhibited more spontaneous helping behaviours than those who engaged in asynchronous play

(Tunçgenç & Cohen, 2018). Similarly, children develop more positive opinions about peers who synchronise with them (Rabinowitch & Knafo-Noam, 2015).

Interpersonal synchrony has been shown to develop differently among individuals with neurodevelopmental conditions, including autism (Bloch et al., 2019; Bowsher-Murray et al., 2022). Atypical parent-infant interaction synchrony has even been thought to be an early indicator of autism in children (Cohen et al., 2013; Saint-Georges et al., 2011). Given the value of interpersonal synchrony in developing interpersonal relationships, researchers have taken an increased interest in autistic individuals' experiences with interpersonal synchrony.

1.4 Interpersonal synchrony in autism

Autism is a neurodevelopmental condition that is characterised by differences in social communication and social interaction (e.g., differences in social-emotional reciprocity, limited nonverbal communicative behaviours, differences in the development and understanding of relationships), and restrictive and repetitive patterns of behaviour (e.g., repetitive motor behaviours, insistence on sameness and routine, highly restricted and fixated interests) (American Psychiatric Association & American Psychiatric Association, 2013). As such, many autistic individuals find social interactions difficult or stressful (Halim et al., 2018). Considering autistic individuals' differing experiences with social relationships, and given social synchrony's value in promoting the development of social relationships among typically developing individuals, researchers have become increasingly interested in how autistic individuals experience interpersonal synchrony. Differences in how autistic and non-autistic individuals engage in interpersonal synchrony are evident from childhood. For example, while autistic children do engage in spontaneous motor synchrony with their parents in rhythmic tasks such as chair rocking, this is at a reduced level compared to non-autistic children (Fitzpatrick et al., 2017b; Marsh et al., 2013). There is also evidence that intentional motor synchrony with peers and adults is less stable in autistic children, with their movements being higher in variability (Fitzpatrick et al., 2017a; Kaur et al., 2018). In summary, autistic children's interpersonal synchrony is thought to be reduced in both its accuracy and frequency (Bowsher-Murray et al., 2022; McNaughton & Redcay, 2020).

There is also evidence suggesting that autistic individuals do not experience the same social effects of interpersonal synchrony as non-autistic individuals. For example, while non-autistic adults reported more empathy towards virtual avatars they had tapped synchronously with during a finger tapping task, autistic adults did not (Koehne et al., 2016). Similarly, while non-autistic individuals tend to perceive synchronous pairs as being socially closer, there is evidence suggesting that this effect is not as strong in autistic individuals (Au & Lo, 2020). As such, it appears that interpersonal synchrony may not promote prosocial attitudes and affiliative effects in autistic people in the same way it does for non-autistic people.

These differences in how autistic people produce and perceive interpersonal synchrony may be driven by differing experiences with some of the underlying mechanisms necessary to synchronise with others successfully.

1.5 Components of successful interpersonal synchrony in autistic and non-autistic individuals

Successful interpersonal synchrony is dependent on many different processes. This section will identify the key processes that are thought to impact interpersonal synchrony and discuss the ways in which autistic and non-autistic individuals may have different experiences with them. The processes discussed in this section are: temporal perception, action prediction, motor behaviour, social cues, and attentional load.

1.5.1 Temporal perception

Temporal perception impacts how individuals estimate the temporal relationship between stimuli (Binder, 2015). The ability to perceive whether one's behaviour is synchronous with a partner's is necessary for successful synchrony, and monitoring one's behaviour is necessary to correctly adapt it to be synchronised with one's social partner (Bowsher-Murray et al., 2022). Subjectively perceiving oneself to be synchronised with one's partner, rather than objectively being synchronised, is also thought to be vital to experiencing the social effects of interpersonal synchrony (Novotny & Bente, 2022). To measure how accurately individuals can identify the temporal relationship between stimuli, researchers often use temporal order judgement (ToJ) tasks, in which participants make judgements about the order in which different stimuli were presented, or simultaneity judgement (also called synchrony judgement, SJ) tasks, where participants must determine if stimuli occurred synchronously or successively (García-Pérez & Alcalá-Quintana, 2012; Miyazaki et al., 2016). These are often quantified with adaptive algorithms that either determine the interstimulus interval (ISI) at which participants can correctly identify the order or simultaneity of the stimulus with 70-75% accuracy (e.g., Kanabus et al., 2002; Kwakye et al., 2011), or average the ISIs at which errors were recorded (e.g., Simon & Balla, 2020).

There is conflicting evidence regarding whether autistic individuals have typical, reduced, or enhanced abilities for perceiving how unimodal stimuli are temporally related compared to non-autistic people (Casassus et al., 2019). For example, research shows that young autistic children have higher thresholds (i.e., poorer performance) than non-autistic children in an auditory ToJ task (Kwakye et al., 2011), but that thresholds were similar to that of non-autistic individuals in autistic adolescents (Poole et al., 2022; Stevenson et al., 2014) and autistic adults (Poole et al., 2022). When determining the temporal relationship of visual stimuli, research indicates that autistic individuals have similar thresholds to non-autistic individuals when completing ToJ tasks (Kwakye et al., 2011; Poole et al., 2022; Stevenson et al., 2014; Zhou et al., 2021). Autistic children have also been shown to have typical thresholds when completing SJ tasks with visual stimuli (Isaksson et al., 2018), but autistic adults have been shown to have lower thresholds (i.e., better performance; Falter et al., 2012).

For multisensory stimuli, the results are equally mixed. Some studies that utilise non-speech audiovisual stimuli (e.g., a flashing shape accompanied by a "beep"; or the audio and visual of a handclap) find that autistic children have higher thresholds (i.e., poorer performance) when completing ToJ tasks (de Boer-Schellekens et al., 2013; Kwakye et al., 2011), while others find that autistic children and adolescents have typical thresholds when completing SJ tasks (Bebko et al., 2006; Smith et al., 2017; Stevenson et al., 2014; Zhou et al., 2021). Studies using speech-based audiovisual stimuli typically measure temporal synchrony perception similarly to SJ tasks, often by having participants differentiate between a video in which the audio and visual stimuli are synchronised and a video in which there is an offset between the audio and visual stimuli. When researchers use face- and speech-based audiovisual stimuli (i.e., words and the accompanying mouth movements, occurring either simultaneously or asynchronously), they typically find that autistic individuals find it more difficult to differentiate between the synchronous and asynchronous videos that non-autistic people do (Bebko et al., 2006; de Boer-Schellekens et al., 2013, 2013; Grossman et al., 2015; Noel et al., 2018; Stevenson et al., 2014; Zhou et al., 2021). However, improved performance has also been found in autistic individuals compared to non-autistic individuals when detecting synchrony between speech and objects (e.g., a bouncing ball moving in time with spoken syllables; Zhou et al., 2021). In summary, the inconsistent results across studies indicates that differences in autistic individuals' synchrony perception compared to non-autistic individuals may be dependent on whether the stimuli are unisensory or multisensory, the type of stimuli used (i.e., objects, speech, faces), how this ability is measured, and participants' developmental stage.

While audiovisual stimuli may be more ecologically valid than unimodal stimuli, autistic individuals have also been shown to have difficulty with multisensory integration in tasks unrelated to the detection of synchrony (Taylor et al., 2010). Additionally, the social differences or difficulties that autistic individuals often experience (American Psychiatric Association & American Psychiatric Association, 2013) could hinder their performance when studies use social stimuli such as speech or faces. As such, tasks which use non-social unimodal stimuli may provide a better representation of an autistic individual's ability to perceive the temporal relationship of stimuli.

1.5.2 Action prediction

Action prediction, the ability to anticipate another's movements, is another important component in interpersonal synchrony (Gvirts Probolovski & Dahan, 2021; Meyer & Hunnius, 2020; Sebanz & Knoblich, 2009). In order to be truly synchronised with their partner, an individual must be able to predict their partner's movements rather than just react to them. For example, in order to successfully high-five, partners would need to anticipate the speed and trajectory of the other person's hand so that theirs accurately meets it. One way in which action prediction is measured is by using eye-tracking data to determine how accurately individuals can predict the reappearance of a moving object after it has moved behind an occluding object (Meyer et al., 2015). Research indicates that for both toddlers and adults, better action prediction abilities are associated with more stable and accurate temporal stability when completing a synchronous task with a partner (Meyer et al., 2015; Pecenka & Keller, 2011). This ability to predict and understand the movements of others is thought to develop in infancy (Reddy et al., 2013) and facilitates coordination with others (Sebanz & Knoblich, 2021).

Action prediction may be atypical in autistic individuals (Schuwerk et al., 2016). Some studies indicate that autistic individuals are less likely to accurately predict the actions of others from gaze (Pierno et al., 2006) and motion cues (Hudson et al., 2021). As such, autistic children find coordination significantly more difficult when they must predict people's movements from kinematic cues, but their coordination is on par with non-autistic children's when the action they are meant to match in a cooperative task is less ambiguous (i.e., when the end-point of a movement is known, rather than when they must interpret the end-point of the movement based on kinematic cues; Fulceri et al., 2018). A study has also found that autistic adults find it significantly more difficult to accurately predict the continued motion of an action after has moved behind an occluding object compared to non-autistic individuals (Gowen et al., 2022). Because synchrony requires partners to accurately anticipate each other's movements (Gvirts Probolovski & Dahan, 2021, 2021; Meyer & Hunnius, 2020), difficulties with action prediction are likely to make synchrony significantly more difficult.

1.5.3 Motor control

Motor control, referring to the ability to plan and execute one's own motor movements, is also an important component in successfully engaging in interpersonal synchrony. For example, in order to clap in time with someone else, one must have enough control over the movement and speed of one's own hands to ensure they meet in space at the correct time. Motor control encompasses fine motor skills (detail-oriented movements using small muscle groups) and gross motor skills (movements using large muscle groups that relate to stability and posture). Motor control can be measured in a number of ways, depending on the particular skill under investigation. The Movement Assessment Battery for Children: 2nd Edition (MABC-2), for example, tests children's fine motor skills by having them insert coins in narrow slots, thread beads on a string, and trace a route between two lines, and tests their gross motor skills by having them catch/toss beanbags and complete several balance assessments (Henderson et al., 2007). Infants typically struggle to entrain their movement to rhythms, which is thought to be related to the relatively poor motor control that people have early in life (Trainor & Cirelli, 2015). Motor skills and the accuracy of synchrony both develop and improve as children age (Drake et al., 2000; McAuley et al., 2006; Monier & Droit-Volet, 2019). As such, an individual's ability to control their motor behaviour is thought to be an important factor in successful interpersonal synchrony (Georgescu et al., 2020).

While not a diagnostic criterion for autism, many autistic children have differences in their gross and fine motor skills compared to non-autistic children, with these skills either being atypical or delayed in their development (Chawarska et al., 2007; Landa & Garrett-Mayer, 2006). Similarly, developmental coordination disorder (previously known as dyspraxia) is significantly more prevalent in both autistic children and adults than in non-autistic populations (Cassidy et al., 2016; Dziuk et al., 2007). Autistic children's motor difficulties are thought to be more pronounced in activities that require complex actions or core balance (Whyatt & Craig, 2012), but these difficulties are not exclusive to childhood. Autistic adults also report life-long difficulties with motor coordination in ways that impact many aspects of their lives (Gowen et al., 2023), and research indicates that autistic individuals have difficulties successfully integrating the information necessary for motor planning (Gowen & Hamilton, 2013). These difficulties could make it more challenging for autistic individuals to coordinate their actions and successfully synchronise with others.

1.5.4 Social cues and attentional load

The ability to attend to social cues is another key factor in achieving interpersonal synchrony (Bowsher-Murray et al., 2022). This skill relates to how well people attend to verbal and non-verbal social communicative cues, such as gaze, body language, and tone of voice. These cues must then be correctly interpreted to aid in the generation of synchrony. For example, people often use gaze and head movements to signal their intentions, and interpret others' cues to predict their intentions (Huang et al., 2015). This promotes successful interpersonal synchrony, as utilising non-verbal gaze cues has been shown to help people predict their partners' movements and thereby improve their coordination with their partners in cooperative tasks compared to when gaze cues were absent, measured by participants' reaction time (Khoramshahi et al., 2016).

Autistic individuals are thought to experience difficulties with interpreting, responding to, and using nonverbal communicative behaviours or social cues (American Psychiatric Association & American Psychiatric Association, 2013; Meindl & Cannella-Malone, 2011), especially compared to the ways in which non-autistic people automatically interpret them (Jellema et al., 2009). For example, autistic individuals often have delayed development in following others' gazes in social situations (Nation & Penny, 2008), which could impact the quality of their interpersonal coordination skills (Khoramshahi et al., 2016). This negatively impacts how autistic children respond to and initiate joint attention (i.e., when two people pay attention to the same object), as autistic children often display difficulties with initiating gaze-shifting and gestural joint attention (Charman et al., 2003; Loveland & Landry, 1986; Meindl & Cannella-Malone, 2011; Mundy et al., 1990), as well as being less responsive to non-verbal bids for joint attention (Loveland & Landry, 1986). Better performance in initiating and responding to joint attention are both correlated with increased interpersonal synchrony (Fitzpatrick et al., 2017a), further underlining the connectedness of successful synchrony and non-verbal social cues.

One theory for why social cues may be missed or misinterpreted by autistic people relates to attentional and perceptual load. Social interactions can be particularly taxing on attentional load

– not only do individuals need to engage in a form of "mindreading" to monitor and interpret their social partner's state of mind (Westra & Nagel, 2021), but there may also be a number of environmental distractors (Bowsher-Murray et al., 2022). Research indicates that autistic individuals' ability to attend to social stimuli is negatively affected by increased perceptual load (e.g., multisensory cues, motion), but their attention toward non-social stimuli, such as objects and places, remains unaffected (Haskins et al., 2022). In fact, researchers have found that when autistic individuals engage in interpersonal synchrony in situations with fewer attentional demands and social cues, such as when synchronising with an unseen partner via pressing a button, they perform similarly to non-autistic people (Koehne et al., 2016). As such, researchers have become interested in how autistic people experience interpersonal synchrony in other scenarios in which social demands are reduced, such as when interacting with a robot rather than a human.

1.6 Robots in social interactions

"Social robots" are robots that are intended for use in social interactions. These are contrasted with other robots that are designed to complete non-social tasks with minimal human interaction, such as manufacturing or packing. Social and non-social robots often differ in their morphology. While non-social robots may have a functional design (form follows function, e.g., a manufacturing robot consisting only of an arm), social robots are more likely to be humanoid, zoomorphic (i.e., resembling an animal), or caricatured (i.e., resembling a cartoon) (Barco et al., 2020; Bartneck et al., 2009; Fong et al., 2003). A robot's morphology is thought to significantly impact how it is perceived with regard to its anthropomorphism, social presence, and similarity to the observer, with humanoid robots ranking highly in these qualities (Breazeal, 2004).

Because perceiving a robot to be social and humanlike has been shown to facilitate the development of human-robot relationships (van Straten et al., 2020), humanoid robots are often selected for use in social settings (Belpaeme et al., 2018; Kouroupa et al., 2022).

1.6.1 Uses for social robots

Social robots are used in a wide range of environments: health care, education, work, public spaces, and the home (Leite et al., 2013). “Socially assistive robots” in healthcare settings are often intended to augment care by both improving health outcomes and making the therapeutic process more enjoyable (Matarić et al., 2007). One such robot is the humanoid Pepper robot, which has been used to help older patients with dementia and schizophrenia with rehabilitation activities (Sato et al., 2020). However, not all social robots are humanoid. Examples of this include the use of the seal-shaped therapeutic robot Paro in care homes, which helped to strengthen social bonds and lower stress in older residents (Wada & Shibata, 2006a, 2006b, 2007). Researchers have also found success in introducing the dog-like robot AIBO to autistic children with the goals of encouraging play, promoting reasoning skills, and eliciting displays of affect (François et al., 2009).

In educational settings, robots are most often used to teach language, science, or technology-related subjects, and they can take the roles of a peer, a tutor, or a tool (Mubin et al., 2013). For example, a robot could act as a peer by praising students when they pronounce words correctly in a language lesson (Han & Kim, 2009). Similarly, the robot could act as a tutor by adapting the difficulty of mathematics exercises based on children’s performance (Janssen et al., 2011), or as a tool by enabling students to investigate its sensors as a way to learn about physics (Church et al., 2010).

Robots fill a wide variety of functions in work environments, public spaces, and the home. These include practical uses, such as the transportation of materials in hospitals like Robotdalen's "RobCab" (Lundqvist, 2008) and guiding guests in banks like YDreams's "Siga" robot (Medeiros, 2011), but they are also used for entertainment, such as the animatronic characters used in Disney parks. Similarly, different kinds of robots in the home can take on many roles, such as a cleaner (Sung et al., 2009, 2010), a pet (Fernaeus et al., 2010), or a social companion (Klamer et al., 2011).

1.6.2 Attitudes towards social robots

The increase in the number of robots in daily life has driven increased attention to the study of human-robot interaction (HRI). A systematic review of people's attitudes towards social robots found while people are typically willing to use social robots, many factors influence people's anxiety about, trust in, and acceptance of robots (Naneva et al., 2020). For example, people typically have less trust in social robots intended for healthcare settings compared to robots which are intended for general human interaction, such as playing games or having conversations (Naneva et al., 2020). Culture can also impact perceptions of robots, as HRI studies conducted in Italy typically report more positive affective attitudes towards robots than those conducted in Germany, Japan, or the USA (Naneva et al., 2020). In summary, attitudes towards robots, while generally positive, are not universally consistent and instead can vary depending on the role the robot is meant to fill and the culture it operates within.

While social robots are not sentient beings with thoughts and feelings, they do often take on roles typically filled by humans. As such, the degree to which robots are anthropomorphised has also been under investigation. The term “anthropomorphism” has been used differently across various domains of research, but for the purpose of this thesis, it refers to the tendency to attribute human characteristics to non-human entities such as animals or inanimate objects. In essence, anthropomorphising an entity is to rationalise its behaviour by attributing cognitive or emotional states to it (Duffy, 2003). This rationalisation is related to the “intentional stance”, or the strategy of interpreting an entity’s behaviour as though it were a rational agent that considers its own beliefs and desires when choosing its actions (Dennett, 1997; Duffy, 2003). This inherently means that one assumes the entity has beliefs, desires, and the ability to choose its actions, when in reality, that may or may not be true. As such, when anthropomorphising a robot, humans may interpret a robot to be acting out of its own volition rather than due to its programming or external controls.

Research has also been conducted regarding how children perceive robots. Various factors can influence whether children interpret a robot to be a person or an object, such as the child’s age or how the robot is operated. For example, younger children are more likely to perceive the robot as a person, but not if they directly observe the researcher operating the robot (Cameron et al., 2017). Similarly, the extent to which children believe that robots have agency has also been shown to decline with age, likely as a result of children further developing an understanding of the technology’s limitations (Flanagan et al., 2023). Research also shows that younger children are more likely to ascribe human characteristics to robots than older children, such as believing that a robot would be able to remember them or could tell how they felt

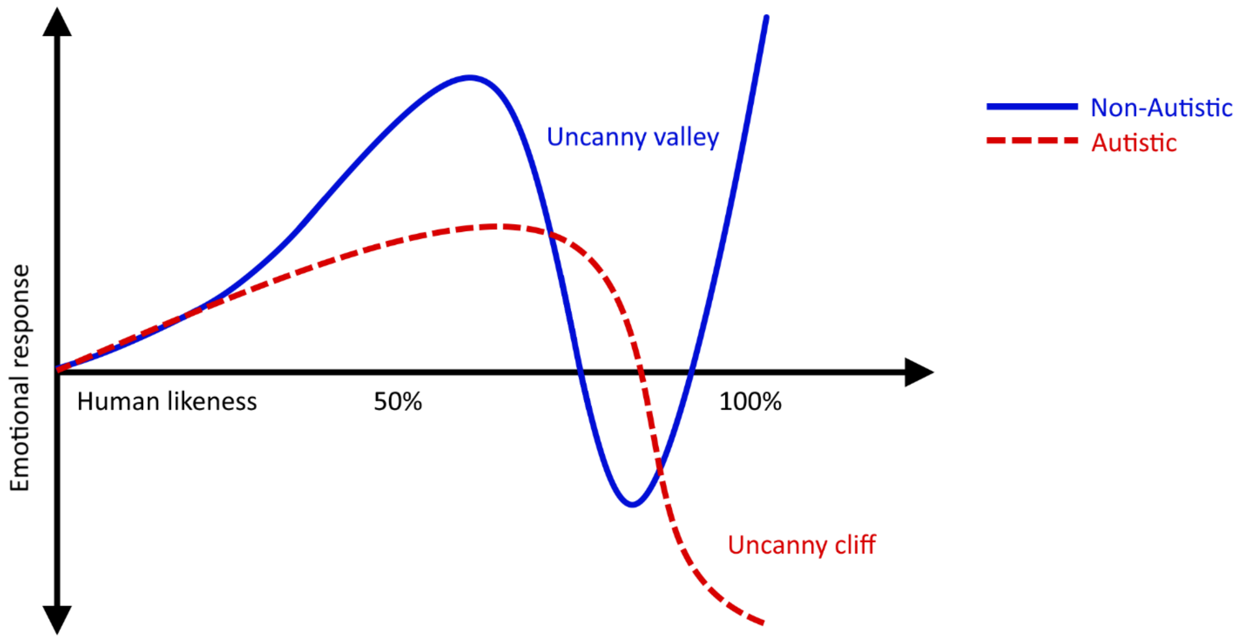
(Beran et al., 2011). Children are also more likely to anthropomorphise robots to a high degree if they have previous exposure to media reports about nonfictional robots (Kühne et al., 2024). Anthropomorphising robots, such as believing that robots can feel emotions, has been shown to increase prosocial behaviour in children towards robots (Nijssen et al., 2021). Many children also appear to conceptualise robots as occupying a middle ground between a living thing and an inanimate object (Cameron et al., 2015; Melson et al., 2009).

Children's attitudes about robots can also vary depending on whether the children are autistic. Young autistic children are more likely to identify robots as machines than non-autistic children (Peca et al., 2014). However, autistic children are also more likely to incorrectly ascribe human-like qualities to humanoid robots, such as the ability to grow up or feel pain (Zhang et al., 2019). While these qualities may seem incompatible, children often treat robots as a new "species" of animate or inanimate things (Szymona et al., 2021). One theory that reconciles these seemingly-conflicting ideas about robots is that children may not simply interpret robots through the binary lens of being "alive" or "not alive" but may instead mentally develop the ontological category of "robots" trait-by-trait (Okita & Schwartz, 2006). Similarly, young children often struggle to fully grasp and differentiate the concepts of "alive" and "inanimate" (Okita & Schwartz, 2006). This makes it possible for autistic children to believe that a robot is both a machine and capable of feeling pain.

Research also suggests that non-autistic and autistic children may have different preferences regarding the physical appearance of robots. While non-autistic children seemed averse to the lifelike humanoid robot Kaspar in one study, many autistic children did not mind it (Peca et al., 2014). This could be due to autistic children being less susceptible to the "uncanny valley" (Feng et al., 2018), a phenomenon in which people experience aversion to entities such as robots that approach but fail to attain a lifelike appearance (see Figure 1.1, Mori et al., 2012). Researchers theorise that this may be a result of autistic children being less sensitive to subtle changes in facial features, which typically developing children may find unsettling (Feng et al., 2018). Other research suggests that autistic children instead have an uncanny "cliff": when entities become extremely humanlike, thus passing beyond the uncanny valley for typically developing children and again becoming favourable, only then do these entities elicit negative emotional responses from autistic children (see Figure 1.1; Ueyama, 2015). As such, autistic and non-autistic children can have very different reactions to robots depending on how "human" the robot appears to be.

Figure 1.1

Mori et al.'s "Uncanny Valley" (2012) vs. Ueyama's "Uncanny Cliff" (2015)



Note. The solid blue line shows the "uncanny valley" proposed by Mori et al. (2012). The dashed red line shows the "uncanny cliff" proposed by Ueyama (2015), which is thought to represent the experiences of autistic individuals.

1.6.3 Using social robots with autistic children

1.6.3.1 Benefits of using robots

For autistic children, robots can present unique opportunities for social interaction in ways that are less overwhelming. While some robots are capable of realistic humanlike facial expressions and body language, many of the robots most commonly used with children are not. The NAO robot by SoftBank Robotics, for example, is the most purchased humanoid robot in the world (Gelin, 2018), and its "facial expressions" are limited to changing the colour of the LED lights in its eyes. As such, autistic individuals who find it difficult to process social information, either in isolation or in combination with other distractors, could have different experiences with robots. Autistic individuals often find it easier to pay attention to objects rather than social cues when there are multiple demands on their attention (Haskins et al., 2022), so they may be better able to attend to robots instead of humans. Beyond environmental distractors, aspects of human-human interactions may also present an abundance of information and distractions, such as the necessity to interpret body language and maintain eye contact. As such, professionals who work with autistic children have identified that because robots typically lack many of these features (e.g., realistic facial expressions), autistic children may find these aspects of the interaction to be less distracting than interacting with humans (Huijnen et al., 2018).

Many professionals who work with autistic children are interested in using social robots because they feel that robots may be more approachable and engaging than a human who would be filling the same role (Huijnen et al., 2018). Furthermore, researchers also anticipate that some children will enjoy interacting with robots, which could, in turn, increase their attention and motivation (Huijnen et al., 2018). As such, there has been increased interest in the possibility of using robots as a means of delivering therapeutic interventions (Alabdulkareem et al., 2022; Pennisi et al., 2016; Ricks & Colton, 2010). The effectiveness of robots in interventions to facilitate imitation (Boccanfuso et al., 2017; Rakhymbayeva et al., 2021), turn-taking (Mengoni et al., 2017; Taheri et al., 2018), emotion recognition (Marino et al., 2020), and joint attention (Ghiglino et al., 2021; Yun et al., 2016) has since been studied. There has also been interest in using robots to support autistic children in educational settings with the aim of improving their learning outcomes and social capabilities (Ismail et al., 2012; Yang et al., 2024).

Social robots are also becoming increasingly popular as a data collection tool. Due to their programmable nature, robots typically offer more experimental control than paradigms including humans (e.g., ability to consistently repeat the exact same motions or gestures) while still offering increased social presence and ecological validity compared to purely screen-based experimental designs (Chevalier et al., 2020). For autistic children in particular, researchers have found that robots are better able to facilitate both verbal and nonverbal emotional expressions from participants than humans (Giannopulu et al., 2014b). Some researchers report that autistic children may perceive robots to be safer, more trustworthy, more predictable, and less threatening than a human person might be (Huijnen et al., 2018). These benefits can make robots a useful tool for data collection in research studies. For example, researchers have used a nodding robot to investigate how nonverbal behaviour facilitates verbal and nonverbal emotional expressions in autistic children (Giannopulu et al., 2014b). Similarly, other researchers have developed a protocol for using robots to elicit certain behaviours from young children to aid in the early diagnosis of autism (Golliot et al., 2015). However, this approach seems to reflect the minority of robotics studies with autistic participants, with most studies focusing either specifically on human-robot interactions or on the viability of using robots in therapeutic interventions.

1.6.3.2 Challenges of using robots with autistic children

While there are benefits to utilising robots, interacting with robots can be challenging for some autistic children, particularly upon initial introduction. While some autistic children may find robots to be more approachable than humans, others may dislike robots or even be afraid of them (Huijnen et al., 2018). As such, researchers report autistic children withdrawing from studies due to not wanting to interact with a robot (Bekele et al., 2014; Ghorbandaei Pour et al., 2018; Huijnen et al., 2021; Petric et al., 2017; Short et al., 2017). Because many autistic children do not like changes to their routine (Leekam et al., 2011), they could find it difficult meeting a robot for the first time. This may be amplified as a result of the sensory sensitivities that autistic children often experience (Leekam et al., 2007), as robots may incorporate many lights, sounds, and textures that could distract or even distress autistic children.

Research into the efficacy and ethics of using robots with children is still developing. Researchers have successfully used robots in educational settings to help non-autistic children develop various skills such as language development skills and problem-solving (Toh et al., 2016), as well as in interventions to aid in autistic children's speech and social communication skills via scaffolding through interactive games (Boccanfuso et al., 2017). However, due to the heterogeneity of autism, it is difficult to design comprehensive robot-based interventions that are effective in this diverse population (Abu-Amara et al., 2021). Research indicates that parents of autistic children are often happy for their children to interact with robots in therapeutic settings, provided that the robot is intended to support the interactions between the therapist and their child rather than replace the therapist (Coeckelbergh et al., 2016). However, some autistic researchers feel that many robot-led interventions are too deficit-based and are focused on '"fixing" autistic children (Hundt et al., 2024), citing the fact that increasing eye contact in autistic children is the most common application for these robots (Damianidou et al., 2020) despite the fact that this is not a desired goal for many autistic people (Chazin et al., 2025).

1.6.3.3 Successfully introducing autistic children to robots

Supporting autistic individuals in research studies. Within and beyond HRI studies, there is a growing awareness of the need to support autistic individuals taking part in research. Researchers have worked to establish guidelines for supporting autistic individuals when they participate in research. These recommendations cover every aspect of the research process, starting from the development of the research questions and continuing through to the dissemination of study results (Gowen et al., 2019).

Regarding participant comfort during the study, researchers stress the importance of sharing as much information as possible about the study and its location with the participant (e.g., showing exactly how to get to the study location, sharing exactly what they will be asked to do during the study), and doing so in a way that is easy for participants to understand (Gowen et al., 2019; Pellicano et al., 2017). Individuals working with autistic people should also create an enabling environment by asking about the participant's specific needs, utilising a testing space that is free from common sensory distractions (e.g., loud background noises, flickering lights, busy patterns), and respecting the steps that individuals may take to reregulate (e.g., wearing ear defenders, stimming) (Pellicano et al., 2017). Similarly, researchers should monitor participants' energy, motivation, and behaviour for signs that they need a break or may not wish to complete certain study tasks, especially in participants who struggle with verbal communication (McKinney et al., 2021). Some researchers have suggested learning about autistic participants' preferences and needs beforehand by using existing frameworks from the healthcare and criminal justice fields, such as “passports” that provide participants with an opportunity to communicate relevant information about themselves (Ashworth et al., 2021).

Existing guidelines focus on how to interact with the autism community in general, and there is an absence of literature addressing difficulties that may be more common among autistic children specifically. Typically, children are more fearful than adults are (Craske, 1997). Combined with autistic individuals’ higher likelihood of experiencing anxiety and struggling in new situations (Accardo et al., 2022; Boulter et al., 2014; Gotham et al., 2013; van Steensel et al., 2011), there are likely to be additional considerations to ensure the comfort and wellbeing of autistic children. Additional research is therefore needed to determine how to best support autistic children in research contexts, especially when they will be interacting with unfamiliar equipment such as robots.

Familiarisation techniques. One way to support autistic children when meeting a robot is through the use of familiarisation techniques, which are steps taken to introduce the child to the robot in a way that feels positive and supportive (Wallbridge et al., 2024). However, there is no standardised familiarisation protocol for helping autistic children feel comfortable around robots (Wallbridge et al., 2024). Furthermore, most studies that involve an autistic individual interacting with a robot either do not include a familiarisation phase or do not include sufficient detail about their familiarisation phases for others to understand what the participant and robot did (Wallbridge et al., 2024). Of the minority of studies that did include information regarding how they familiarised autistic participants with robots, a systematic review has identified a number of approaches that have been used (see Table 1.1; Wallbridge et al., 2024).

Table 1.1

Familiarisation techniques for successfully introducing autistic children to robots

Familiarisation technique	Description
Capability demonstration	Show the participant all the capabilities of the robot
Static exploration	Let the participant explore the physical form of the robot while it is static and unresponsive
Stimulus and response	Encourage two-way interactions between the participant and the robot
Initial experimental session	Familiarisation phase is identical to an experimental phase
Remote control	The participant operates the robot
Free play	Participant chooses how to interact with the robot

Note. These techniques were identified by Wallbridge et al., 2024.

As identified by Wallbridge et al. (2024), many researchers choose to introduce the participant to the robot by showing everything that the robot can do (capability demonstration; e.g., Giannopulu et al., 2014a; Pop et al., 2013; Robins et al., 2004). For example, one study had a trusted adult demonstrate all of the robot's capabilities and label each of its different facial expressions (Schadenberg et al., 2020). Another had the robot move in a way that let the participant see its entire body and demonstrated the features of its multimedia system (Goulart et al., 2019). Similarly, some studies had the participant practise a phase of the actual experiment with the robot as a means of helping familiarise them with it (initial experimental session; e.g., Aryania et al., 2020; Kajopoulos et al., 2015; Pliasa et al., 2021). These approaches have the benefit of enabling the child to get used to the robot's presence and capabilities so that nothing comes as a surprise later on in the study during data collection (Wallbridge et al., 2024).

Another familiarisation approach involves two-way interactions between the robot and the participant (stimulus and response). Many studies utilise question-and-answer sessions (e.g., Aziz et al., 2015; Malik et al., 2013; Tapus et al., 2012), while others had the robot make requests of the participant (Korneder et al., 2021) or react when the participant touched it (Golliot et al., 2015). This approach was thought to encourage active engagement from the participants (Wallbridge et al., 2024). Other researchers utilised a more participant-led approach by having the participant touch the robot while it was powered off or otherwise static (static exploration; e.g., Brivio et al., 2021; Fachantidis et al., 2020; Karakosta et al., 2019). This enabled participants to familiarise themselves with the robot's physical form without the risk of being startled by any sudden movements or reactions by the robot (Wallbridge et al., 2024). Research also indicates that touching a robot can promote a sense of friendship with it (Park & Lee, 2014). Some researchers enabled participants to take the lead by letting them control the robot's actions using a remote control (e.g., Boccanfuso et al., 2017; Brivio et al., 2021; Kumazaki et al., 2019).

The inclusion of a familiarisation phase has been shown to be an effective method for promoting the comfort of participants and reducing participant withdrawal. In Petric et al., researchers reported an unsuccessful pilot study in which only one of the seven recruited non-autistic children completed the experimental task with the robot (Petric et al., 2017). The authors largely attributed this to the participants being too wary of the robot to approach or engage with it. After further developing their familiarisation phase based on feedback from the parents and children who participated in the initial trials, only two of the 19 total autistic and non-autistic children withdrew from the main study. Other fields have also found success in using familiarisation strategies to help autistic children feel comfortable during research studies. For example, researchers using magnetic resonance imaging (MRI) machines identified that autistic children can often find the process difficult because they are required to remain still in an unfamiliar, noisy, confined space (Pua et al., 2020). In addition to the ethical concerns of putting autistic children in environments that may cause them to feel distressed, children often become restless when uncomfortable, the movement of which can severely negatively impact the quality of the imaging data (Raschle et al., 2012). To address these issues, researchers successfully developed a child-focused familiarisation approach that used pre-visit interviews, orientation videos and games for parents and children to complete together before their visit, an MRI orientation session, and a mock MRI scan that helped children successfully complete the study (Pua et al., 2020). Other researchers have had similar success using familiarisation techniques to help autistic children participate in studies that utilise electroencephalogram (EEG)/event-related potential (ERP) technology (Turcios et al., 2017) and mixed reality (MR) technology (Leharanger et al., 2023).

While there are many options for designing familiarisation phases for HRI studies, it is difficult to determine which familiarisation techniques are the most effective in promoting participant comfort. One indirect metric of this would be participant withdrawals, but most studies analysed in the systematic review did not include details regarding if, when, and why participants withdrew (Wallbridge et al., 2024). Additionally, it is unknown whether any of these approaches were developed with input from autistic children and their parents. As such, it is necessary to investigate which approaches are the best at helping autistic participants feel comfortable when meeting a robot, as well as which approaches are preferred by autistic children and their parents. Implementing these findings should yield more successful testing sessions and encourage future research participation from autistic children and their parents.

Familiarisation sessions, although often beneficial for participants, should be designed carefully to protect experimental control in the study. For example, methods that allow participants to familiarise themselves with the robot and the study protocol by practising an exact copy of the experiment may not be appropriate for studies in which the stimuli presented are meant to be novel to the participants. Similarly, promoting a strong positive relationship between the robot and the participant during the familiarisation session may not be appropriate if the participant's feelings toward the robot are a dependent variable in the experimental portion of the study. As such, even the "best" approaches are unlikely to be universally applicable and should be modified to suit the goals of each particular study.

1.7 Interpersonal synchrony and robots

Research has been conducted to determine how interpersonal synchrony differs between human-human and human-robot interactions. One such area has been whether people naturally tend to engage in synchrony with robots in the same way they often automatically do with other humans. There is evidence suggesting that synchrony does not emerge as readily when a non-autistic person is interacting with a robot compared to when they interact with other humans. For example, one study found that while a moving non-humanoid robotic arm did prompt imitation from participants, the response was not as strong as that produced by a human arm (Press et al., 2005). Others have found that synchrony does not successfully emerge with robots that do not adapt their movements to their partners', suggesting that bidirectional coordination is an important aspect of synchrony and that human partners do not completely take over the additional necessary cooperative effort that their robotic partner does not provide (Lorenz et al., 2013; Marin et al., 2009). However, for robots that were able to adapt their movements to their human partner's, the pair's movements synchronised and stabilised much more readily (Miyake, 2009). Together, these findings suggest that the more human-like a robot is in its appearance and adaptation of its movements, the more readily and easily people will synchronise with it in non-autistic populations.

Another area under investigation has been the social effects that non-autistic people typically receive from synchrony. It has been established that humans are capable of exhibiting positive feelings and behaviours towards robots, such as empathy (Kwak et al., 2013), trust (Schaefer, 2013), and intervening when a robot appears to face mistreatment (Connolly et al., 2020). However, because robots serve as a conceptual midpoint between a social partner and an inanimate object, the social effects experienced when interacting with robots may not be the same as those experienced with humans. As such, researchers have questioned whether acting synchronously with a robot can encourage these feelings and behaviours. When non-autistic people do synchronise with robots, there is conflicting evidence regarding whether social effects emerge. One study found that there was no difference in how much participants liked robots they moved synchronously with compared to asynchronous robots, nor was there a difference in the level of social motivation that participants experienced towards the different robots

(Henschel & Cross, 2020). However, a different study found that watching a robot synchronise with a researcher improved the robot's likeability compared to robots that did not (Lehmann et al., 2015), while another study investigating experienced synchrony found that children preferred robots that moved asynchronously with the children rather than synchronously (Sweezy, 2023).

The differing results between studies could be due to the degree to which participants anthropomorphised the robots, as humans only experience the social effects of synchrony if they attribute a mind to their social partner (Lorenz et al., 2016; Wheatley et al., 2012). Because humans often determine whether something has a mind based on a range of converging factors, such as the way in which an entity moves, looks, and speaks (Kilner et al., 2007; Stanley et al., 2007; Wheatley et al., 2012), multiple aspects of a robot's construction and programming could promote or interrupt this attribution and by extension the social effects of synchrony. For example, the study which found that witnessed synchrony improved likability used a non-humanoid Care-O-bot3 (Lehmann et al., 2015). Synchronous movement from this robot could indicate a level of intentionality and responsiveness that suggests the presence of a mind, despite its appearance not suggesting sentience. However, the experienced synchrony study which found that asynchronous robots were preferable utilised a humanoid NAO robot (Sweezy, 2023). These researchers speculated that the asynchronous robots in the study moved in ways that were interpreted as unexpected or unpredictable, which may have appeared more human if children expected that robots could only move in accordance with certain rhythms (Sweezy, 2023). The asynchronous movements could even be interpreted as the robot having its own personality or character, which is considered to be a human social characteristic (Fong et al., 2003). As such, synchrony can make the robot appear to be more or less autonomous depending on its other characteristics. However, because autistic individuals often interpret social cues differently than non-autistic people (Jellema et al., 2009) and also experience human-human interpersonal synchrony differently than non-autistic people (Bowsher-Murray et al., 2022), it is unknown whether these findings would be similar among autistic participants.

The ways in which synchrony with robots has been measured thus far also may not be suitable for studies that include autistic children. For example, some studies had the participant complete a task while the robot moved either synchronously or asynchronously with them (Henschel & Cross, 2020). However, atypical attention is common in autistic individuals (Ames & Fletcher-Watson, 2010) and given the high co-occurrence of autism and ADHD (Bougeard et al., 2021), this setup may make it difficult for autistic children to both focus on their assigned task and pay attention to the robot's behaviour. Indeed, accurately perceiving the behaviour of the robot while focusing on a different task has been demonstrated to be a challenge even among typically developing adults. In one study that used this method, a manipulation check showed that 11 of 56 participants (19.6%) failed to accurately report whether the robot had moved synchronously or asynchronously with them (Henschel & Cross, 2020). As such, this is likely not an ideal paradigm for autistic children. Another study had the participant and the robot clap along to the same metronome, presented as a game that they would play together as partners (Sweezy, 2023). While this may make the synchrony or asynchrony more salient, this too comes with problems. Because autistic children often have motor skills that are atypical or delayed in their development (Chawarska et al., 2007; Landa & Garrett-Mayer, 2006), they may have trouble physically matching the tempo of the metronome exactly. Because the robot is synchronised with the metronome rather than the child, this means there is no way to guarantee that the robot and child are exactly synchronised, nor is there a way to tightly control the degree to which they are out of synchrony. As such, studies measuring the effects of synchrony between autistic children and robots will likely have more validity if they do not present a secondary task which might fully command the child's attention, and ensure that the robot is exactly synchronised with the child rather than an external tempo regardless of how irregular the child's actions are.

1.8 Summary of existing literature and thesis outline

Interpersonal synchrony is an important factor in the formation of social bonds, impacting both how individuals feel about others and how they act towards them (1.2 and 1.3). However, interpersonal synchrony is often experienced differently by autistic people (1.4). This could be due to differences in many of the underlying components of successful interpersonal synchrony, such as temporal perception processing (1.5.1), action prediction (1.5.2), motor behaviour (1.5.3), social cues, and attentional load (1.5.4). It is unclear as to the degree to which these experiential differences with interpersonal synchrony are the result of differing attention to and interpretation of social interactions, or underlying differences in how accurately autistic people can perceive and produce synchrony. Autistic children may find it easier to socially interact with robots than with humans, but special care should still be taken to ensure participant comfort when autistic children are meeting robots in a research setting (1.6). Research indicates that synchrony with robots may be more difficult to achieve than with humans, and there is conflicting evidence regarding the social effects of this synchrony (1.7).

This thesis aims to contribute to the understanding of autistic children's experiences with interpersonal synchrony in human-human and human-robot dyads. This will be done by examining underlying processes that contribute to their interpersonal synchrony, whether they are sensitive to the social effects of synchrony when it is experienced themselves or witnessed in others, and comparing the ways in which autistic and typically developing children are socially sensitive to witnessed and experienced synchrony with humanoid robots. The following questions are addressed:

(1) To effectively utilise robots in studies with autistic children, how can researchers first familiarise autistic children with robots during a laboratory visit?

(2) Compared to non-autistic children, how accurate are autistic children's perceptual and motor synchrony abilities in the absence of confounding demands such as action prediction and social cues?

(3) When witnessing a human-human dyad, to what degree are autistic children sensitive to the social effects of synchrony compared to non-autistic children? Is this different when they are instead witnessing a human-robot dyad?

(4) Do autistic and non-autistic children experience the social effects of interpersonal synchrony when synchronising with a humanoid robot?

1.8.1 Overview of experimental chapters

Chapter 2 investigates the efficacy of various familiarisation techniques for helping autistic children feel comfortable interacting with robots in a research setting. These techniques are evaluated in a mixed-methods two-part study by interviewing autistic children and their parents, and a laboratory visit in which autistic children are introduced to robots using the familiarisation techniques.

Chapter 3 investigates differences in how autistic and non-autistic children perform at fundamental processes that contribute to synchrony, measuring them in the absence of confounds such as social processing and multisensory processing. This is done using a SJ task to determine the threshold at which autistic and non-autistic children can differentiate between auditory synchrony and asynchrony, and a tapping task to measure how accurately they can physically entrain to auditory stimuli.

Chapter 4 explores how autistic and non-autistic children experience the potential social effects of interpersonal synchrony. This will be done by measuring the perceived affiliated effects of witnessed synchrony between human-human and human-robot pairs, and what affiliative effects they experience when a humanoid robot taps with them either synchronously or asynchronously.

Chapter 2 Statement of Authorship and Commentary

The paper listed below has been included in the thesis.

McGregor, Carly; von dem Hagen, Elisabeth; Wallbridge, Christopher; Dobbs, Jenna; Svenson-Tree, Caitlyn; Jones, Catherine R. G. (Forthcoming 2025). Supporting Autistic Children's Participation in Research Studies: A Mixed-Methods Study of Familiarising Autistic Children with a Humanoid Robot. *Autism & Developmental Language Impairments*.

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CM contribution: 80%

CM developed the methodology with assistance from CJ, EVDH, and CW. CM and JD collected the data. CM and CST carried out the analysis, with the assistance of CJ, EVDH, and CW. CM led the writing of the paper with input from CJ, EVDH, and CW.

Because I intend to use robots to investigate children's social responses to synchrony, it is first necessary to determine how to ensure that autistic children feel safe and supported when meeting a robot in a laboratory environment. This is necessary from both an ethical and practical perspective, as autistic children are at increased risk for experiencing distress when encountering something new in their environment, which has been shown to lead to participant withdrawal. Furthermore, because I planned to measure children's affiliation towards robots, it was necessary to determine how to reduce autistic children's potential fear of the robots, as strong negative emotions would likely negate any possible positive social effects from synchrony. Familiarisation methods for promoting autistic participants' comfort exist, but they are not standardised, nor are they typically created with input from members of the autistic community. As such, it was necessary to evaluate the effectiveness of these methods and incorporate the opinions of autistic children and their parents.

Chapter 2

Supporting Autistic Children's Participation in Research Studies: A Mixed-Methods Study of Familiarising Autistic Children with a Humanoid Robot

2.1 Introduction

The importance of promoting inclusivity and positive experiences for autistic individuals who participate in research is becoming increasingly recognised (e.g., Gowen et al., 2019; Haas et al., 2016; Pellicano et al., 2017). Many autistic characteristics, such as sensory sensitivities (Yuan et al., 2022), the need for routine (Louis-Delsoin et al., 2024), and communication difficulties (Askari et al., 2015), may present as barriers to study participation. Co-occurring features, such as anxiety (e.g., van Steensel et al., 2011) and intolerance for uncertainty (e.g., Boulter et al., 2014), can also limit inclusion. Not only do researchers have a responsibility to ensure participation is as comfortable and as positive as possible, but inclusive research practices are key to ensuring that autism research is not limited to a narrow range of autistic people.

Guidance exists for researchers on how to promote the comfort of autistic participants during research participation. These recommendations include environmental considerations, such as considering the sensory environment and providing breaks during testing, as well as the provision of clear instructions, both on what will happen during the testing session and how to find the venue (Gowen et al., 2019). Guidelines framed specifically for autistic adults also highlight the importance of accessible consent processes and offering multiple modes of participation (Nicolaidis et al., 2019). Related to this is the recommended use of research passports, which can help autistic people communicate their needs and preferences to researchers (Ashworth et al., 2021). Researchers have also developed recommendations for working with autistic children who are non-speaking or who have intellectual disabilities, and stress the importance of monitoring participants' energy levels and paying attention to behavioural signs that the participant may not wish to continue testing (McKinney et al., 2021). However, existing insights and recommendations are based on surveys of the literature, reflections on researchers' own experiences, or consultation with autistic adults or parents of autistic children of their previous experiences with research. To date, no research study has used preparation for or participation in a research study to directly generate insights from autistic people or family members.

Research involving children necessarily involves additional considerations compared to adult participants (Fargas-Malet et al., 2010), and this is particularly the case for children with additional needs. For autistic children, a relevant consideration is how they might experience the novel equipment that is often a feature of experimental studies. Autistic children are often invited to take part in studies that include specialist equipment, including neuroimaging (Rafiee et al., 2022), eye tracking (Papagiannopoulou et al., 2014), virtual reality (Chen et al., 2022), and robots (Alabdulkareem et al., 2022). Research with robots, particularly with a focus on human-robot interaction (HRI), has become increasingly popular in recent years. Robots are often favoured as a data collection tool because of the experimental control they afford (e.g., Chevalier et al., 2020; Giannopulu et al., 2014; Golliot et al., 2015). Human experimenters may send unintentional messages via subconscious modifications to their voice or facial expressions, but this can be tightly controlled in HRI studies (Huijnen et al., 2018). Other studies focus on HRI specifically, using robots in interventions to improve the wellbeing of autistic children (e.g., Boccanfuso et al., 2017; Fachantidis et al., 2020; Huijnen et al., 2021; Kajopoulos et al., 2015).

Autistic children can find meeting a novel robot in an experimental setting difficult, leading to discomfort, distress, and even participant withdrawal (Huijnen et al., 2021; Short et al., 2017). There are a range of factors that may make the experimental setting uncomfortable for autistic children. Many of these, including the disruption to routine and the introduction to unfamiliar people and settings, are generalisable to many types of study. However, there are likely additional challenges that occur when meeting an unfamiliar robot. Indeed, researchers have identified the engineering challenge of designing robot interactions in a way that is both engaging and perceived as nonthreatening for children (Scassellati et al., 2012). Specific anxiety about the robot has been highlighted as a driver of discomfort in previous HRI studies with autistic children (e.g., Di Nuovo et al., 2020; Petric et al., 2017). Difficulties with tolerating the uncertainty of the robot's behaviours (e.g., Boulter et al., 2014) and sensory discomfort (e.g., Kirby et al., 2022) are additional factors that may be relevant.

Familiarisation phases are a potential way of helping autistic children overcome discomfort when meeting a robot. A familiarisation phase is an initial phase of an experiment designed to introduce participants to key aspects of the methodology, and is used in HRI research (Wallbridge et al., 2024). Previously, including a familiarisation phase in an HRI study reduced the withdrawal rate of autistic child participants from 87.5% to 10.5% (Petric et al., 2017), indicating they can have a significant impact. Our systematic review of the familiarisation strategies used by researchers to introduce autistic participants found that a wide variety of approaches were used (Wallbridge et al., 2024), such as showing the participant what the robot can do, or having the participant and the robot participate in an activity together. However, the majority of studies that reported using a familiarisation phase provided limited detail. As such, understanding of familiarisation approaches remains limited. Other researchers who use specialised equipment that would likely be unfamiliar to children, such as magnetic resonance imaging (MRI) scanners, have successfully taken steps to generate bespoke guidance for familiarising autistic children with their study equipment (Tziraki et al., 2021). Although familiarisation methods do exist within the field of HRI (Wallbridge et al., 2024), there has been no specific exploration of the success of these techniques, including the perspectives of parents and autistic children.

In the current study, our primary aim was to investigate how to promote the comfort and enjoyment of autistic children in research, using the specific example of meeting a humanoid robot in a laboratory setting. By using a real-world example, we wanted to generate nuanced and ecologically-valid insights that could complement previous consultation work (e.g., Gowen et al., 2019; Nicolaidis et al., 2019). Additionally, we wanted to focus on the voice of autistic children and their parents. As such, we used a two-phase, mixed-methods design that involved a preparatory interview and a study visit. In the first phase, we conducted online semi-structured interviews with parents to discuss how to promote their children's comfort in a research setting, alongside a more specific exploration of the suitability of various robot familiarisation techniques. In the second phase, their children visited our lab to meet a humanoid robot, giving opportunity to explore the effectiveness of different familiarisation methods. Both the parents and children provided feedback on the child's experience of meeting the robot.

2.2 Methods

2.2.1 Participants

Fourteen parents and their autistic child were recruited through an advertisement on social media. The sample size was guided by research showing that having between 8 and 16 interviews was likely enough to produce adequate thematic saturation (Namey et al., 2016). The children were aged 6-11 years old, had a clinical diagnosis of autism, and had no significant physical disability that would limit their ability to interact with a humanoid robot. Children in this age range were recruited as younger children would be unlikely to be able to fully engage with the tasks, and the specific familiarisation methods used had the potential to be too simplistic or childish for older children and teens.

All parents participated in Phase 1, an online interview, and were invited to take part in Phase 2, which occurred in the lab an average of 11.2 days (SD = 7.7) after Phase 1. Ten of the fourteen parents took part with their autistic child in Phase 2. Three other children chose not to participate: one decided not to take part on the morning of the study, and two chose not to participate upon arrival at the lab, but before beginning the study.

Parents completed the lifetime version of the Social Communication Questionnaire (SCQ) (Rutter et al., 2003). Scores ranged from 18 to 36 (M = 25.8, SD = 6.1), with a score of 15 or higher indicating that a child might be autistic. While all parents reported in the SCQ that their children were "able to talk using short phrases or sentences", three parents answered that they were unable have a “to a to and fro ‘conversation’ with [their child] that involves taking turns or building on what [they] have said”. Participant demographics for each phase of the study are shown in Table 2.1.

Table 2.1

Participant demographics

Sample Characteristics	n	Range	Mean	SD
Phase 1 – Parents (n = 14)				
Gender				
Female	13			
Male	0			
Unknown	1			
Race/Ethnicity				
White British	11			
Mexican	1			
White and Black African	1			
Unknown	1			
Age (years)		31-44	37.3	3.2
Phase 2 – Parents (n = 10)				
Gender				
Female	9			
Male	0			
Unknown	1			
Race/Ethnicity				
White British	7			
Mexican	1			
White and Black African	1			
Unknown	1			
Age (years)		36-44	36.7	3.0
Phase 2 – Children (n = 10)				
Gender				
Female	2			
Male	7			
Unknown	1			
Race/Ethnicity				
White British	7			
Mexican	1			
Indian, White, and Black African	1			
Unknown	1			
Age (years)		6.4-11.3	8.8	1.5

Parents received a £15 shopping voucher for participating. Children received a certificate and a sticker. The study was approved by the [redacted for anonymity]. Each parent provided written informed consent and children provided verbal assent.

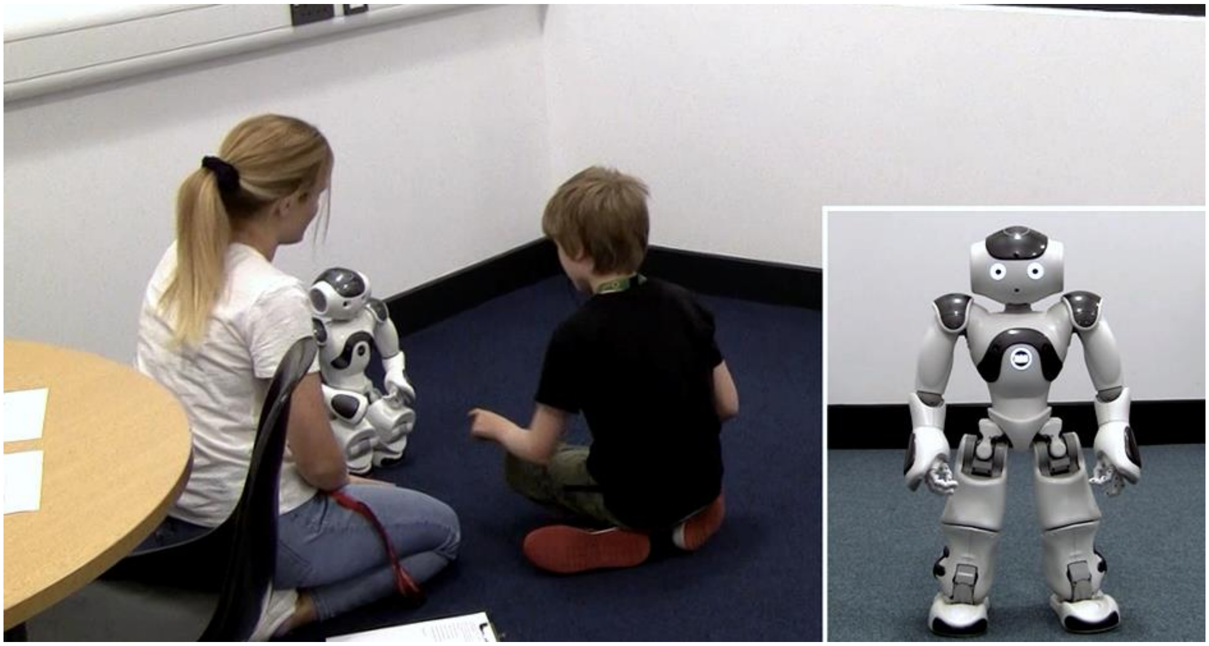
2.2.2 Materials

2.2.2.1 Humanoid robot

We used a NAO robot from United Robotics Group, which is commonly used in studies with autistic participants (Wallbridge et al., 2024). NAO robots are 57.4 cm tall, with tactile sensors and speakers, and are capable of speech, movement, and playing music (Figure 2.1). They connect to a computer via Wi-Fi and are controlled using Choregraphe (Pot et al., 2009) software. Further details of the NAO robot can be found elsewhere (e.g., Puglisi et al., 2022). We named the NAO robot Russell and used male pronouns.

Figure 2.1

Humanoid robot NAO by SoftBank Robotics



Note. A member of the research team and a child participant interacting with the NAO robot. A clearer photo of the NAO robot is shown on the right.

2.2.2.2 Familiarisation approaches

The familiarisation approaches (see Table 2.2) were discussed with parents in the Phase 1 interviews and used with the children in the Phase 2 lab visits. The approaches were based on a subset of those identified in Wallbridge et al. (2023) that were considered suitable for the NAO robot and/or the current method. These approaches were developed in Choregraphe version 2.8.7.4 (Pot et al., 2009), and are available as part of a git repository.[1] Additional details are located in the Appendix A.

[1] https://github.com/CWallbridge/Familiarisation

Capability Demonstration. This approach gradually displayed each of the robot's capabilities. This was achieved by the robot conducting a wake-up sequence (Part 1), which was followed by a song and dance routine (Part 2). The child is not required to do anything during this approach.

Stimulus and Response. This approach enabled two-way interactions between the robot and the child. Three different stimulus and response exchange options were available: a question and answer session, a following game where the child completed simple instructions given by the robot, and a mindful breathing exercise.

Static Exploration. This approach enabled the child to explore the robot using touch without the robot responding. Two types of Static Exploration were available: Free Exploration, in which the researcher invited the child to touch the robot, and Guided Exploration, in which the researcher guided the child through touching different parts of the robot in the context of giving the robot a "check-up".

Table 2.2

Familiarisation approaches discussed with parents in the Phase 1 interviews and used with the children in the Phase 2 lab visit

Familiarisation Approach	Description
Capability Demonstration	
Wake-Up Sequence	The robot gradually wakes up and introduces itself.
Song and Dance	The robot plays a song and does a dance along with it.
Stimulus and Response	
Question and Answer Session	The robot asks the child several questions, and also provides its own answers.
Following Game	The robot asks the child to do several simple movements.
Mindful Breathing	The robot leads the child through a mindful breathing exercise.
Static Exploration	
Free Exploration	The robot is "powered off" and the researcher invites the child to touch the robot.
Guided Exploration	The robot is "powered off" and the researcher asks the child to touch specific parts of the robot.

2.2.2.3 Phase 1 parent interview

A semi-structured online interview was conducted to explore parents' perspectives on how their child could be supported to visit our lab to meet a humanoid robot. Parents were shown a video of the NAO robot and its capabilities were described. The first part of the interview included a discussion of how the parent's child might feel about meeting the robot, alongside topics about how to promote the child's comfort during the visit. For the second part of the interview, parents were shown videos of the NAO robot enacting the Capability Demonstration (Wake-Up Sequence; Song and Dance) and Stimulus and Response. Static Exploration was described to parents verbally. Each familiarisation approach was followed by a discussion about how the parent thought their child would feel about the approach. For approaches that had multiple implementation options (e.g., Free Exploration or Guided Exploration), parents were asked to reflect on which option might best suit their child. The interview ended with a focus on parents' opinions about sharing information about their child's needs with researchers before a study, and how they thought this should be carried out. The full interview schedule is available in Appendix B.

2.2.2.4 Phase 2 parent ratings and interview

Parents used Likert scales to indicate how comfortable they thought their child was during each familiarisation approach, and how much their child enjoyed each approach. At the end of the session, parents also reported how much their child enjoyed themselves overall. All scales ranged from 1 to 5, with 1 representing the most negative response and 5 the most positive.

A semi-structured interview was also conducted with the parent in which they elaborated on their Likert scores. Questions were also asked about the appropriateness of the duration of each approach and the number of approaches used. The full interview schedule is available in Appendix C.

2.2.2.5 Phase 2 child interviews

Child participants were asked about their experience of spending time with the robot using three questions, answered using a 5-point Likert scale where 1 was the most negative response and 5 the most positive. The questions were, “Do you think Russell is friendly?”, “Do you think Russell is happy?”, and “How happy would you be to play with Russell again?”. The first two questions were adapted from the Robotic Social Attributes Scale (Carpinella et al., 2017). Participants were first given three options and told to select the one they most agreed with (e.g., Friendly, In the middle, Unfriendly). If participants selected Friendly, then they were asked if they thought the robot was Very friendly or Just a little friendly. Analogous options were provided for Unfriendly, whereas In the middle was recorded as is. Answers could be expressed verbally, through pointing, or head shaking/nodding.

Children who could answer open-ended questions also completed a short semi-structured interview where they were asked about what they liked or disliked about the robot, what their favourite activity was (Song and Dance portion of the Capability Demonstration, Stimulus and Response approach, or Static Exploration), and what other games that the robot should learn to play. If open-ended questions were not accessible to a child, they were instead shown pictures representing the different activities and asked to point at their favourite activity, and any activities they did not like.

2.3 Procedure

The order of the different parts of the study is represented visually in Figure 2.2.

2.3.1 Phase 1 – Parent interview

Interviews were conducted online in Microsoft Teams by one of two researchers and lasted an average of 38 min (range: 28 min to 52 min). The interviews were recorded and transcribed. Researchers showed parents the familiarisation methods by sharing their screen and playing a pre-recorded video.

2.3.2 Phase 2 – Child and parent lab visit

As suggested by a parent in Phase 1, prior to the lab visit, each family was sent a storyboard that explained in simple terms what the child would be doing, accompanied by photographs (available in Appendix A). Parents could also request additional preparation materials during Phase 1. Two parents requested a video of the researchers introducing themselves, and another requested a letter from the researchers assuring the child that they were allowed to bring their comfort object.

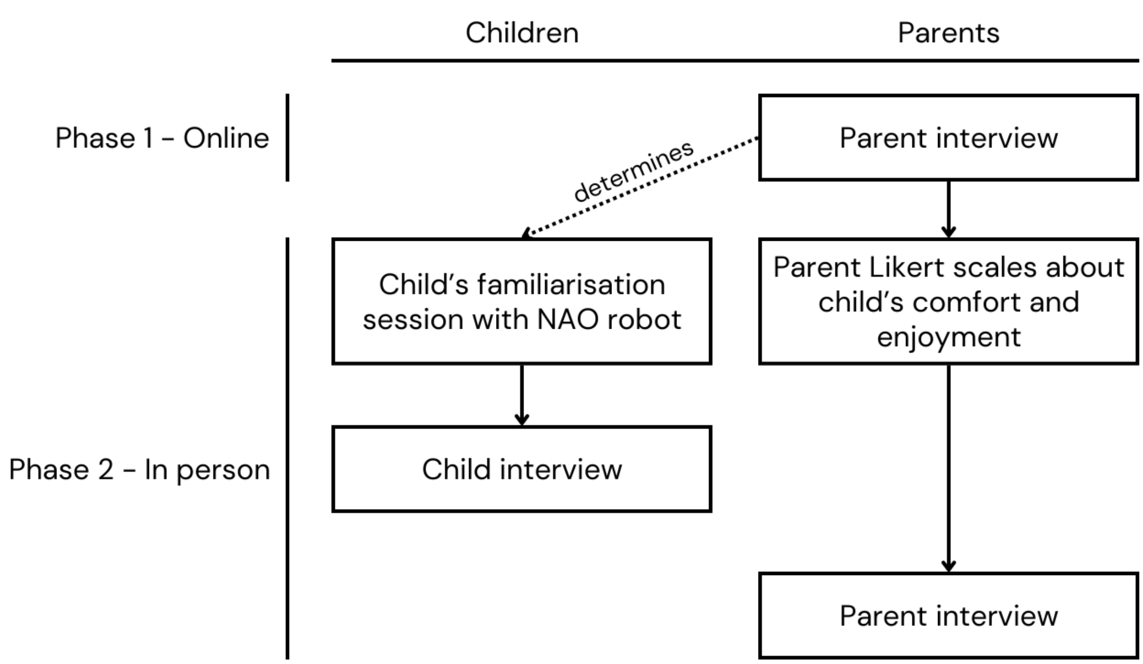
During the lab visit, one researcher worked directly with the child while a second researcher operated the robot. Before entering the testing room, the child was shown a photograph of the robot and was given the opportunity to ask questions. Upon entering the room, the child could choose where they sat.

The child was then presented with the three familiarisation approaches in the order: Capability Demonstration, Stimulus and Response, Static Exploration. This fixed order was chosen as the level of interaction with the robot increases across the approaches. The specific implementation of each approach was predetermined in the Phase 1 parent interview. After all familiarisation approaches were completed, the researcher asked the child about their experience with the robot using Likert scales and the child interview.

During the child's session with the robot, their parent sat in an observation room with the second researcher, where they observed the testing session through a one-way mirror. Parents completed the Likert interviews regarding their child's perceived enjoyment and comfort after each familiarisation approach. Parents' ratings were based on their own observations without conversing with their child. This was followed by the semi-structured interview with the parent, which lasted an average of 11 min (range: 7 min to 15 min).

Figure 2.2

Order of activities within the study phases



2.4 Data Analysis

Parents' semi-structured interviews in Phase 1 and Phase 2 were recorded and automatically transcribed in Microsoft Teams, then later checked for accuracy and anonymised. We used the method of thematic analysis to explore our data, drawing in particular on the approach of reflexive thematic analysis (RTA; Braun & Clarke, 2021b). With this method, we identified patterns and generated themes across both sets of interviews, with information from transcripts of Phase 1 and Phase 2 treated with equal weight. The pragmatic nature of our research aim, with its focus on what supports autistic children in a research setting, informed our approach to the RTA. Our analysis was embedded in an experiential and realist framework, where we aimed to capture participant's perspectives and insights as directly expressed within the data. Aligned with this, our approach was inductive, meaning that it was our aim for our data coding and subsequent theme creation to be driven by the data, rather than being shaped by pre-existing constructs about good research practices for autistic children. We focused on a semantic level of meaning in the data, which meant we explored what was being said directly rather than searching for latent, implicit meaning. An RTA approach also meant that our subjectivity and experiences with supporting autistic individuals were conceptualised as a useful tool to scaffold our understanding of the data, rather than as a threat to the validity of the results (Braun & Clarke, 2021a).

For the TA, two researchers independently coded all parent interview transcripts in NVivo 12 (Dhakal, 2022), coding in reverse order of one another. All interviews were double coded. Periodic checks were made to ensure consensus between coders, agreeing upon what data was relevant and how the codes should be labelled. Codes were then merged across the two coders to create a single dataset, with each coder independently merging half of the coded interviews. Where the codes used were different between coders, the coder selected the one that they considered most accurately represented the parents' comments. Both researchers refined the codes together, identifying and merging similar codes across the dataset. The coders then established initial thematic groupings together, which were further refined through discussion with the wider research team. Likert scales and child interviews were not integrated into the themes, and were analysed separately.

Both coders were non-autistic and were not parents. However, both coders were raised with autistic family members, and one had several years of experience working with autistic children, which meant they had professional experience of strategies for supporting autistic children in daily life. One of the coders was not British and they were sensitive to the possibility of cultural misreading. However, the collaborative coding strategy provided reassurance. It was also reflected that one coder conducted most interviews while the other did not collect any data; this created a balance between having a richer but more subjective position and having a position of greater objectivity.

The use of two coders allowed exploration of different subjective interpretations of the data, driven by distinct perspectives and backgrounds, enabling development of a richer conceptualisation of participants' responses. Our pre-existing intention to develop guidelines for researchers affected the framing of our themes as we wanted them to have salience as potential action points. In generating information meant to be used by other researchers, the two primary coders and the wider research team subjectively and intentionally use their viewpoints as researchers to thematically interpret the dataset.

The children's answers to the open-ended questions in the interview were transcribed and summarised; data were too limited for TA. The Likert scales for both parents and children were explored using summary statistics.

Community involvement statement

Autistic community members were not involved in the development of this research study.

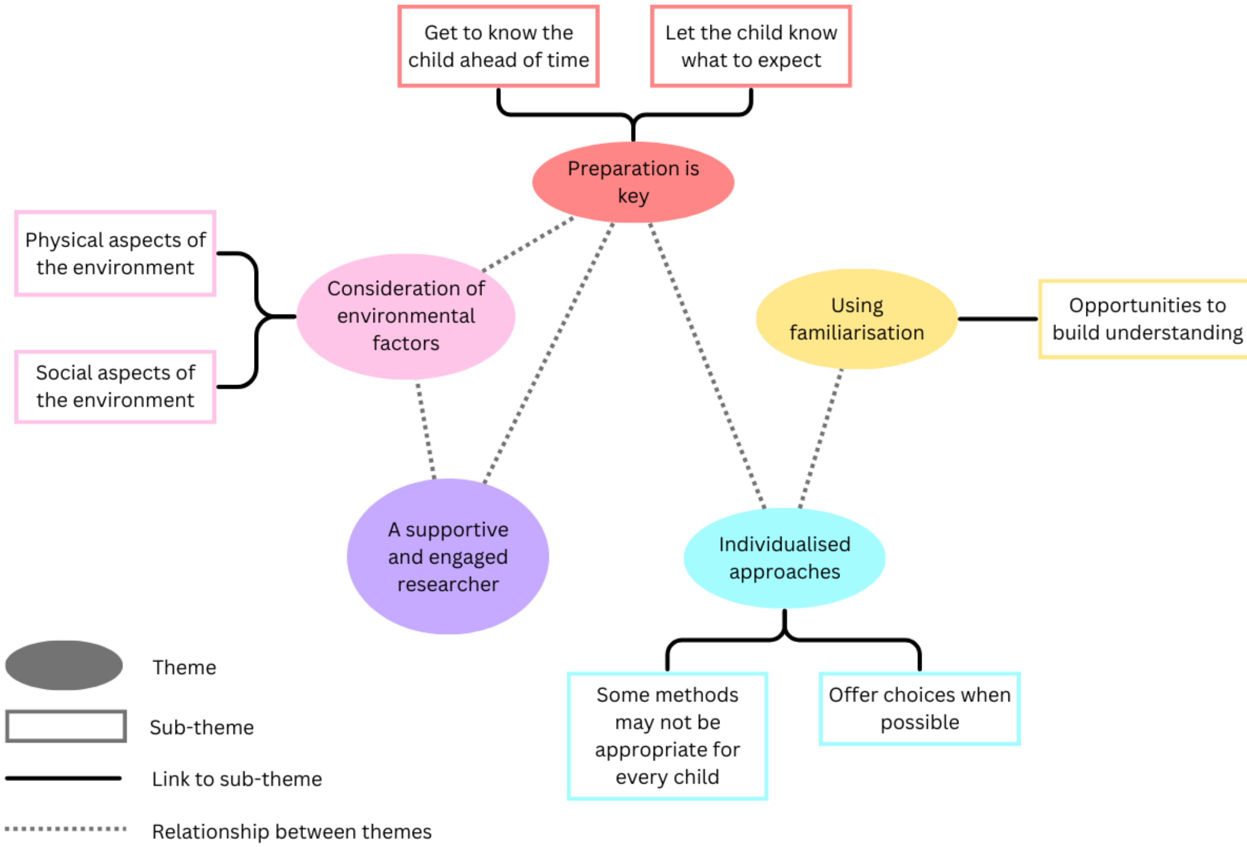
2.5 Results

2.5.1 Thematic analysis

Five main themes were generated from the parents' interviews: (1) Preparation is key, (2) Consideration of environmental factors, (3) Using familiarisation, (4) A supportive and engaged researcher, and (5) Individualised approaches. Four of the themes had distinct subthemes. The relationships between the themes are depicted in Figure 2.3.

Figure 2.3

Thematic map of parents' perspectives on how to effectively engage autistic children in research with humanoid robots



2.5.1.1 Preparation is key

Parents reflected that sharing information between the family and researchers before the child's visit was an important part of ensuring their child's comfort, because it helped the research team prepare for how to best support their child and gave the child a clearer idea of what to expect. Two subthemes were generated within this theme: *Get to know the child ahead of time*, and *Let the child know what to expect*.

Get to know the child ahead of time. Many parents explained that their child had differences in their communication style or additional conditions that impacted their interactions (e.g., anxiety, ADHD, speech delay). Some offered guidance for how to communicate with their child to help facilitate positive interactions:

[My child] communicates through a third person, so to speak, or he prefers to be told in the third person. So inside him, he has somebody called "Fluffy Puppy". Now, if you want him to do something, if you ask Puppy to do it, he finds it far easier.*

- Parent #14

**This term has been anonymised*

Some parents reported that sensory sensitivities, anxieties, or fears could cause significant distress for their child. A parent noted the importance of researchers knowing about these before meeting their child:

I think it's better to do this 'cause you can kind of understand what's gonna frighten [my child].

- Parent #8

Let the child know what to expect. Many parents expressed that their child feels anxious when dealing with the unknown. One parent explained a routine their child regularly completed before going somewhere new:

He will look at videos of the place and what there is to do there, who is there, and what things look like . . . Otherwise . . . he's got to do that all before he actually gets through to what he needs to do.

- Parent #14

The storyboard each family received was cited by many as a valuable tool in helping prepare their child. As one parent explained:

He was a bit, "What do I do? Wait, what is my purpose to be here?" When I read [the storyboard] *it was like, "Oh, right, I'm here to have fun."*

- Parent #10

Some parents explained that it was important for them to have a complete understanding of what would happen, as it would enable them to help prepare their child.

2.5.1.2 Consideration of environmental factors

This theme was represented by two subthemes; parents thought that both physical and social environmental factors had the potential to make their child uncomfortable during their visit.

Physical aspects of the environment. Anxiety related to being in an unfamiliar space was a common concern among parents. Some indicated that this would be a greater source of anxiety for their child than the robot:

He might be less comfortable with the setting than the robot. The robot, he won't have a problem with. It might just be the setting it's used in.

- Parent #10

Some parents also reported that visual aspects of the space, such as the room appearing too clinical, could cause their child to be nervous.

Social aspects of the environment. Interpersonal aspects of the study were another concern, particularly in relation to the child's anxiety around strangers. Many parents highlighted that their child found it difficult to effectively communicate with people they did not know.

He does struggle to speak to most people, unless he knows them really well. He kind of shuts down and withdraws, and just kind of shakes his head. So he just gets really *anxious and nervous and doesn't know how to express himself properly.*

- Parent #16

This relates closely to the theme *Preparation is key*, as some parents suggested this anxiety might be reduced if their child could see photographs of the researchers before their visit. Some parents said that their child may also feel self-conscious, awkward, or embarrassed if they sensed they were being watched. This was both in reference to the child being aware of their parent and a researcher observing them through a one-way mirror, and the sentiment that their child may feel embarrassed engaging in certain activities in the presence of any audience. One parent suggested that this feeling of awkwardness can be reduced by limiting the number of people who are observing the child.

Some parents commented that their child may feel more comfortable if their parent was in the testing room, providing a “familiar face”. However, other parents said that their child might find this distracting:

. . . I think he's more likely to focus if I'm not there. So I've taken him to an optician's appointment, and because I was there, he got more distracted. He was trying to interact with me and not the optician.

- Parent #13

In summary, parents felt that there were several elements of the study environment unrelated to the robot that could impact how their child feels and behaves.

2.5.1.3 Using familiarisation

Parents viewed familiarisation as an important factor in promoting a successful study session, with many saying that their child would initially need time to "warm up" to the robot. Some parents also highlighted the importance the child forming a "connection" with the robot.

Some parents were less concerned about their child being anxious around the robot, and instead thought their child might lose interest in it. Potential causes included the child's short attention span, the robot being less responsive than expected, or robots not being one of their child's interests. The duration of the familiarisation activities was therefore deemed an important consideration.

Ultimately, parents felt that taking part in a research study should be fun for their child. Some stressed this as being crucial, indicating that their child was resistant to participating in things they didn't enjoy.

> *Because [if] you mentioned school or homework . . . he just completely shuts down. But if he thinks it's gonna be fun, yeah, he'd be all for it and probably get really involved.*
>
> *- Parent #16*

Within this theme, there was one subtheme related to the benefits of increasing the child's understanding of the robot.

Opportunities to build understanding. Parents indicated that effective familiarisation methods were ones that built the child's understanding of the robot. Some parents highlighted activities that gave the child an opportunity to explore the robot on a mechanical level. Other parents stressed the importance of activities that showed the robot's capabilities or nature, saying their child may initially worry that the robot was unfriendly or dangerous:

> *He might be a little, like, daunted at first . . . because of the things we see about robots being like, good robots and bad robots . . . He'll probably get more comfortable when he realizes that it's not any sort of threat.*
>
> *- Parent #13*

In summary, parents thought it was important for the familiarisation session to build the child's trust and understanding in the robot, while still keeping them engaged.

2.5.1.4 A supportive and engaged researcher

Parents noted having a researcher lead their child through the interactions helped the child understand that it was safe for them to follow the robot's instructions. As one parent explained:

> *Notice that sort of about halfway through, [the researcher] didn't have to repeat what Russell said. [My child] was just going off what Russell said. So that's sort of like, a sort of gradual level of trust… "I can do it and nothing bad's gonna happen . . . It's safe to do."*
>
> *- Parent #9*

Similarly, some parents reported that their child may have been anxious about what they were allowed to do, such as how to touch the robot without damaging it, causing the child to be more cautious and reserved. Parents suggested that this could be overcome by having the researcher give explicit permission, clear boundaries, and demonstrate what to do.

This theme closely relates to the theme *Preparation is key*, as having a good understanding of the child's anxieties, communication style, and needs enables researchers to better support them during the study. It also relates to *Consideration of environmental factors*, as the research team has the potential to be a source of support for the child's anxiety.

2.5.1.5 Individualised approaches

Parents described that the most effective familiarisation method may depend on the child. There were two subthemes: *Some methods may not be appropriate for every child*, and *Offer choices when possible*.

Some methods may not be appropriate for every child. Many parents said some familiarisation options may not be appropriate for their child due to their age or perception of their own maturity. One parent, when reflecting on the song choices, explained why they chose the robot dance over the nursery rhyme options:

> *I think that he would think that the other two are quite babyish, and he thinks that he's a lot more grown-up than that.*
>
> *- Parent #4*

Others reported some methods would be too complex for their child, which could cause them to lose interest in the robot. Similarly, many children experienced difficulties with speech or movement, which that would make it difficult for them to complete certain tasks.

Some parents suggested their child would not need to experience all of the familiarisation approaches, as they anticipated their child would feel comfortable around the robot almost immediately. Conversely, others said that their child would need them all, and may even need additional time with a particular activity, or more time with the robot in general, to feel comfortable.

This subtheme is also closely related to the theme *Preparation is key*, as having this information ahead of time enables researchers to make adjustments to the familiarisation protocol where necessary.

Offer choices when possible. Parents suggested that, when possible, it would be beneficial to let their child choose how they would like to interact with the robot. While this was not the case for every child, many parents said that their child would feel comfortable communicating their needs and preferences with the researchers. Parents also reflected on the benefits of giving children choices in less formal ways. For example, children were allowed to sit anywhere in the room during the study, whilst the robot remained stationary. Parents said this enabled their child to choose how far away from the robot they would like to be:

> *It's like staying in the one spot . . . He can move away if he needs to . . .*
>
> *- Parent #15*

In summary, individualised approaches were considered beneficial and reflected the children's abilities and preferences. This is closely related to the theme *Using familiarisation*, as the most appropriate way to acclimate each child to the robot varied.

2.5.2 Parent and child Preferences

2.5.2.1 Phase 1 parent selection of familiarisation activities

The 14 parents who participated in the Phase 1 interview selected which Stimulus and Response and Static Exploration activities would be most appropriate for their child. The Following Game was the most common Stimulus and Response choice, and Guided Exploration was the most common Static Exploration choice (see Table 2.3).

Table 2.3

Parent's familiarisation choices during the Phase 1 pre-visit interview

Familiarisation Approach	Number of Parents
Stimulus and Response	
Following Game	9 (64%)
Question and Answer	4 (29%)
Mindful Breathing	1 (7%)
Static Exploration	
Guided Exploration	9 (64%)
Free Exploration	5 (36%)

2.5.2.2 Phase 2 parent and child preferences

Nine children completed all of the familiarisation approaches, whereas one child chose to end the familiarisation session after the Wake-Up Sequence. Their parent explained the child was eager to attend another activity. Children who completed all of the familiarisation activities were asked which activity was their favourite: the Song and Dance portion of the Capability Demonstration segment, the Stimulus and Response activity, or the Static Exploration. The Stimulus and Response activity was the most popular choice amongst the children (Table 2.4). One child did not have a favourite activity.

The children's parents were asked which one approach would be the most helpful in familiarising their child with the robot. Similar to the children, the Stimulus and Response approach was the most popular choice amongst parents (Table 2.4).

Table 2.4

Parents' and children's preferred familiarisation activities in Phase 2

Familiarisation Approach	Number of Participants
Children	
Stimulus and Response	4 (50%)
Capability Demonstration	3 (38%)
Static Exploration	1 (13%)
Parents	
Stimulus and Response	7 (78%)
Capability Demonstration	1 (13%)
Static Exploration	1 (13%)

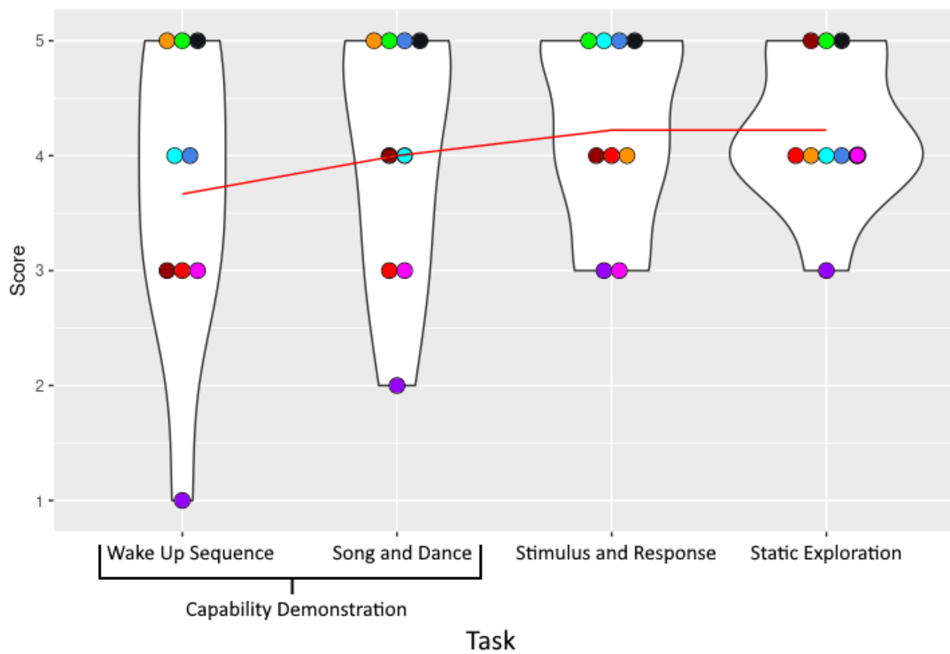
2.5.3 Comfort and enjoyment ratings

Overall, parents rated their children as showing high levels of comfort with, and enjoyment of, the activities (Figure 2.4). Although statistical analysis was not appropriate with the small sample, both comfort and enjoyment improved for the group as a whole across the activities.

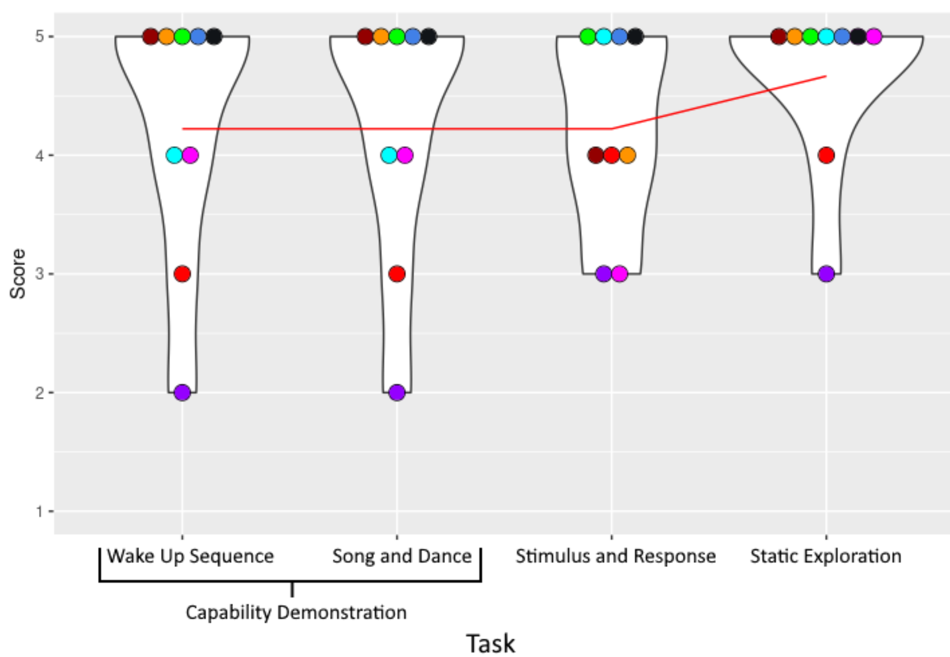
Figure 2.4

Parent ratings of (a) child comfort and (b) enjoyment during each familiarisation activity in Phase 2

(a)



(b)



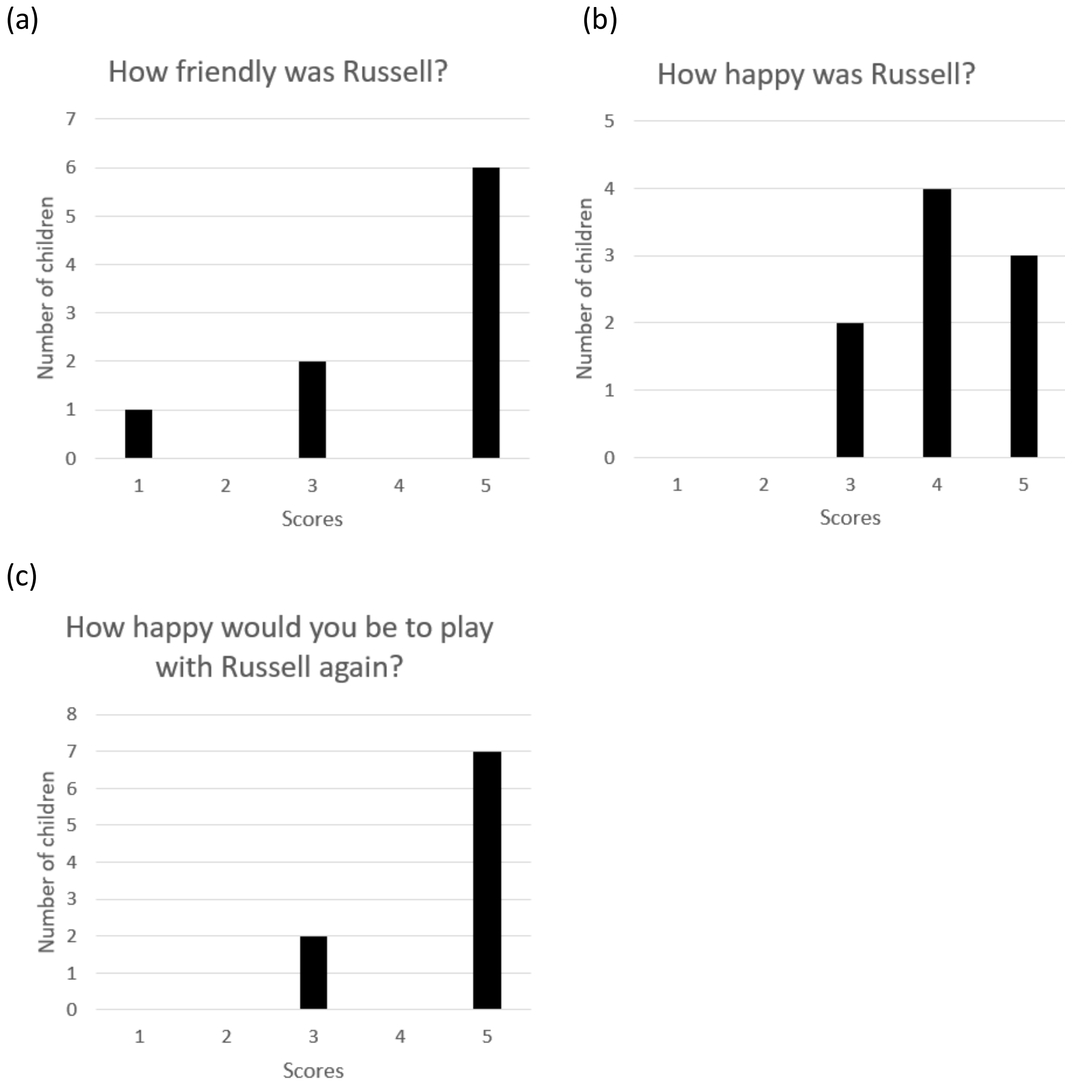
Note: Each colour represents an individual child. The line shows the mean scores. For scoring, 1 = very uncomfortable/did not enjoy and 5 = very comfortable/really enjoyed.

2.5.4 Children's opinions about the robot

Following familiarisation, children were asked to rate how friendly the robot was (mean score of 4.1 (*SD* = 1.45)), how happy the robot was (mean = 4.1 ± 0.78), and how happy they would be to play with the robot again (mean = 4.6 ± 0.88) (Figure 2.5). Some children found these questions difficult to answer. When asked if the robot was friendly, one child said, "I don't know what that means." Another, when asked if he thought the robot was happy, said "I can't really tell if he's happy." The researcher offered clarification and all children made selections.

Figure 2.5

Children's Opinions About the Robot in Phase 2



Note: For scoring, 1 = most negative and 5 = most positive response options.

Seven children were able to verbally answer open-ended questions and were asked about what they liked/disliked about the robot. Children volunteered limited information, but most responses were positive. Some children identified their favourite thing about the robot, with responses encompassing specific features (his fingers, his waking up sequence, his dancing), his mood (“very happy”, “fun”), and generic endorsement (“everything”). Most children did not identify anything they disliked about the robot, but one commented about the robot being a bit loud when he talked. An additional child observed that the robot’s gaze followed them when they moved, which was “a little bit creepy”.

2.6 Discussion

Using mixed-methods, we explored the most effective approaches for supporting the comfort and enjoyment of autistic children when meeting a humanoid robot in a research setting. Qualitative analysis of interviews with autistic children’s parents identified five themes regarding how to best support autistic children in a research setting, using the specific example of meeting a humanoid robot: (1) Preparation is key, (2) Consideration of environmental factors, (3) Using familiarisation, (4) A supportive and engaged researcher, and (5) Individualised approaches. Additional qualitative and quantitative data indicated that parents and children felt positively about the child’s experience of meeting the robot and our familiarisation techniques were successful. Synthesising across our findings, we present a set of preliminary recommendations for researchers wanting to support the inclusion of autistic children in research.

In our investigation of research inclusion for autistic children, we explored three different approaches for familiarising autistic children with a humanoid robot. Across qualitative and quantitative measurements, all familiarisation methods were well received and can be recommended for use with autistic children, depending on the child’s needs and the study requirements. Parents and children were generally well aligned in their preferences for different familiarisation approaches. Children preferred the Stimulus and Response and Capability Demonstration approaches over the Static Exploration, and parents showed a strong preference for Stimulus and Response activities. The Stimulus and Response approach was unique in that it elicited two-way interactions between the child and the robot, which may be an important factor. Static Exploration, which could be very open-ended and relatively un-scaffolded, was the least preferred and may reflect the preference for routine in autistic people (e.g., Leekam et al., 2011). However, the fixed order of the approaches, chosen to enable a graded introduction, may have influenced opinions.

One consideration when recommending our familiarisation techniques is how generalisable they would be to studies using other robots. However, the familiarisation approaches used in the current study were drawn from a previous systematic review of studies that collectively used 28 different models of robots with autistic participants (Wallbridge et al., 2024). Further, the majority of studies did not use the NAO robot, as used in the current study. As such, the techniques are likely to be applicable to other robots being used in research. However, the specific execution of our familiarisation techniques will depend on the capabilities of the robot and some adaptations may be required (e.g., if the robot cannot play music). Similarly, the specific features of the robot (e.g., quality of sound; fluidity of movement) may enhance or inhibit the impact of certain familiarisation approaches.

Despite humanoid robots potentially being a source of discomfort for autistic children (Wallbridge et al., 2024), they include properties that may be particularly appealing. Indeed, many autistic children find meeting a robot positive (e.g., Garnier et al., 2023). Both autistic adults and educators of autistic children have highlighted that the consistent and predictable nature of robots, compared to the complexity of human interaction, may make them attractive to autistic children (Alcorn et al., 2019; Silvera-Tawil et al., 2022). Educators also recognised that robots could be inherently engaging to autistic children (Alcorn et al., 2019). Further, although robots may contain sensory features that some autistic children find difficult, these can invariably be adjusted to suit the child's needs (e.g., Kumazaki et al., 2022). Thus, arguably, the role of the familiarisation phase is to convey these appealing properties to an autistic child, so that initial uncertainty and wariness can be replaced by confidence in the parameters of the robot.

While parents typically found the familiarisation approaches to be effective, they also stressed the importance of beginning the familiarisation process before the lab visit. Parents' reports that their children benefit from having comprehensive information ahead of time is consistent with the perspectives of autistic adults, who also value pre-study information (Gowen et al., 2019). In the current study, a parent specifically suggested we use a storyboard to explain the laboratory visit to their child, and this was used with all children. Building from this, we recommend a digestible introduction to the study is given to all child participants. This could take the form of Social Stories™ (Gray & Garand, 1993), an existing storyboard framework that is widely used (Qi et al., 2018). However, our data also indicated that parents should be encouraged to suggest specific preparatory materials that may support their child (e.g., a letter that allays a concern). Supplementing introductory materials with photos and videos, framed in the context of "What to expect", were considered useful by autistic adult participants (Gowen et al., 2019). This highlights that many needs will not be age-specific, although approaches must be age-appropriate. The benefit of preparatory materials likely reflects the elevated intolerance of uncertainty (Boulter et al., 2014; Wigham et al., 2015) and anxiety (MacNeil et al., 2009) often seen in autistic people.

Although a humanoid robot was the focus of the current study, many other studies also use novel equipment that may be difficult for autistic children. For example, sources of discomfort for autistic children in the MRI scanning environment were similar to those identified in the current study, including sensitivity to loud noises and being in an unfamiliar space (Tziraki et al., 2021). Tziraki et al. identified techniques that could help introduce autistic children to an MRI scanner that have resonance with our own findings, including learning about each child's communication style and providing families with preparatory materials. However, some techniques reflected the specific challenges of the equipment, such as showing children a miniature "toy" MR scanner and listening to the scanner noise in advance of the scanning session. These findings highlight that there will be shared sources of potential discomfort across most experimental studies, alongside study-specific considerations. Indeed, although the focus of our qualitative interview with parents was about familiarising autistic children with a humanoid robot, discussion of the study visit elicited many comments that reflected general study features. These included the potential challenge of meeting unfamiliar people and being in an unfamiliar place. Researchers should therefore consider both the general and study-specific elements of their research when preparing autistic children and families for a research study.

Expanding on the wider relevance of the current study, many of the approaches we identified are applicable outside of research contexts. Autistic children may encounter robots or other novel equipment in clinical or educational settings (Huijnen et al., 2017; Saleh et al., 2020), with negative reactions to meeting a humanoid robot documented in both classroom and clinical settings (e.g., Di Nuovo et al., 2020; Garnier et al., 2023). Introductions to robots may need to be different in applied contexts, for example, managing expectations about access to the robot in the classroom (Silvera-Tawil et al., 2022). However, many of the fundamental principles described in the current study will be applicable to these settings.

Many of the parents we interviewed indicated that their child might struggle with aspects of the study because of characteristics that were not directly related to being autistic. Several children experienced co-occurring difficulties, including attentional difficulties, specific fears, and anxiety. The high prevalence and wide range of additional diagnoses and/or traits in autistic populations (Bougeard et al., 2021; Rodriguez-Seijas et al., 2020; Rosen et al., 2018) further exemplify the importance of learning about each child before they participate in a study. Utilising existing frameworks such as research passports (Ashworth et al., 2021) can support this aim of enabling autistic participants to share their needs and preferences with researchers. While autistic children may need familiarisation more than other groups, the diversity of children's needs make it likely that *all* children would respond positively to tailored approaches to promote their comfort and enjoyment while participating in research.

2.6.1 Recommendations

Utilising themes that were generated from parent interviews, we have developed a set of recommendations for promoting the comfort of autistic children in research settings (Table 2.5). As illustrated in Table 2.5, each recommendation draws from one of the themes we generated through RTA. Reflecting our data, the recommendations are focused on steps that can be taken before the testing phase of the study. Importantly, the recommendations are not specific to studies that include robots, but are broadly applicable to studies with autistic children. Many of our suggestions complement recommendations offered by Gowen et al. (2019) on how to make studies more accessible for autistic participants, particularly how to prepare participants and selecting comfortable, sensory-friendly testing spaces.

Table 2.5

Recommendations for supporting autistic children in research settings based on themes generated from the current study

		Description	Associated Theme
1	Testing Space	Choose a testing space that is child-friendly and that avoids common sensory triggers, such as bright lights or loud background noise.	Consideration of environmental factors
2	Learn About the Participant	Provide an opportunity for parents to share information about their child before the study session. Researchers can ask about the child sensory sensitivities, communication style, and nonverbal signs of discomfort.	Preparation is key
3	Adjust Protocol	Adjust the familiarisation and study protocol based on the information received from the parents.	Individualised approaches
4	Preparation Materials	Send families preparation materials to help the children better understand what to expect when they come for the study (e.g., storyboard, video walkthrough of building and testing room).	Preparation is key
5	Supportive Researcher	Have a member of the research team present who is prepared to support the child throughout the study. Where appropriate, the researcher can answer the child's questions, clarify the robot's requests, and demonstrate how to appropriately interact with the robot.	A supportive and engaged researcher

2.6.2 Limitations and future directions

In the current study, the preparation materials sent to families prior to the lab visit prepared most children for their familiarisation sessions, but three children did not want to visit the lab for the study. This suggests that more work is needed to identify the most effective preparation materials.

Additional work can also be done to collect richer feedback from autistic children. We used simple questions to be inclusive of children with limited verbal communication. However, this approach limited the depth of feedback gained from children with more advanced communication abilities. In future, a tiered approach, where the data collected from children is adapted to suit their abilities, may enable children to be better represented. There are also creative qualitative methods that can be used to interview autistic children, including more visual and embodied child-led interviews (Lewis et al., 2023). It is likely that these approaches would have enabled better inclusivity of children with alternative communication styles or more limited receptive language.

Expanding on the appropriateness of the child questions, two children found it difficult to decide how happy or friendly the robot was. These questions were adapted from an existing questionnaire about how people perceive robots (Carpinella et al., 2017). However, autistic children often understand or define friendships differently than non-autistic children (Petrina et al., 2014), which may have explained the challenges some children experienced. It is also unknown whether the perceived happiness or friendliness of a robot are key factors in influencing how much autistic children like robots. Additional research is needed to determine what attributes of robots influence autistic children's opinions. This will enable researchers to more accurately evaluate robots' interactions in accordance with what is important to autistic children.

The current study was not an exhaustive exploration of familiarisation methods that have been used in research with autistic children and humanoid robots (see Wallbridge et al., 2023), and only one type of robot was used. Further research is needed to evaluate the effectiveness of other approaches across a wider range of robots.

The parent interviews' focus on evaluating the effectiveness of our developed familiarisation options also biased the responses and the resulting themes to highlight these elements of our approach over other possible methods of introducing children to robots. As such, it was not possible for the data analysis to be purely inductive, as the structure of the interviews inherently introduced our own preconceived beliefs about the importance of familiarisation and offering choices. While this is not inherently a flaw in the research design, as reflexive thematic analysis embraces researcher subjectivity and the active role researchers take in generating the resulting themes (Braun & Clarke, 2021b), the structure of the interviews did likely limit the scope of the approaches that were discussed and inflate the importance of familiarisation and choice. This study could be repeated without a strict focus on familiarisation to further explore additional methods for promoting participant comfort and wellbeing.

2.7 Conclusion

Using mixed-methods, we worked with parents and autistic children to determine how to promote children's comfort and wellbeing during research, using the specific example of a laboratory visit to meet a humanoid robot. We found that our robot familiarisation methods were well received, and also gained valuable insights into generalisable techniques for supporting positive participant experiences. We have summarised our findings into a set of general recommendations that we hope will support future researchers in delivering inclusive research with autistic children.

Chapter 3

Auditory Synchrony Perception and Motor Synchrony in Autistic and Non-Autistic Children

3.1 Introduction

It has been established that autistic children typically engage in interpersonal synchrony less frequently and less accurately (Fitzpatrick et al., 2016, 2017a; Kaur et al., 2018; Marsh et al., 2013), and that they are less sensitive to the social effects of interpersonal synchrony (Koehne et al., 2016) when compared to non-autistic children. As discussed in Chapter 1, this could be due to autistic children's differing experiences with the underlying components that contribute to interpersonal synchrony. Successful intentional synchrony with a partner requires individuals to both accurately differentiate between synchrony and asynchrony, and successfully execute their motor movements to match their partner's (Bowsher-Murray et al., 2022). Because autistic children often experience differences in temporal perception (Bebko et al., 2006; de Boer-Schellekens et al., 2013; Foss-Feig et al., 2010; Kwakye et al., 2011; Stevenson et al., 2014; Zhou et al., 2021) and motor development (Cassidy et al., 2016; Chawarska et al., 2007; Dziuk et al., 2007; Landa & Garrett-Mayer, 2006; Whyatt & Craig, 2012), these disruptions could potentially explain autistic children's difficulties with interpersonal synchrony.

Many additional factors in real-world social interactions can also make interpersonal synchrony more difficult for autistic children. Temporal perception is often more difficult for autistic children when they must integrate multiple senses (e.g., audiovisual) (de Boer-Schellekens et al., 2013; Foss-Feig et al., 2010; Kwakye et al., 2011), especially when speech is involved (Bebko et al., 2006; de Boer-Schellekens et al., 2013; Stevenson et al., 2014; Zhou et al., 2021). For motor production, it is known that autistic children tend to particularly struggle with complex movements and those requiring core balance (Whyatt & Craig, 2012), perhaps due to the high prevalence of developmental coordination disorder among autistic children (Cassidy et al., 2016; Dziuk et al., 2007). Similarly, the social aspect of interpersonal synchrony could be a driving factor in autistic children's reduced engagement, as autism itself is, in part, characterised by differences in social communication and social interaction (American Psychiatric Association & American Psychiatric Association, 2013). As such, in order to accurately determine the extent to which autistic children's abilities to produce synchronous movement and perceive synchrony contribute to their reduced engagement and accuracy with interpersonal synchrony, these two processes must be studied without additional confounding factors.

This chapter will compare how autistic and non-autistic children perform in tasks designed to measure their abilities to accurately detect synchrony vs asynchrony (i.e., Synchrony Perception) and produce basic motor synchrony with an external non-social stimulus (i.e., Motor Synchrony). In the Synchrony Perception Task, confounding factors were reduced by using auditory stimuli that were unisensory non-speech sounds, which are thought to be easier for autistic children to process than multisensory or speech stimuli (Bebko et al., 2006; Kwakye et al., 2011; Stevenson et al., 2014; Zhou et al., 2021). These stimuli were presented in the absence of a social context to reduce the effect of autistic children's differing experiences with social interactions (American Psychiatric Association & American Psychiatric Association, 2013). To reduce additional demands in the Motor Synchrony task, participants tapped with just one finger, once again using unisensory, non-speech stimuli in the absence of a social context. This tapping task is well-established as an assessment of basic motor synchrony abilities in typically developing and neurodivergent populations (Hove et al., 2017; Repp, 2005; Tryfon et al., 2017).

Based on the prevalence of motor difficulties among autistic children (Whyatt & Craig, 2012) and evidence suggesting autistic children may have reduced temporal perception abilities for auditory stimuli (Kwakye et al., 2011), autistic children were predicted to have poorer motor synchrony and poorer synchrony perception abilities than typically developing children. Because accurately monitoring the quality of synchrony is a necessary component of successful motor synchrony (Bowsher-Murray et al., 2022), I also predicted that performance on the Motor Synchrony and Synchrony Perception Tasks would be positively associated.

3.2 Method

3.2.1 Participants

While power calculations showed that a total sample size of at least 102 (51 in each group) would be necessary to detect medium effect sizes at 80% power in independent samples t-tests, this was not logistically possible within the timeframe of this study. A total sample size of 60 (30 in each group) was therefore aimed for, as this would be more than sufficient to detect large effect sizes, and compromise power analysis calculated this would provide 60% power for medium effect sizes.

Two groups of children aged 6 – 11 years were recruited through social media. The autistic group (n = 29) consisted of children with an autism diagnosis from appropriate clinical professionals (e.g., multi-disciplinary team, neurodevelopmental service). Many children within this group also had additional neurodevelopmental conditions and/or difficulties which parents reported that their children either had or were being assessed for (see Table 3.1). The non-autistic group (n = 27) did not have any neurodevelopmental diagnoses and/or difficulties. Children with significant physical disabilities were excluded due to task demands. As not all children completed each task, full demographic data is provided in the Results section for each task separately (see Section 3.3). None of the participants had taken part in the familiarisation study presented in Chapter 2.

Table 3.1

Additional neurodevelopmental conditions and/or difficulties reported for autistic children by their parents (n = 29)

Condition/Difficulty	Number of autistic participants		
	Confirmed	Under assessment	Total
Attention deficit hyperactivity disorder (ADHD)	6	6	12
Auditory processing disorder	0	1	1
Developmental trauma	1	0	1
Developmental co-ordination disorder (dyspraxia)	1	0	1
Dysgraphia	0	1	1
Dyslexia	1	3	4
Foetal alcohol spectrum disorder	0	1	1
Global developmental delay	1	0	1
Learning difficulty	2	0	2
Sensory processing disorder	1	0	1
Speech delay	1	0	1
Motor and vocal ticks	1	0	1

Note: Status of each diagnosis was reported by each child's parent.

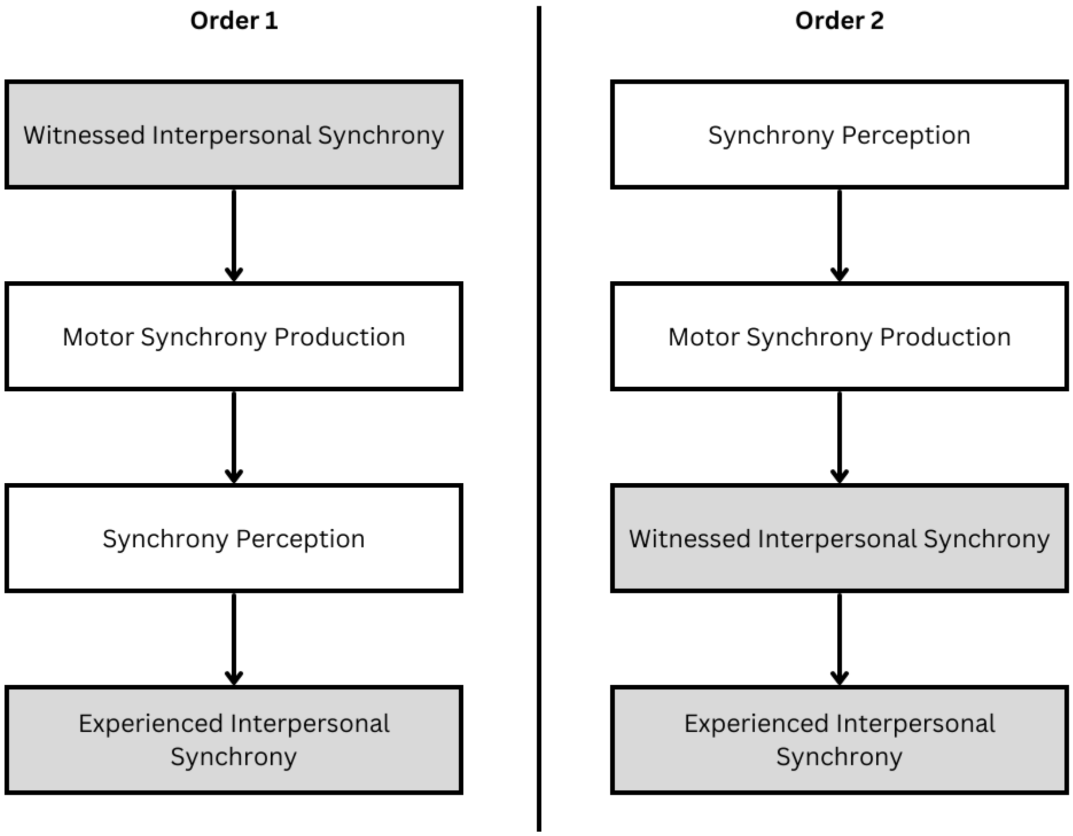
Participants were given a certificate and a small gift for taking part. Parents/guardians provided written consent for their children to take part, and children provided verbal assent. The study received ethical approval from the Cardiff University School of Psychology Research Ethics Committee.

3.2.2 Materials and procedures

The two tasks described below were part of a set of four tasks. The other two tasks are described in Chapter 4. Each participant was assigned one of two orders in which to complete the tasks (see Figure 3.1) to reduce potential order effects, after which they completed the Two-Subtest form of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II) (Wechsler, 2011) and manipulation checks for the tasks presented in Chapter 4. For practical purposes, the task order was set up to alternate between laptop-based tasks (i.e., Witnessed Interpersonal Synchrony, Synchrony Perception) and iPad-based tasks (i.e., Motor Synchrony, Experienced Interpersonal Synchrony). The Experienced Interpersonal Synchrony task come after the Witnessed Interpersonal Synchrony task – there was a "correct" way in which pairs were meant to perform in the Experienced task, which was not the case in the Witnessed task, so this order eliminated the possibility that the rules set forward in the Experienced task would erroneously lead participants to believe that some of the pairs in the Witnessed task were performing incorrectly.

Figure 3.1

Order of study tasks



Note. Participants completed the four tasks in one of two orders. Tasks in white are discussed in this chapter, and tasks in grey are discussed in Chapter 4.

3.2.2.1 Participant preparation for the study visit

Per the recommendations identified in Chapter 2, each family received a storyboard prior to their visit to the lab using simple language and photographs to explain what the child would do during the study. These photographs showed the researchers and the study equipment. They were also sent a video walkthrough of the building. Parents were told that they could use these materials to help their child understand what to expect during their visit.

To promote participant comfort, parents of autistic children also provided the researchers with information about their child through a brief online questionnaire about their child's communication style, sensory needs, and any other relevant information that they wanted to share. They had the opportunity to have an online meeting with the researchers to further discuss these topics prior to their visit, but no parents requested a meeting.

3.2.2.2 Synchrony Perception

In this task, participants differentiated between a synchronous sound pair (i.e., two sounds that play at the same time) and an asynchronous sound pair (i.e., two sounds that play at slightly different times).

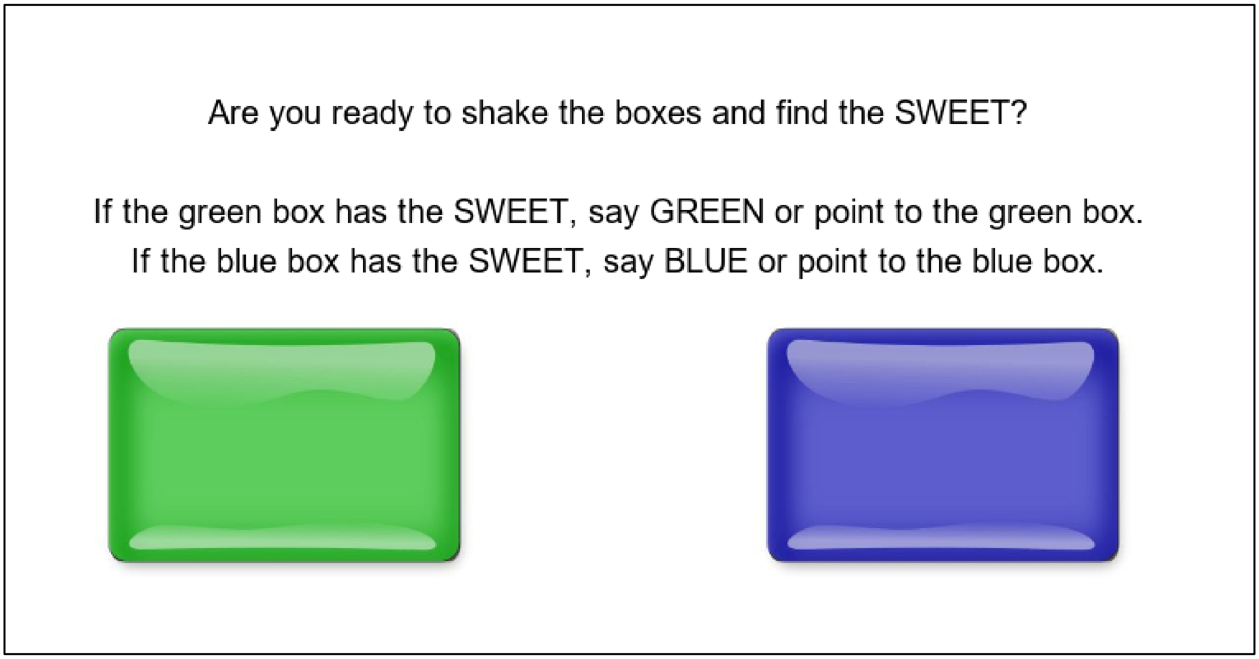
Stimuli. Each pair of sounds consisted of a "high" sound, a plastic beater striking a glockenspiel (G4, 392 Hz approximately), and a "low" sound, a piano key (C3, 131 Hz approximately). Stimuli are available for listening at https://github.com/CarlyAMcGregor/Synchrony. Sounds were recorded using Audacity, version 3.0.2. In the synchronous sound pairs, the high and low sounds played simultaneously. In the asynchronous sound pairs, the stimulus onset asynchrony (SOA) of the high and low sounds (i.e., the interval between the sounds) ranged between 20-300 ms in 10 ms intervals (i.e., 20, 30, 40, … 290, 300).

Procedure. Participants completed the task on a laptop. The task was developed with MATLAB (Version R2019a, The MathWorks, Natwick, MI, USA) code using the Psychophysics Toolbox (Version 3.0.14) (Kleiner et al., 2007; Pelli, 1997) and the Palamedes Toolbox (Prins & Kingdom, 2018). The volume was adjusted for each participant to be both audible and comfortable. The task was presented as a game in which participants attempted to collect as many "sweets" as they could by differentiating between the sound pairs. Instructions were presented on the laptop screen and read aloud by the researcher. The researcher controlled the pace of the task.

At the beginning of the instructions, the computer screen displayed a green box on the left, and a blue box on the right. Participants were told that one box would contain a sweet, and the other would contain stones. They were then told, “The box with the sweet always sounds like this”, followed by the synchronous sound pair playing accompanied by a picture of the sweet. Next, they were told, “The box with the stones always sounds different”, accompanied by a picture of the stones. They were reminded that they wanted to find the sweet, and the sweet picture and synchronous audio were presented again. The researcher explained that they could “shake” the boxes to hear the sounds they make (Figure 3.2). The participant could indicate which box they thought had the sweet by saying the colour of the box or pointing at it, and the researcher would input their answer via the laptop keyboard.

Figure 3.2

Instruction slide for Synchrony Perception Task



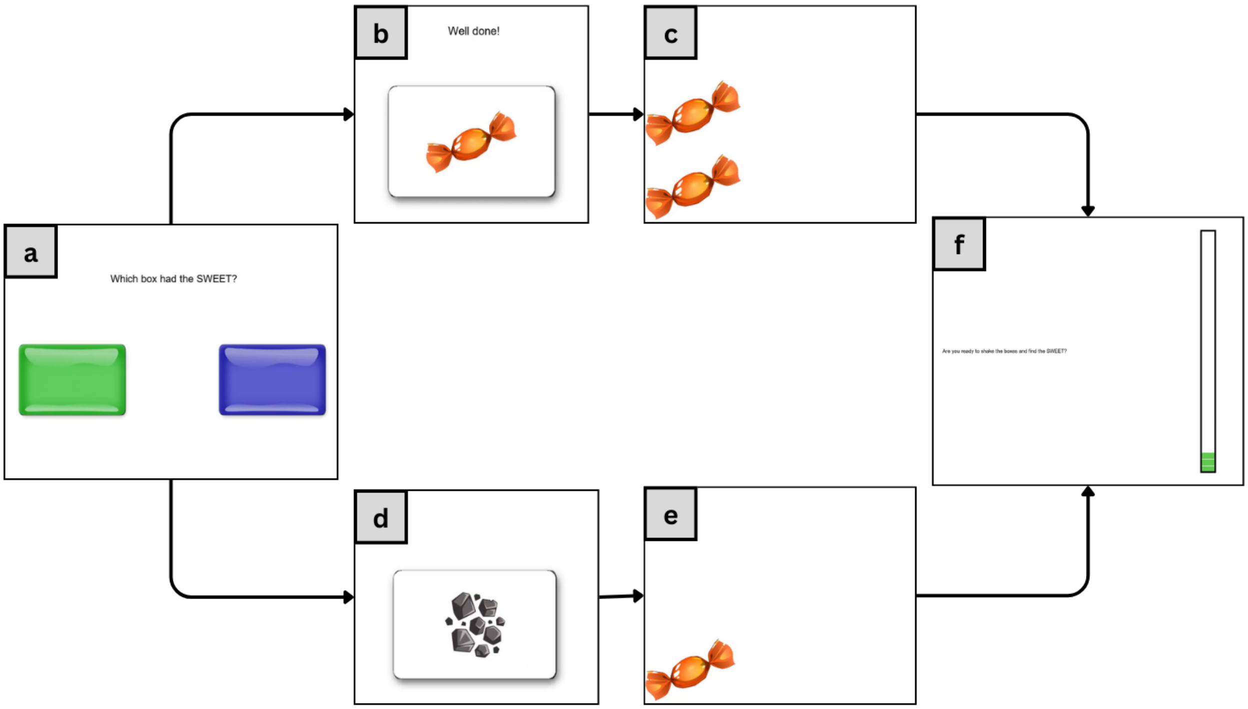
***Demonstration Phase*.** Asynchronous and synchronous pairs of sounds were played to demonstrate the task. The picture of the green box on the left was displayed when the first pair of sounds played, and the picture of the blue box on the right was displayed when the second pair of sounds played 1.2 s later. Afterwards, both boxes appeared on the screen, and the participant was asked which box had the sweet in it. When the participant responded, the correct answer was revealed by displaying a picture of the sweet underneath the box that had played the synchronous sounds. The participant was then reminded what the box with the sweet sounded like by being shown a picture of the sweet and playing the synchronous sound pair. The participant completed this three times. The stimulus onset asynchrony (SOA) of the asynchronous sound pairs in the demonstration trials were 600, 370, and 300 ms, respectively.

Practice Phase. Participants were told that they would practise the game with the researcher. For each trial of this phase, the two pairs of sounds were presented in a random order, with the first sound pair presented with the green box and the second presented with the blue box. Both boxes then reappeared, and the participant was asked which box had the sweet. The researcher inputted their answer. The participant completed this four times and received feedback similar to that in the Demonstration phase after each trial. The first trial's asynchronous sound pair always had an SOA of 180ms. Subsequent trial SOAs for the asynchronous pair were determined on a trial-by-trial basis via the Psi method (Kontsevich & Tyler, 1999). This Bayesian adaptive procedure updated the SOA based on the participant's previous response as it tried to optimise data collection to determine the threshold at which a participant could detect asynchrony. To achieve this, the SOA became smaller after a correct answer and larger after an incorrect answer. After completing all the practice trials, the participant was reminded what the box with the sweet sounded like by presenting the picture of the sweet and the synchronous sound pair.

Experimental Phase. Each participant completed 36 trials of the experiment, following the same format as the trials in the Practice Phase. The researcher controlled when each trial began. After each trial, a screen showing how many sweets the participant had found was displayed, followed by a screen with a progress bar (Figure 3.3). The number of sweets incremented for each correct answer to provide feedback on performance, and the progress bar moved forward after each trial. Every sixth trial was a "catch trial" in which the SOA was 400 ms as an attention check and to ensure continued motivation as the trials became more difficult.

Figure 3.3

Example trial of the Synchrony Perception Task



Note. The participant is asked, “Which box has the SWEET?” (a). If they answer correctly, a sweet is shown with the text “Well done!” (b) and the number of sweets they’ve collected increments (c). If they answer incorrectly, the rocks are shown (d) and the number of sweets remains the same (e). The progress bar then increments, and the text reads, “Are you ready to shake the boxes and find the SWEET?” (f).

Calculation of Synchrony Perception Threshold. To calculate the threshold at which participants could detect asynchrony, psychometric functions based on a Cumulative Gaussian distribution were fitted to each participant’s data using the Palamedes Toolbox (Prins & Kingdom, 2018) in MATLAB. Based on psychophysical methods (Kingdom & Prins, 2010), the threshold was determined to be the estimated SOA in ms between sounds where the participant would answer correctly 75% of the time. For participants whose threshold was calculated to fall below the range of stimuli presented (i.e., below 20 ms), a lower bound of 15 ms was set for their thresholds.

Data analysis. Group differences in Synchrony Perception Thresholds were analysed using an independent samples *t*-test, followed by an ANCOVA to account for group demographic differences.

3.2.2.3 Motor Production

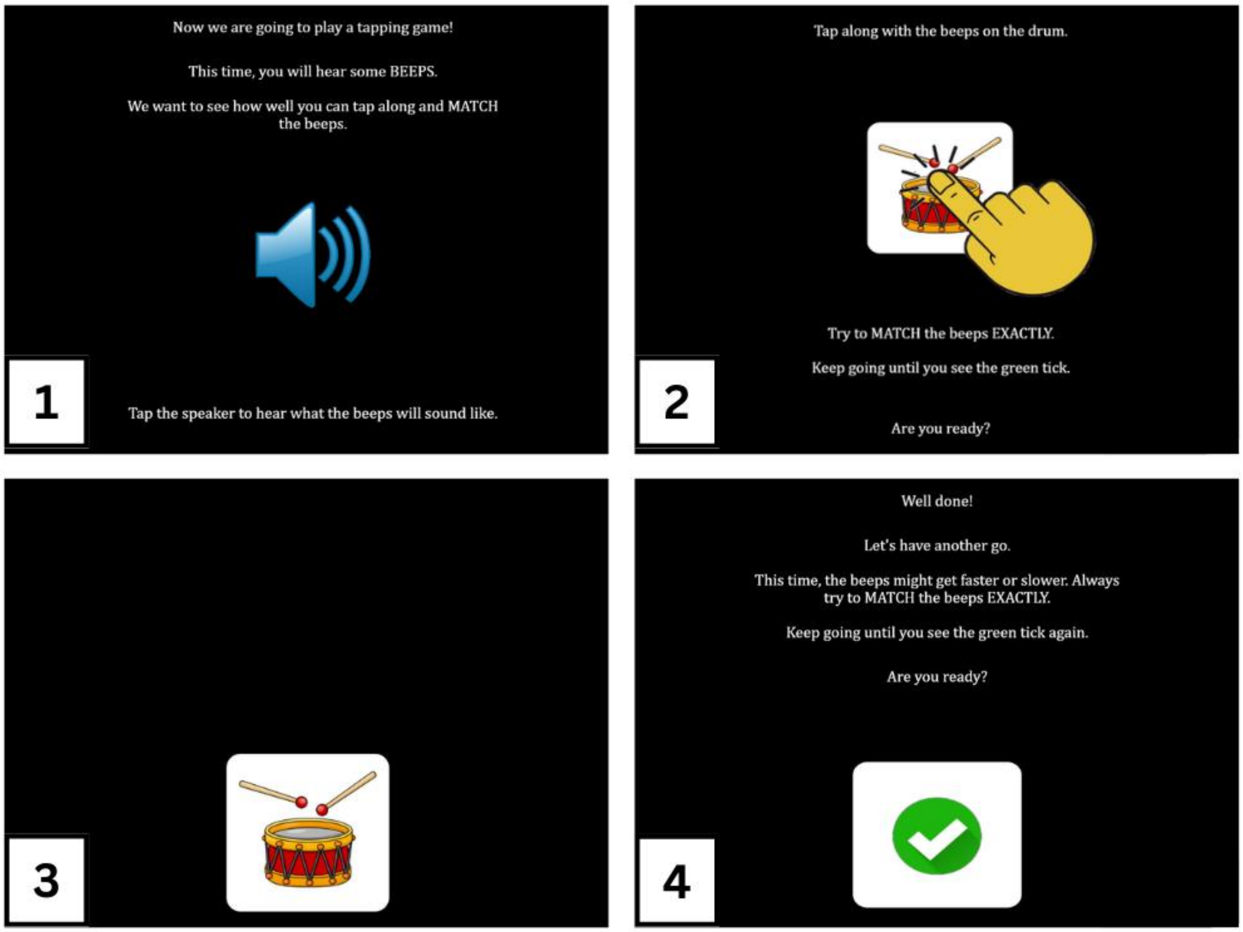
This motor synchrony task was adapted from a subsection of the Beat Alignment Test (Iversen & Patel, 2008) and re-programmed in PsychoPy3 (Peirce et al., 2019). It was administered via Pavlovia (pavlovia.org) using an iPad. All task instructions were displayed on the screen and read aloud to the participant by the researcher.

Procedure. The researcher told the participant they would play a tapping game on the iPad. The participant would hear some beeps (440 Hz), and the objective of the game was to tap along and match the beeps. An example audio of the stimulus was played. A picture of a drum was then displayed with instructions telling the participant to tap along with the beeps on the drum and to try to match the beeps exactly. They were instructed to keep tapping until a green tick appeared on the screen, indicating that they had completed the trial.

For the practice phase of the experiment, a 15-second audio clip with an interstimulus interval (ISI) of 600 ms between each beep played, accompanied by the picture of the drum. The participant tapped on the picture of the drum with their finger. When the audio clip ended, the picture of the drum was replaced by the green tick (Figure 3.4).

Figure 3.4

First phase of the Motor Production Task



Note. 1) The text reads, "Now we are going to play a tapping game! This time, you will hear some BEEPS. We want to see how well you can tap along and MATCH the beeps. Tap the speaker to hear what the beeps will sound like." 2) The text reads, "Tap along with the beeps on the drum. Try to MATCH the beeps EXACTLY. Keep going until you see the green tick. Are you ready?" 3) The picture of the drum remains on the screen for the duration of the trial. 4) A green tick replaces the drum, and the text reads, "Well done! Let's have another go. This time, the beeps might get faster or slower. Always try to MATCH the beeps EXACTLY. Keep going until you see the green tick again. Are you ready?"

For the second phase of the task, the participant was told the beeps might get faster or slower.

They were reminded to keep tapping with the beeps as accurately as they could. The three trials of this phase – stimuli with ISIs of 350 ms (fast), 600 ms (medium), and 850 ms (slow) – were presented consecutively in a random order, and each trial lasted 15 seconds. There was a 1 s pause in between trials. The green tick reappeared once all three trials had been completed.

***Calculation of entrainment variables*.** To give participants time to adjust to each new tempo, taps occurring during the first three seconds of each trial were not included in the analysis. The remaining 12 seconds of each trial were used to determine the extent to which each participant entrained their tapping to the stimuli. This was calculated using circular statistics (Fisher, 1995; Mardia & Jupp, 2000), a method that is often used to measure synchronisation with stimuli (Kirschner & Tomasello, 2009; Puyjarinet et al., 2017). Each tap is measured against the "beep" it occurred closest to, rather than a predetermined beep, which can be beneficial when tapping is highly variable (Kirschner & Tomasello, 2009; Pecenka & Keller, 2011). It also means that participants' scores are not negatively impacted if they miss a beat. This method generated two variables that measure each participant's ability to synchronise their tapping with the stimuli: the stability of their entrainment (taps' consistency with the tempo of the stimulus), and the accuracy of the entrainment (how close the taps were to the actual beats of the stimulus).

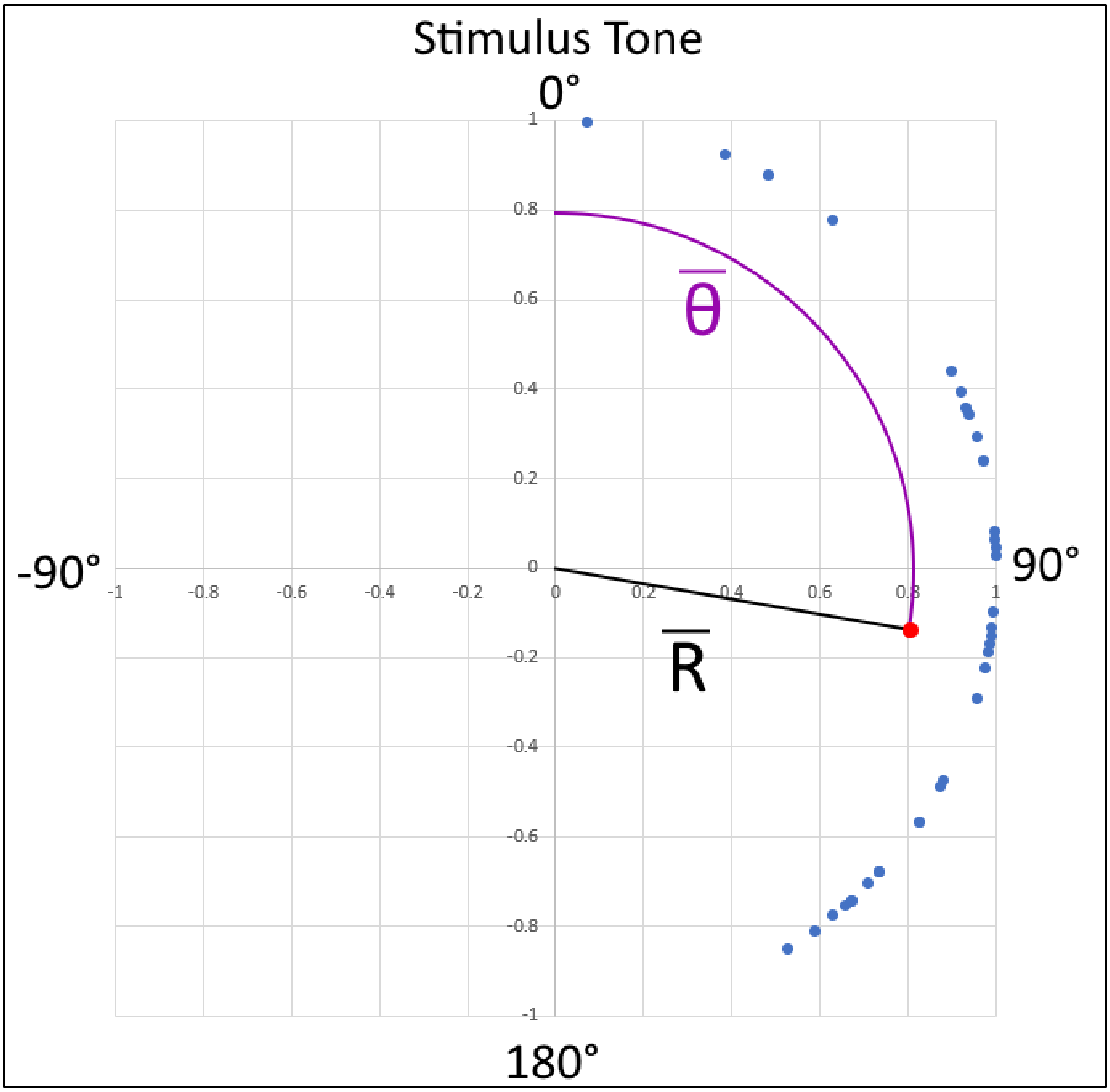
To calculate stability and accuracy, each trial was converted to a circular scale ranging from 0° to 360°. Each tap the participant made was given a point on the circumference of a circle with a radius of 1. The position of each tap on the circle reflected the angular deviation of each response from the beep of the pacing stimulus track. The points were then converted to Cartesian coordinates (x, y). Within each trial, the x and y coordinates of all of the tap points were averaged to generate a summary of the participant's performance. The resulting point was used to produce a mean vector (Fisher, 1995; Kirschner & Tomasello, 2009) with a length of $\bar{R}$ and a direction of $\bar{\theta}$.

The length $\bar{R}$ of the vector represented the stability of the participant's entrainment to the pacing stimuli. If participants tap randomly, their taps will be dispersed randomly around the circle, resulting in an $\bar{R}$ close to 0. If participants replicate the pace of the stimulus tempo perfectly, the taps will fall in the exact same spot on the circle, resulting in an $\bar{R}$ of 1. Participants with a more stable tempo will have points closer to one another on the circumference of the circle, resulting in an $\bar{R}$ value closer to 1 than those whose entrainment is less stable. Therefore, higher $\bar{R}$ values indicate better stability of entrainment.

The angle $\bar{\theta}$ of the vector represented the accuracy of the entrainment. This angle is the shortest absolute angular distance between the calculated average point and 0°. For example, an average direction of 270° would be converted to a $\bar{\theta}$ of 90°. The resulting $\bar{\theta}$ values can range from 0° to 180°. A $\bar{\theta}$ value of 0° indicates that the participant's average tapping point was simultaneous with the beeps of the pacing stimuli, and a $\bar{\theta}$ value of 180° indicates that the average tapping point was exactly halfway between two beeps. Therefore, lower $\bar{\theta}$ values indicate better accuracy of entrainment. An example is shown in Figure 3.5.

Figure 3.5

Example participant's data for a Motor Production Task trial



Note. The blue dots represent each of the participant's taps. The red dot represents the average of the blue dots after they had been converted to Cartesian coordinates. The purple arch shows the angular distance between the average point and the origin, representing the accuracy of their entrainment ($\bar{\theta}$). Smaller $\bar{\theta}$ values indicate better accuracy, ranging from 0 to 180. This participant, who is non-autistic, has a $\bar{\theta}$ of 99.89. The black line shows the linear distance between the average point and the origin, representing the stability of their entrainment ($\bar{R}$). Larger $\bar{R}$ values indicate better stability, ranging from 0 to 1. This participant's $\bar{R}$ is 0.82.

Principal components analysis (PCA) was used to combine stability ($\bar{R}$) and accuracy ($\bar{\theta}$) across all three tempos into one variable representing each participant's overall ability to synchronise with the stimulus, called their Overall Motor Synchrony Score. This enables participants' performance to be more easily compared, rather than using six separate scores, and also facilitates the calculation of correlations between participants' motor synchrony ability and other measures. PCA suggested that 5 of the 6 scores mapped onto one component, so one score was ultimately left out of the calculated Overall Motor Synchrony Score (further discussed in Section 3.3.2.2).

Data analysis. One-way repeated measures ANOVAs were used to compare the stability ($\bar{\theta}$) and accuracy ($\bar{R}$) of tapping entrainment across tempos, and mixed ANOVAs compared these variables between groups. A *t*-test was used to compare the Overall Motor Synchrony Scores between groups.

3.2.2.4 Measure of general ability

The Two-Subtest form of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II) was used as an index of general ability. As per WASI-II guidelines, participants first completed the vocabulary subtest, followed by the matrix reasoning subtest. The scores from each subtest were combined into one composite score and standardised based on the participant's age. Because the vocabulary subtest required participants to answer verbally, scores could not be calculated for participants who significantly struggled with verbal communication (n = 4).

3.2.2.5 Parent-report questionnaires

The Autism Symptom Dimensions Questionnaire (ASDQ) (Frazier et al., 2023) was completed by parents as a measure of their child's autistic traits. The first 17 questions of this 39-item instrument focus on social communication and interactions, and the other 22 questions focus on restrictive or repetitive behaviours. Each question asked parents to rate how frequently their child engages in a particular behaviour, with responses ranging from 1 (Never) to 5 (Very Often). Questions on restrictive and repetitive behaviours are reverse-coded. Example items include "Start interactions with others without prompting" and "Dislike certain lights, sounds, textures, foods, or smells". The responses are averaged to provide each participant's overall score, with a possible range of scores from 1 to 5. Higher scores indicate a higher prevalence of autistic traits. The cutoff point for ASD screening in a population context is a score of 2.7 or higher. The ASDQ was chosen over the SCQ for this study to provide a more detailed measure of participants' autistic traits, as the SCQ only focuses on features of autism related to social communication. The SCQ was deemed suitable for Chapter 2, as it was merely used as a secondary means of confirming whether a participant was likely autistic outside of parental reports, whereas the ASDQ provided a more in-depth measure to aid in the current study's quantitative data analysis.

The adapted version (Stahl & Mignon, 2009) of the Strengths and Weaknesses of Attention-Deficit/Hyperactivity Symptoms and Normal Behavior Scale (SWAN) (Swanson et al., 2001) was completed by parents as a measure of their child's attention deficit hyperactivity disorder (ADHD) traits. Of the 18 items, the first 9 items comprised the Inattentive-type subscale, and the last 9 items comprised the Hyperactive-Impulsive-type subscale. Each item related to a behaviour that children with ADHD may struggle with. Example items include "Gives close attention to detail and avoids careless mistakes" and "Remembers daily activities". The adapted version uses a simplified scoring system, with parents endorsing the presence or absence of these behaviours using a 4-point Likert scale. Responses of "Not at all" and "Just a little" were given 1 point, and responses of "Quite a bit" and "Very much" were given 0 points. The score of each subscale was calculated by tallying the points, with a possible range of 0-9.

3.2.2.6 Statistical analysis

Data were prepared in Microsoft Excel and then imported into IBM SPSS version 27.0 for analysis. Groups' gender distributions were compared using Fisher's Exact test, and other demographic information was compared using *t*-tests. For the Synchrony Perception Task, Synchrony Perception Thresholds were compared between groups using an independent samples *t*-test to determine how autistic and non-autistic groups compare in their temporal perception abilities. For the Motor Production Task, the $\bar{R}$ and $\bar{\theta}$ values at each tempo were compared within each group using repeated measures ANOVAS. Separate 1 x 3 mixed ANOVAS with repeated measures compared $\bar{R}$ and $\bar{\theta}$ values between groups to determine how autistic and non-autistic children compared in the stability and accuracy of their motor synchrony. The calculation of each participant's Overall Motor Synchrony Score was done using PCA. To compare autistic and non-autistic children's motor synchrony abilities, Overall Motor Synchrony Scores were compared between groups using an independent samples *t*-test. All between-group comparisons were repeated with ANCOVAs to account for the effects of age, gender, and ability differences between groups, when applicable as demographic variables of no interest. Pearson correlations then were calculated to compare participants' Synchrony Perception

Thresholds and Overall Motor Synchrony Scores to determine the relationship between perceiving and producing synchrony, as well as how these scores relate to general ability (WASI-II), autistic traits (ASDQ), ADHD traits (SWAN), and age.

3.3 Results

3.3.1 Synchrony Perception

Twenty-two autistic participants and 24 non-autistic participants completed the synchrony perception task (reasons for participant exclusion: Table 3.2; demographic information: Table 3.3). Twenty-one (95.5%) autistic children and no non-autistic children scored above the ASDQ threshold of 2.7. The autistic group had a lower proportion of female participants (p = .04), higher levels of autistic traits and ADHD traits, and lower general ability (WASI-II) scores than the non-autistic group. Because this thesis is focused on the potential factors that influence children's social responses to interpersonal synchrony, gender was reported instead of sex to prioritise socialisation over genetics.

Table 3.2

Reasons for participant exclusion in the Synchrony Perception Task

Reason for Exclusion	Number of Participants	
	Autistic (n = 29)	Non-Autistic (n = 27)
Threshold could not be calculated.	2	0
Participant performed worse than chance in first ten trials.	3	2
Participant noncompletion of task.	2	0
Technical error.	0	1
Number of participants following exclusions	22	24

Note. When the threshold could not be calculated, this was due to visual inspection of the psychometric function indicating that no psychometric function could accurately fit the data. Participants who performed "worse than chance" answered correctly less than 50% of the time, indicating that they likely did not understand the instructions. Because there are two response options, participants who understand the instructions but who cannot differentiate between the stimuli would still be expected to guess the correct answer approximately 50% of the time.

Table 3.3

Demographics of participants included in the Synchrony Perception Task data analysis

	Autistic Children n = 22				Non-Autistic Children n = 24				*t*-test
Sample Characteristics	n	Mean	SD	Range	n	Mean	SD	Range	
Gender									
Male	17				11				
Female	4				12				
Other	1				1				
Race/Ethnicity									
White British	19				17				
Other White background	1				5				
Asian	0				2				
Mixed Race	2				0				
Age (years)		9.48	1.53	6.50-11.75		9.17	1.34	6.92-11.83	0.73
General Ability (WASI-II)[a]		93.86	17.22	70-121		106.58	14.27	85-142	-2.71*
Autistic Traits (ASDQ)[b]		3.59	0.44	2.46-4.25		1.58	0.38	1.10-2.51	16.73***
Inattentive-Type ADHD Traits (SWAN)[c]		5.45	2.46	0-9		2.63	2.58	0-9	3.79***
Hyperactive-Impulsive-Type ADHD Traits (SWAN)[c]		6.55	2.7	0-9		1.17	1.4	0-4	8.36***
Total ADHD Traits (SWAN)[c]		12.00	4.78	0-18		3.79	3.60	0-11	6.82***

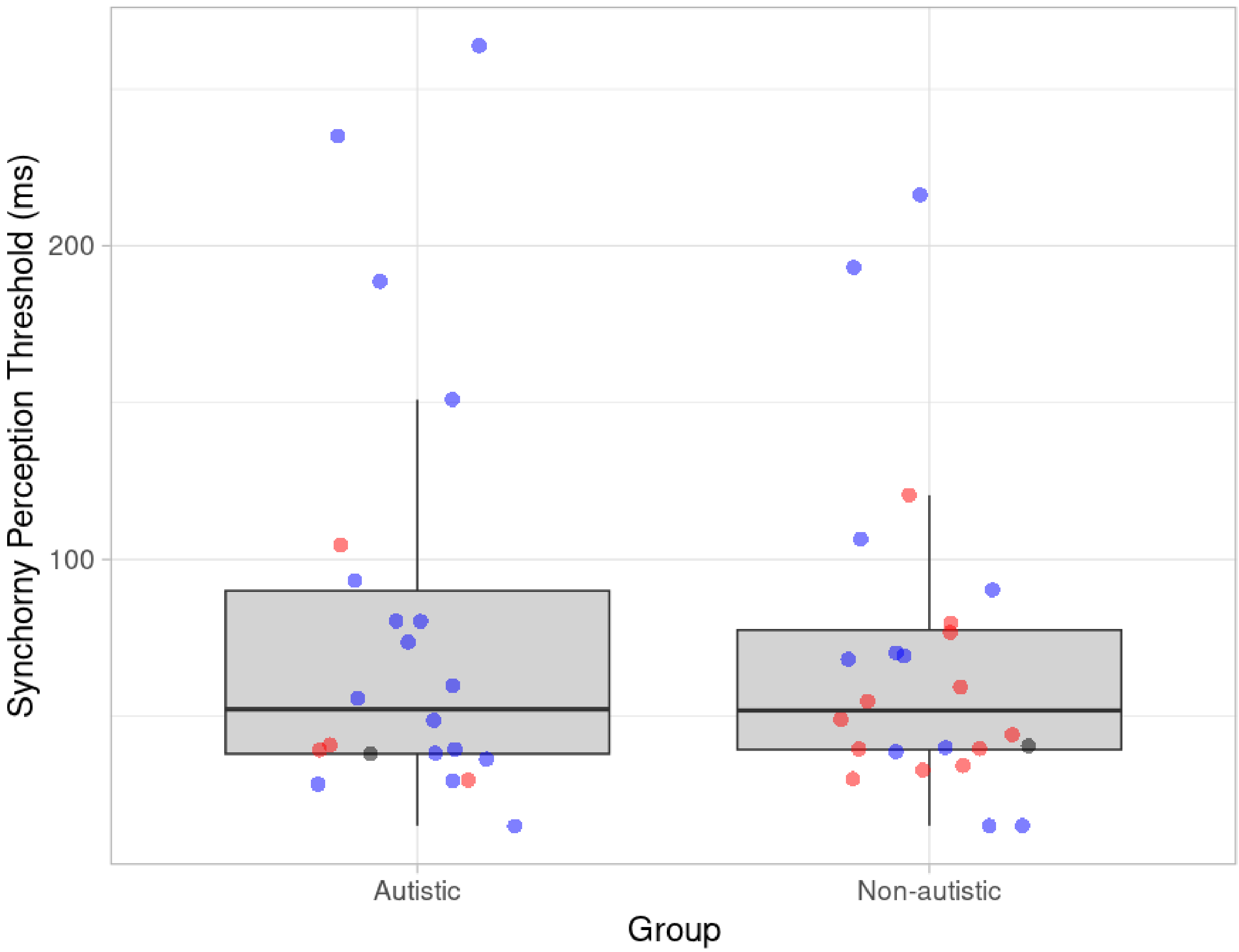
Note. [a] Wechsler Abbreviated Scale of Intelligence – Second Edition, [b] Autism Symptom Dimensions Questionnaire, [c] Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale.

* $p < .05$, *** $p < .001$

There was no significant difference in Synchrony Perception Thresholds between autistic children (M = 80.42 ms, SD = 68.94, range = 15.00 – 263.83 ms) and non-autistic children (M = 67.65 ms, SD = 49.88, range = 15.00 – 216.29 ms); t(44) = .724, *p* = .473, suggestive of similar synchrony perception abilities. A post-hoc Levene's test showed no significant difference in the groups' standard deviations, F(1, 44) = 1.747, *p* = .193 (Figure 3.6).

Figure 3.6

Synchrony Perception Thresholds of autistic and non-autistic children



Note: Dots show individual data points. Lower numbers indicate greater sensitivity to synchrony.

Because the groups differed significantly in gender distribution and WASI-II scores, an ANCOVA controlled for the effect of both variables on the Synchrony Perception Threshold. The difference between groups remained non-significant [$F(1, 41) = .046$, $p = .831$].

3.3.2 Motor Production

Twenty-eight autistic participants and 25 non-autistic participants successfully completed the Motor Production Task (participant exclusion details: Table 3.4; demographic information: Table 3.5). Twenty-seven autistic children (96.8%) and one non-autistic child (4%) scored above the ASDQ threshold of 2.7. There was no difference in the groups' gender distributions (p = .171). The autistic group had significantly higher levels of autistic traits and ADHD traits, and general ability (WASI-II) scores were significantly lower than in the non-autistic group (Table 3.5). Because this thesis is focused on the potential factors that influence children's social responses to interpersonal synchrony, gender was reported instead of sex to prioritise socialisation over genetics.

Table 3.4

Participant exclusions for Motor Production Task

Reason for Exclusion	Number of Participants	
	Autistic (n = 29)	Non-Autistic (n = 27)
Participant did not tap during one of the trials.	1	0
Technical error.	0	2
Number of participants following exclusions	28	25

Table 3.5

Demographics of participants included in the Motor Production Task data analysis

	Autistic Children (n = 28)				Non-Autistic Children (n = 25)				*t*-test
Sample Characteristics	n	Mean	SD	Range	n	Mean	SD	Range	
Gender									
Male	22				14				
Female	5				10				
Other	1				1				
Race/Ethnicity									
White British	23				17				
Other White background	1				5				
Asian	0				2				
African	0				1				
Mixed Race	4				0				
Age (years)		9.35	1.6	6.5-11.75		9	1.43	6.67-11.83	0.81
General Ability (WASI-II)[a]		94.52	16.22	70-121		106.32	13.7	85-142	-2.73**
Autistic Traits (ASDQ)[b]		3.68	0.46	2.46-4.42		1.68	0.48	1.10-2.92	15.61***
Inattentive-Type ADHD Traits (SWAN)[c]		5.64	2.77	0-9		2.76	1.52	0-9	3.89***
Hyperactive-Impulsive-Type ADHD Traits (SWAN)[c]		6.79	2.51	0-9		2.62	1.73	0-6	8.77***
Total ADHD Traits (SWAN)[c]		12.43	4.77	0-18		4.28	3.97	0-12	6.72***

Note. [a] Wechsler Abbreviated Scale of Intelligence – Second Edition, [b] Autism Symptom Dimensions Questionnaire, [c] Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale.

** $p < .01$, *** $p < .001$

3.3.2.1 Comparison of stability of entrainment ($\bar{R}$) and entrainment accuracy ($\bar{\theta}$) at different tempos

Comparisons between groups. When comparing $\bar{R}$ scores, there was a significant effect of tempo [F(2, 102) = 19.46, $p < .001$, $\eta_p^2 = .28$]. There was not a significant effect of group [F(1, 51) = .90, $p = .35$], nor was there a significant interaction of group and tempo [F(1, 102) = .93, $p = .40$, $\eta_p^2 = .02$]. When repeated as an ANCOVA to account for the groups' significantly different WASI-II scores, there was no longer an effect of tempo [F(2, 92) = .06, $p = .94$, $\eta_p^2 = .001$] and other comparisons remained non-significant.

When comparing $\bar{\theta}$ scores, there was a significant effect of tempo [F(2, 102) = 7.19, $p = .001$, $\eta_p^2 = .12$]. There was not a significant effect of group [F(1, 51) = 2.83, $p = .10$, $\eta_p^2 = .05$], nor was there a significant interaction of group and tempo [F(1, 102) = .25, $p = .78$, $\eta_p^2 = .01$. When including WASI-II scores as a covariate, there was no longer an effect of tempo [F(2, 92) = .45, $p = .65$, $\eta_p^2 = .65$] and other comparisons remained non-significant.

Autistic group. For autistic participants, there was a main effect of tempo on $\bar{R}$ values [F(1.429, 38.590) = 6.311, $p = .009$, $\eta_p^2 = 0.178$] (see Table 3.6). Bonferroni-corrected post hoc comparisons showed that the $\bar{R}$ values were significantly lower in the Fast tempo than in the Medium tempo [-.168 (95% CI, -.298 to -.038), $p = .008$], indicating poorer entrainment stability on the Fast tempo than the Medium tempo. There were no other significant comparisons (all $p \geq .05$).

Table 3.6

Mean $\bar{R}$ and $\bar{\theta}$ values for autistic participants at each tempo in the Motor Production Task

	$\bar{R}$			$\bar{\theta}$		
Tempo (ISI)	Mean	SD	Range	Mean	SD	Range
Fast (350)	.47	.34	.01 - .97	73.49	53.39	.97 – 176.48
Medium (600)	.63	.29	.05 - .97	53.06	46.42	.80 – 150.30
Slow (850)	.65	.34	.02 - .98	46.28	45.48	.14 – 150.06

Note. SD = Standard Deviation. ISI = interstimulus interval in milliseconds. $\bar{R}$ represents the stability of the entrainment, or how temporally consistent the participant's taps were. Higher values reflect better performance. $\bar{\theta}$ represents the accuracy of the entrainment, or how close the participant's taps were to the pacing stimulus. Lower values reflect better performance.

There was no significant difference in $\bar{\theta}$ for the different tempos ($F(1.72, 46.29) = 2.67$, $p = .09$, $\eta_p^2 = 0.09$). Due to the p-value below 0.1, post hoc comparisons with a Bonferroni adjustment were conducted, with no significant comparisons (all $p \geq .1$).

Non-Autistic group. For non-autistic participants, there was a main effect of tempo on $\bar{R}$ values ($F(1.42, 34.06) = 16.12$, $p < .001$, $\eta_p^2 = 0.40$). Post hoc comparisons showed that the $\bar{R}$ values were significantly lower in the Fast tempo than in the Medium tempo [-.17 (95% CI, -.27 to -.07), $p < .001$] and the Slow tempo [-.27 (95% CI, -.44 to -.11), $p < .001$], indicating poorer entrainment stability on the Fast tempo than the Medium and Slow tempos (Table 3.7). There was no difference in the entrainment stability between the Medium and Slow tempos (p = .06).

Table 3.7

Mean $\bar{R}$ and $\bar{\theta}$ values for non-autistic participants at each tempo in the Motor Production Task

	$\bar{R}$			$\bar{\theta}$		
Tempo (ISI)	Mean	SD	Range	Mean	SD	Range
Fast (350)	.50	.30	.05 - .90	65.60	37.52	9.94 – 153.10
Medium (600)	.67	.27	.07 - .98	34.31	29.79	.66 – 127.83
Slow (850)	.78	.29	.08 - .99	36.39	42.49	.24 – 155.32

Note. SD = Standard Deviation. ISI = interstimulus interval in milliseconds. $\bar{R}$ represents the stability of the entrainment, or how temporally consistent the participant's taps were. Higher values reflect better performance. $\bar{\theta}$ represents the accuracy of the entrainment, or how close the participant's taps were to the pacing stimulus. Lower values reflect better performance.

There was a main effect of tempo for $\bar{\theta}$ values ($F(1.82, 43.60) = 5.24$, $p = .01$, $\eta_p^2 = 0.18$). Bonferroni-corrected post hoc comparisons showed that $\bar{\theta}$ values were significantly larger in the Fast tempo than the Medium tempo ($p = .01$), indicating poorer entrainment accuracy in the Fast tempo than the Medium tempo. There were no other significant comparisons (all $p \geq .1$).

3.3.2.2 Calculation of overall score for motor synchrony

PCA was used to combine five of the six motor synchrony variables into one measure. The $\bar{\theta}$ variable for the fast tempo did not correlate with any of the other $\bar{\theta}$ or $\bar{R}$ variables across all participants, within the non-autistic group, or within the autistic group (see Table 3.8). This variable was therefore excluded from the PCA.

Table 3.8

Pearson correlations of the accuracy and stability of entrainment across tempos

Variable	Fast $\bar{R}$	Fast $\bar{\theta}$	Med $\bar{R}$	Med $\bar{\theta}$	Slow $\bar{R}$	Slow $\bar{\theta}$
			All Participants			
Fast $\bar{R}$	-	-	-	-	-	-
Fast $\bar{\theta}$	.11	-	-	-	-	-
Med $\bar{R}$	**.70****	-.19	-	-	-	-
Med $\bar{\theta}$	**-.31***	.04	**-.50****	-	-	-
Slow $\bar{R}$	**.40****	-.20	**.74****	-.24	-	-
Slow $\bar{\theta}$	**-.29***	-.12	**-.43****	**.30***	**-.50****	-
			Autistic Participants			
Fast $\bar{R}$	-	-	-	-	-	-
Fast $\bar{\theta}$	.15	-	-	-	-	-
Med $\bar{R}$	**.65****	-.31	-	-	-	-
Med $\bar{\theta}$	**-.50****	.06	**-.67****	-	-	-
Slow $\bar{R}$	.36	-.27	**.74****	-.36	-	-
Slow $\bar{\theta}$	-.27	-.09	-.29	**.40***	-.31	-
			Non-Autistic Participants			
Fast $\bar{R}$	-	-	-	-	-	-
Fast $\bar{\theta}$	.05	-	-	-	-	-
Med $\bar{R}$	**.76****	.05	-	-	-	-
Med $\bar{\theta}$	.05	-.07	-.04	-	-	-
Slow $\bar{R}$	**.43***	-.05	**.73****	.13	-	-
Slow $\bar{\theta}$	-.30	-.20	**-.59****	.09	**-.76****	-

Note. $\bar{R}$ represents the stability of the entrainment, or how temporally consistent the participant's taps were. Higher values reflect better performance. $\bar{\theta}$ represents the accuracy of the entrainment, or how close the participant's taps were to the pacing stimulus. Lower values reflect better performance.
* $p < .05$, ** $p < .01$

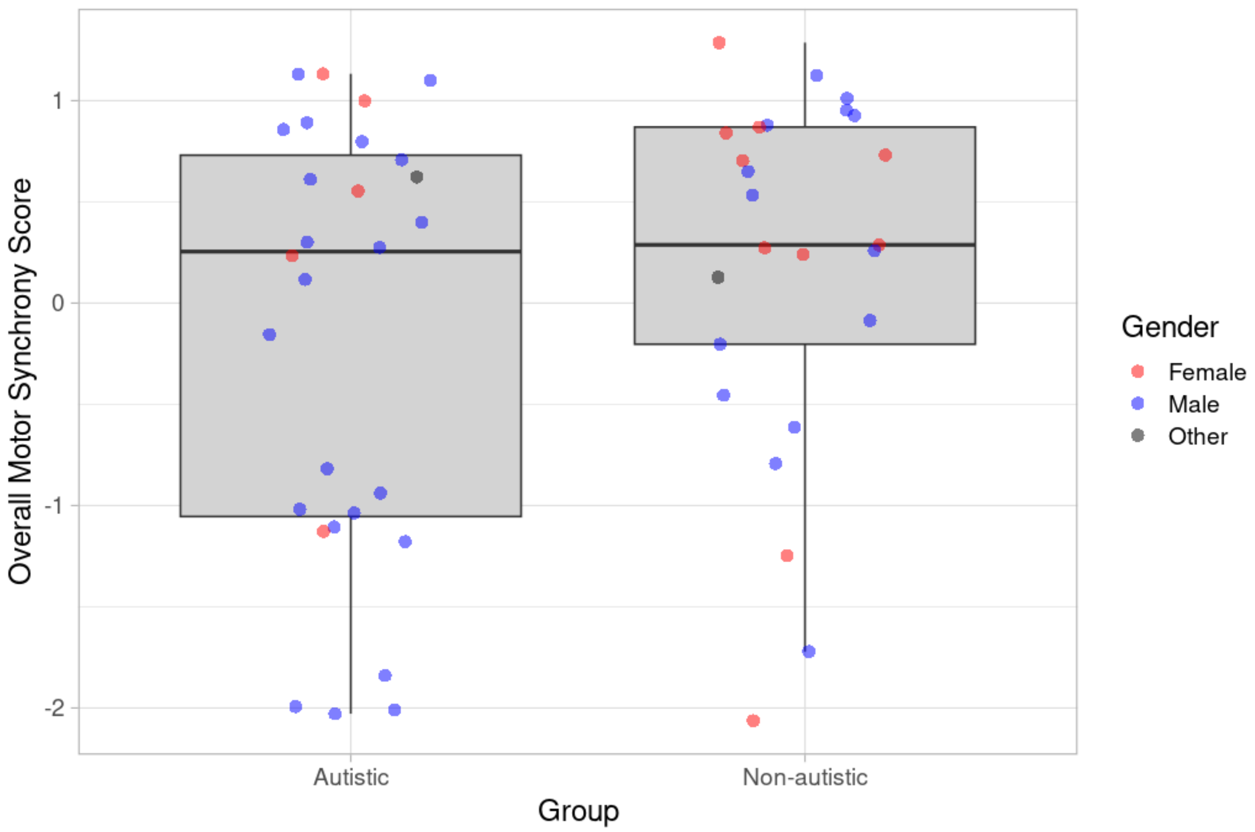
The remaining five variables were included in the PCA. The Kaiser-Meyer-Olkin (KMO) value of 0.631 indicated an acceptable score for using PCA (Kaiser, 1974), and Bartlett's test of sphericity was significant ($p < .001$). PCA generated one component with an initial Eigenvalue greater than one, and inspection of the scree plot showed that the inflexion point of the graph was after one component. The resulting single component score accounted for 55.81% of the variance and was utilised as a composite measure of motor synchrony ability. Higher Overall Motor Synchrony Scores indicate a greater ability to synchronise with the stimuli.

3.3.2.3 Group differences in Overall Motor Synchrony Scores

There was no significant difference in Overall Motor Synchrony Scores between autistic participants (M = -.16, SD = 1.08, range = -2.03 – 1.13) and non-autistic participants (M = .18, SD = .89, range = -2.06 – 1.29); t(51) = -1.25, *p* = .217 (Figure 3.7). An ANCOVA was carried out to account for the group difference in WASI-II scores, with the difference between groups remaining non-significant [F(1, 45) = .743, *p* = .393].

Figure 3.7

Overall Motor Synchrony Scores of autistic and non-autistic children



Note: Dots show individual data points. Higher scores indicate a greater entrainment with the stimuli.

3.3.3 Correlating Synchrony Perception Threshold and Overall Motor Synchrony Score

For the whole sample, the correlation between Synchrony Perception Thresholds and Overall Motor Synchrony Scores was not statistically significant (r = -.08, n = 43, p = .60). This was also the case for the Autistic (r = -.11, n = 21, p = .62) and Non-Autistic groups (r = -.03, n = 22, p = .89). Neither measure correlated with measures of autistic traits, ADHD traits, IQ scores, or age (Table 3.9).

Table 3.9

Pearson correlation of Synchrony Perception Threshold, Overall Motor Synchrony Scores, and additional measures

	1	2	3	4	5	6	7
1. Synchrony Perception Threshold	–	–	–	–	–	–	–
2. Overall Motor Synchrony Score	-.08	–	–	–	–	–	–
3. IQ (WASI-II)[a]	-.04	.08	–	–	–	–	–
4. Autistic Traits (ASDQ)[b]	.15	-.21	-.41**	–	–	–	–
5. Inattentive ADHD Traits (SWAN)[c]	-.02	-.17	-.46**	.65**	–	–	–
6. Hyperactive ADHD Traits (SWAN)[c]	.13	-.22	-.40**	.89**	.73**	–	–
7. Total ADHD Traits (SWAN)[c]	.06	-.21	-.46**	.83**	.92**	.94**	–
8. Age	.05	.04	-.14	.05	-.02	-.03	-.03

Note. [a] Wechsler Abbreviated Scale of Intelligence – Second Edition, [b] Autism Symptom Dimensions Questionnaire, [c] Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale.
** p < .01.

3.4 Discussion

This chapter explored children's ability to temporally detect synchrony in audio stimuli (synchrony perception), and synchronise movement to an audio stimulus (motor synchrony production), in non-social contexts. While autistic children had significantly higher ASDQ scores and more traits associated with ADHD than non-autistic children, both groups demonstrated similar abilities in synchrony perception and motor production. Additionally, there was no significant correlation between children's synchrony perception and motor production abilities.

3.4.1 Synchrony Perception

The data indicated there was no difference in the Synchrony Perception Thresholds of autistic and non-autistic children at the group level. As shown by the distributions in Figure 3.6, this is unlikely to be due to a ceiling effect. Only two children (1 autistic, 1 non-autistic) answered every trial correctly. While the autistic group had a larger range of scores, this was not statistically significant. Taken together, these findings suggest that there is no difference in perceptual sensitivity to detect auditory synchrony between autistic and non-autistic children. This finding is contrary to my hypothesis that autistic children would have poorer performance on the Synchrony Perception Task.

To my knowledge, no other study to date has used a simultaneity judgement (SJ) task to examine auditory temporal perception in autistic participants. However, studies examining auditory temporal perception using temporal order judgement (ToJ) tasks with auditory stimuli also found that autistic and non-autistic children performed similarly (Stevenson et al., 2014; Zhou et al., 2021). Notably, one study using a temporal order judgement (ToJ) task found that autistic children exhibited poorer performance when determining the temporal relationship of auditory stimuli (Kwakye et al., 2011). While ToJ tasks and SJ tasks are often used to study the same concepts and have often been considered to examine the same underlying psychological and neurological mechanisms (Miyazaki et al., 2016), research has indicated that ToJ tasks may be more complex than SJ tasks and require additional processes (Allan, 1975; Miyazaki et al., 2016). As such, it is possible that the basic processes required to detect auditory synchrony, as directly measured by SJ tasks such as the one used in this study, may be unaffected in autistic children, but that their performance can worsen when the task requires additional processes such as needing to also determine the order in which the stimuli were presented, as is the case with ToJ tasks, or those that use more complex stimuli.

As discussed in Chapter 1, in general, there is conflicting research regarding temporal sensory perception in autistic children. Results can vary, even when participants complete the same type of task with the same mode of stimuli. For example, a study using auditory stimuli with ToJ tasks found reduced acuity in sensory perception among autistic children, meaning autistic children were less accurately able to determine the temporal order of auditory stimuli compared to non-autistic children (Kwakye et al., 2011), while other studies found no difference between groups (Stevenson et al., 2014; Zhou et al., 2021). This could be due to the specific format of the auditory stimuli used in the ToJ tasks. For example, Kwakye et al. found a difference between groups when they played the same stimuli successively in both sides of a headset and had participants answer which side played first, while Stevenson et al. and Zhou et al. found no group differences when using stimuli of different pitches (similar to the current study). Similarly, one study using visual stimuli with SJ tasks found enhanced sensory acuity in autistic children when two grey bars appeared on a screen either successively or simultaneously (Falter et al., 2012), while another study found no difference between autistic and non-autistic individuals in this domain using images of cartoon birds (Isaksson et al., 2018). Given the mixed results across studies and that the current study did not find significant differences in temporal sensory perception between autistic and non-autistic children, it is unlikely that autistic children's difficulties with interpersonal synchrony are driven by basic differences in their ability to temporally order or detect synchrony in unisensory stimuli. Differences in this domain are likely to vary with other features of the stimuli beyond their modality.

Real-world social interactions require the integration of multiple sensory modalities, such as both audio and visual signals. Research regarding autistic individuals' sensitivity to the temporal relationship of non-social audiovisual stimuli has mixed results. Studies using ToJ tasks suggest that autistic individuals have reduced sensitivity compared to non-autistic individuals (de Boer-Schellekens et al., 2013; Kwakye et al., 2011), while studies using SJ tasks suggest that the groups are equivalent (Bebko et al., 2006; Stevenson et al., 2014; Suri et al., 2023). Once again, because ToJ tasks are considered to include more processes than SJ tasks (Allan, 1975; Miyazaki et al., 2016), this supports the idea that autistic individuals find it easier to determine the temporal relationship of stimuli when task demands are reduced. There is consistent evidence suggesting that autistic individuals have reduced acuity when detecting synchrony of audiovisual social stimuli (i.e., face and speech) (Bebko et al., 2006; de Boer-Schellekens et al., 2013; Noel et al., 2018; Stevenson et al., 2014; Zhou et al., 2021), which is likely to be a better representation of how individuals would experience real-world social interactions. Because the current study used an SJ task with unisensory stimuli and no social context, the absence of these additional factors and processes in the current study could explain why there was no significant difference between groups, despite other studies with more complex tasks and stimuli consistently finding significant differences.

While autistic and non-autistic children's ability to detect synchrony were similar in the current study, this does not mean that these perceptual abilities will be as robust in real-world settings. This task investigated fundamental differences in perception at a relatively low level of information processing. Therefore, it does not account for additional aspects of real-world social interactions (de Boer-Schellekens et al., 2013; Kwakye et al., 2011) such as distractions, nor for stimuli that are more complex than the simple tones used in the current study. These elements have the potential to reduce perceptual acuity. For example, one study found that autistic and non-autistic participants had similar temporal binding windows (i.e., the span of temporal offsets during which information from sensory stimuli from multiple modalities is perceived as being a single event or object) using simple stimuli (flashes and beeps), but that autistic participants had significantly larger (i.e., less accurate) temporal binding windows for audiovisual speech stimuli (Stevenson et al., 2014). As such, the findings of the current study suggest that differences in how autistic and non-autistic people perceive synchrony are likely not due to fundamental differences in auditory perception, but instead are more likely linked to other aspects and components of real-world interactions.

There was a considerable amount of individual variation in the Synchrony Perception Thresholds in both groups, with each having a range of over 200 ms. However, differences in scores did not appear to be driven by individual differences in general ability, autistic traits, ADHD traits, or age. Ranges of this size seem common in tasks similar to these – two studies using auditory ToJ tasks with typically developing children reported that their standard deviations were 94.16 ms (Zhou et al., 2021) and 156 ms (Oram Cardy et al., 2010), compared to the current study's standard deviation of 49.88 ms which likely had less variation because SJ tasks are less complex than ToJ tasks (Allan, 1975; Miyazaki et al., 2016). In essence, performance on auditory perception tasks is typically quite varied. As such, it is likely that each participant's ability to accurately perceive the temporal relationship of auditory stimuli is a combination of how it is measured, the particular stimuli used, and individual differences.

3.4.2 Motor Production

At the group level, autistic children and non-autistic children showed similar synchrony entrainment accuracy, synchrony entrainment stability, and Overall Motor Synchrony Scores. This is contrary to my hypothesis that autistic children would have poorer performance on the Motor Production Task. While it is known that autistic children often broadly struggle with motor movements (Cassidy et al., 2016; Hilton et al., 2012), this did not seem to have a significant impact on their ability to produce simple motor movements in time. This could be because autistic children's motor difficulties are thought to be more pronounced when tasks require complex movements or core balance (Whyatt & Craig, 2012) and the current study only required tapping with one finger. Indeed, while autistic individuals in one study had significantly poorer performance on tasks that required speed, visually-guided movements, muscle tone, grip force, and balance, their performance on a task requiring them to tap along with beeps was similar to that of non-autistic participants (Gowen & Miall, 2005). Another study that required participants to tap along with regular auditory stimuli also found that autistic participants had similar mean synchronisation errors to non-autistic participants (measured as the time difference between the participant's tap and the stimulus, similar to the current study's entrainment accuracy measure), but that the autistic group's performance was significantly more varied (Morimoto et al., 2018). This could be because participants had to tap their thumb and index finger together rather than tapping a screen with one finger, likely increasing the motor complexity of the task. This methodological difference between the two studies could require different levels or aspects of coordination and could potentially drive higher variability in autistic participants' performance in the other study. However, it was notable that mean entrainment accuracy was not significantly worse in the autistic group, even in the context of the more demanding motor execution. Indeed, other research has also found that autistic children's ability to produce motor synchrony with nonverbal rhythms is similar to that of non-autistic children across the course of childhood development (Tryfon et al., 2017). This suggests it is unlikely that autistic children's struggles with interpersonal synchrony are due to fundamental differences in how accurately they can produce basic motor synchrony.

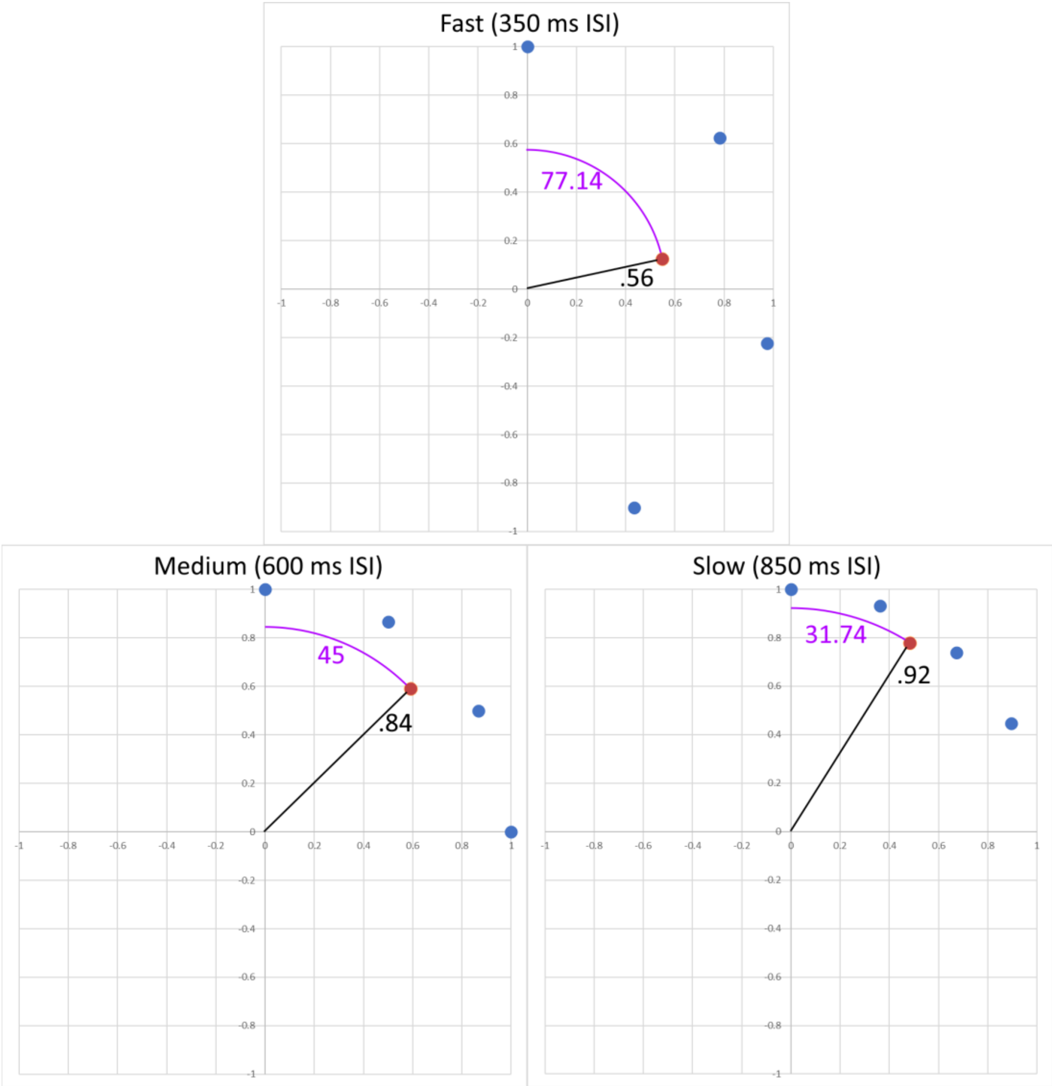
Most studies that investigate complex motor movements in social contexts, such as mirroring a partner's head and body movements during an interaction, more consistently find that autistic individuals engage in less motor synchrony than non-autistic people (Georgescu et al., 2020; Koehler et al., 2022; McNaughton & Redcay, 2020). The results of the current study align with evidence that autistic and non-autistic participants engage in interpersonal synchrony more similarly when the task's motor movements are less complex (Koehne et al., 2016). While it is known that autistic individuals often struggle with motor abilities (Gowen et al., 2023; Gowen & Hamilton, 2013), researchers have also proposed that autistic individuals' differences in producing interpersonal synchrony may not strictly be due to differences in motor skills, but instead result from a combination of social, motor, and attention/perception differences (Fitzpatrick et al., 2016). As such, it is likely that autistic individuals' tendency to engage in less interpersonal synchrony than their non-autistic peers is not due to a difference in how accurately these groups can produce motor synchrony at a very basic level, but that these differences may instead arise when demands are increased and in the presence of additional factors.

In the current study, performance on the Motor Production Task was worse for the fastest tempo (350 ms ISI) for both groups of children. One possible explanation for this is the way in which the entrainment stability ($\bar{R}$) and entrainment accuracy ($\bar{\theta}$) were calculated. Because performance was calculated using circular statistics, similar absolute delays between the stimulus and response for different tempos are proportionately greater at faster tempos. For example, Figure 3.8 shows dummy data with taps at delays of 0, 50, 100, and 150 ms at each of the three tempos. Proportionally, the taps appear much more spread out in the Fast tempo than in the Medium and Slow tempos. This causes the entrainment stability and accuracy scores in the Fast tempo to be worse than that of the Medium and Slow tempos. In essence, even if participants' taps have a consistent absolute difference in timing between their taps and the stimuli, their performance will appear to be worse as the tempo increases. This could partially explain the poorer scores on the fastest tempo and why this impacted both groups similarly.

A limitation of this study is that the samples were predominantly male, with the autistic samples being almost entirely male. This limited the ability to explore gender/sex differences in the sample, despite a number of studies showing sex differences in fine motor skills (Bondi et al., 2022; Liutsko et al., 2020) in children of this age range. This study could be repeated with a more balanced sample in order to investigate synchrony from a more developmental perspective.

Figure 3.8

Circular statistics calculations at different tempos using dummy data



Note. This is simulated dummy data for illustrative purposes. The blue dots represent taps at a delay of 0, 50, 100, and 150 ms from the stimulus. The red dot represents the average of the blue dots in Cartesian coordinates. The purple arch and accompanying value show the angular distance between the average point and the origin, representing the accuracy of their entrainment ($\bar{\theta}$). Smaller $\bar{\theta}$ values indicate better accuracy, ranging from 0 to 180. The black line and accompanying value show the linear distance between the average point and the origin, representing the stability of their entrainment ($\bar{R}$). Larger $\bar{R}$ values indicate better stability, ranging from 0 to 1.
ISI = interstimulus interval

3.4.3 The association between Synchrony Perception Threshold and Overall Motor Synchrony Score

Contrary to my hypothesis that participants' Synchrony Perception Thresholds and Overall Motor Synchrony Scores would be correlated, these values did not have a significant correlation; this was true for the group as a whole and for the autistic and non-autistic groups separately. Because monitoring both one's own actions and those of an interacting partner is a necessary component of rhythmic coordination (Keller et al., 2014), it could be expected that participants who are more accurately able to perceive synchrony would also be better at producing synchrony. However, the knowledge that one is moving asynchronously would only be useful if one can then effectively act on that information. In essence, individuals must also have the ability to adjust their own behaviour in response to the partner's (Cacioppo et al., 2014) rather than merely knowing whether or not they are synchronised. While the detection of asynchrony is likely dependent on accurate synchrony perception, the ability to correct asynchrony is thought to draw upon action prediction and motor abilities (Bowsher-Murray et al., 2022). For example, although most infants struggle to produce synchrony themselves due to their not-yet-developed motor skills, moving in synchrony with them still encourages prosocial behaviours (Trainor & Cirelli, 2015). As such, it is possible that participants' Overall Motor Synchrony Scores may be more closely influenced by children's ability to produce and adapt their motor movements rather than differences in how they perceive synchrony.

3.5 Conclusion

The results of this chapter have indicated that there are no significant differences in how autistic and non-autistic children perceive auditory synchrony, and in how they produce motor synchrony, in the absence of confounding factors such as complex stimuli and social contexts. However, as outlined in Chapter 1, there is an abundance of evidence showing that autistic and non-autistic people experience and engage in synchrony differently in real-world social situations. Therefore, Chapter 4 will investigate how these groups perceive and produce these stimuli with an added social context.

Chapter 4

Witnessed and Experienced Interpersonal Synchrony in Autistic and Non-Autistic Children

4.1 Introduction

As discussed in Chapter 1, interpersonal synchrony impacts how non-autistic people understand and form social relationships (Bowsher-Murray et al., 2022). Whether someone receives social benefits from interpersonal synchrony is considered to depend on several prerequisite processes that encompass motor, perceptual, and social skills (Trainor & Cirelli, 2015). Through investigating the processes that underpin interpersonal synchrony in Chapter 3, it was demonstrated that when stimuli were simplified (i.e., unisensory non-social auditory stimuli) and task demands were reduced (i.e., using a synchrony judgement task that only required participants to detect whether stimuli occurred simultaneously), autistic and non-autistic participants demonstrated similar performance in their ability to perceive synchrony. Similarly, in a task designed to measure participants' motor synchrony production skills in the absence of confounding factors (i.e., by tapping along with simple rhythmic auditory stimuli in the absence of a social context), autistic and non-autistic children again performed similarly to one another.

While these tasks compared how children perceive and produce synchrony in non-social contexts, they did not directly measure the affiliative effects of interpersonal synchrony. Introducing a social context increases the complexity of tasks that require the perception or production of synchrony through the addition of factors such as social orienting and increased attentional load (Bowsher-Murray et al., 2022). These processes may be particularly difficult for autistic people, as autistic children are often less likely to attend to social stimuli, especially when there are increased demands on their attention (Remington et al., 2012). Witnessed and experienced interpersonal synchrony have both been shown to impact the perception of social relationships. When non-autistic individuals witness partners acting synchronously, they typically interpret the partners to have higher levels of affiliation than partners they witness acting asynchronously (Abraham et al., 2022; Fawcett & Tunçgenç, 2017). Similarly, when non-autistic people act in synchrony with another person, this typically has social effects such as increased rapport between synchronous partners (LaFrance, 1979; Vacharkulksemsuk & Fredrickson, 2012), a sense of affiliation (Hove & Risen, 2009; Tunçgenç et al., 2015), improved cooperation (Knoblich et al., 2011; Sebanz et al., 2006; Valdesolo et al., 2010), and fostering perceived similarity and closeness (Mazzurega et al., 2011). However, these findings are often different for autistic individuals (Au & Lo, 2020; Koehne et al., 2016). Autistic children may not consider synchronous partners to be socially closer in the way that non-autistic children typically do (Au & Lo, 2020), and are less sensitive to the social effects of acting synchronously with someone else (Koehne et al., 2016). Similarly, research has also shown that autistic individuals may not rely on synchrony to build rapport with others in the way that non-autistic people tend to do (Efthimiou et al., 2025).

One way of exploring how a social context impacts autistic and non-autistic children's experiences with synchrony is to manipulate the complexity of the social information presented, which can be achieved through the use of humanoid robots. Robots are a robust way of creating a limited and controlled social presence that removes many of the additional demands on attentional load that are often present in real-world social interactions with humans. For example, robots may lack social cues such as emotions (Liberčanová, 2022) or the ability to make eye contact (Ansari, 2024). It is possible that the affiliative effects of interpersonal synchrony may be more similar between autistic and non-autistic people when the complexity of the social demands is reduced in this way. It is also possible that children, regardless of their neurodivergence, will interpret synchronous actions from robots in a different way than synchronous actions from humans because research shows that children often perceive robots as having different qualities and abilities compared to humans (Okita & Schwartz, 2006; Szymona et al., 2021). There is conflicting evidence regarding whether synchronising with a robot influences their actions and feelings towards it – different studies have indicated that synchrony may have no effect (Henschel & Cross, 2020), or that asynchrony may even produce the strongest positive response (Sweezy, 2023). Because producing interpersonal synchrony requires additional motor processes compared to merely witnessing interpersonal synchrony in others, it is necessary to investigate both of these cases independently.

Interpersonal synchrony can take many forms, some of which have distinct rhythmic components (e.g., walking in step, dancing), and some of which do not (e.g., entraining facial expressions). Both simultaneity and regularity indicate that partners' actions are temporally related (Wan & Zhu, 2022), but because they are not both universally present in all forms of interpersonal synchrony, it is necessary to determine the degree to which each component drives the social effects. Simultaneity and regularity have both been shown to increase perceived affiliation when non-autistic children witness interpersonal synchrony in others (Bowsher-Murray et al., 2023), but because autistic children often experience social interactions differently than non-autistic children (American Psychiatric Association & American Psychiatric Association, 2013), it is not clear whether this pattern would also be found in autistic children. Similarly, it is unknown how these components separately impact affiliative effects of witnessed interpersonal synchrony involving robots compared to interactions which only involve humans.

To further understand the effects of simultaneity and regularity, it is also necessary to disentangle the objective presence of simultaneity and the subjective perception of simultaneity. As demonstrated in the Synchrony Perception Task in Chapter 3, people often perceive non-simultaneous stimuli as occurring together when there is a slight delay between them. Indeed, stimuli are typically perceived as being temporally grouped together if they occur within a certain time frame, referred to as the temporal binding window (Wallace & Stevenson, 2014). As such, this thesis will also investigate how perceived "togetherness" mediates any effects that simultaneity and regularity have on perceived affiliation between partners, as well as how regularity and simultaneity impact perceived togetherness. Previous research has shown that perceived togetherness mediated the relationships that simultaneity and regularity had with affiliative effects (Bowsher-Murray et al., 2023). However, it is unknown whether these patterns will remain the same in autistic children or when synchrony involves robots.

To compare how witnessing interpersonal synchrony impacts how autistic and non-autistic children understand others' relationships, participants completed a Witnessed Interpersonal Synchrony Task in which they listened to audio clips of human-human and human-robot dyads playing a tapping game. These dyads tapped in ways that varied in their simultaneity and regularity. Dyads' perceived affiliation and togetherness were measured. This could perhaps more accurately be described as a "Heard" Interpersonal Synchrony task, as the stimuli is auditory, but I will refer to it as "Witnessed" in this thesis in line with the research this study was based on, Bowsher-Murray et al. (2023). To determine whether autistic and non-autistic children can experience social effects from synchronising with a robot themselves, participants then completed an Experienced Interpersonal Synchrony Task in which they played a tapping game with multiple robots. These robots also tapped with the participant in ways that varied in simultaneity and regularity, and participants' sense of affiliation with the robot was measured to determine the social effects of interpersonal synchrony.

I predict that in the Witnessed Interpersonal Synchrony Task, non-autistic children will perceive fully synchronous human-human pairs to be more highly affiliated than fully asynchronous or silent pairs, but autistic children will not (H1). For human-robot pairs, I expect that both non-autistic and autistic children will perceive fully synchronous pairs to be more highly affiliated than fully asynchronous or silent pairs (H2). Where interpersonal synchrony increases affiliation ratings, I expect that both the degree of regularity and simultaneity will increase these ratings (H3) and that these relationships will be mediated by perceived togetherness (H4). I predict that participants' social sensitivity to witnessed interpersonal synchrony will be significantly correlated with their ability to detect synchrony in simply non-social auditory stimuli, as represented by their Synchrony Perception Threshold in Chapter 3 (H5). I had also initially expected autistic participants to be less accurate in rating whether pairs tapped together (H6).

In the Experienced Interpersonal Synchrony Task, I predict that both autistic and non-autistic children will develop a stronger sense of affiliation with synchronous robots than with asynchronous or silent robots (H7). I predict that participants' social sensitivity to experienced interpersonal synchrony will be significantly correlated with their Synchrony

Perception Threshold and their ability to keep time with their finger to a rhythmic non-social auditory stimulus, as represented by their Overall Motor Synchrony Score in Chapter 3 (H8).

4.2 Method

4.2.1 Participants

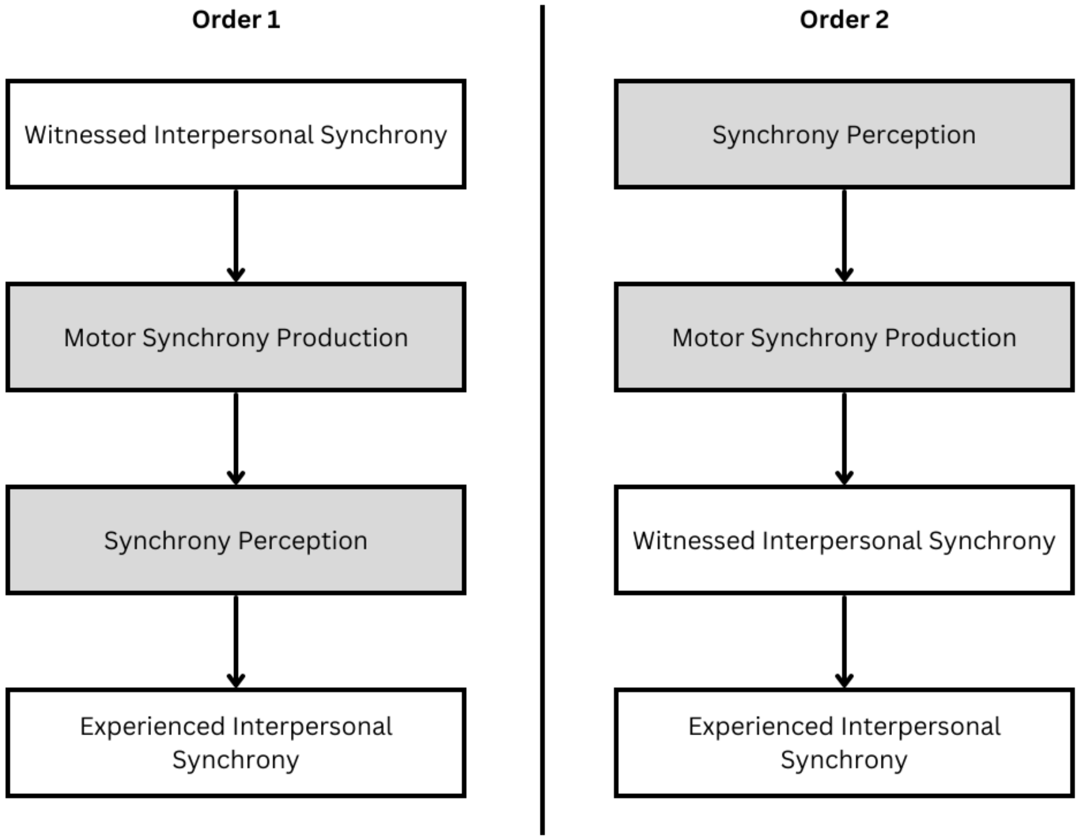
Participants were part of the same sample described in Chapter 3, consisting of 29 autistic children and 27 non-autistic children aged 6 to 11 years old. Parents/guardians provided written consent for their children to take part, and children provided verbal assent. The study received ethical approval from the Cardiff University School of Psychology Research Ethics Committee. Power analysis determined that a total sample size of 28 would be sufficient to detect within-between factor interactions in the ANOVAs used in the Witnessed and Experienced Interpersonal Synchrony task analysis (described in Section 4.2.3), assuming a medium effect size with a .05 significance level and .80 power.

4.2.2 Materials and procedure

The two tasks described below were part of a set of four tasks. The other two tasks are described in Chapter 3. Each participant was assigned one of two orders in which they would complete the tasks (Figure 4.1), after which they completed the Two-Subtest form of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II) (Wechsler, 2011) and manipulation checks.

Figure 4.1

Order of study tasks



Note. Participants completed the four tasks in one of two orders. Tasks in white are discussed in this chapter, and tasks in grey are discussed in Chapter 3.

4.2.2.1 Witnessed Interpersonal Synchrony

In the Witnessed Interpersonal Synchrony Task, participants listened to sounds that they were told were generated by two partners tapping on an iPad. Depending on the phase of the task, the partners were either two children (Human-Human), or one child and one NAO humanoid robot (Human-Robot). More details about the NAO robot can be found in Chapter 2. The way in which each pair tapped varied, as described below. The task consisted of two "Affiliation Phases" (Human-Human phase and Human-Robot phase), followed by two "Togetherness Phases" (Human-Human phase and Human-Robot phase). Each phase appeared in one of two orders. This task was adapted from a shorter online version that did not include a Human-Robot phase (Bowsher-Murray et al., 2023).

Stimuli. Ten auditory stimuli were used in this task, each lasting 11.5 s. Eight of the stimuli consisted of a series of two sets of taps, as described in section 3.2.2.2. Participants were told that tapping was controlled by two partners, with one controlling the "high" tap (a plastic beater striking the G4 bar of a glockenspiel, 392 Hz approximately) and the other controlling the "low" tap (a C3 piano key, 131 Hz approximately). The tapping between partners varied across three dichotomous features: simultaneity, regularity, and speed, resulting in a total of eight possible conditions (Table 4.1). All eight of these conditions can be heard at https://github.com/CarlyAMcGregor/InterpersonalSynchrony. In irregular trials, taps were timed quasi-randomly such that the time between taps followed a normal distribution and had a mean delay equal to that of the corresponding Non-Simultaneous/Regular trials (i.e., 125 ms delay in fast tempo; 200 ms delay in slow tempo). The remaining two stimuli were silent and were used as controls.

Table 4.1

Tapping conditions in the Witnessed Interpersonal Synchrony Task

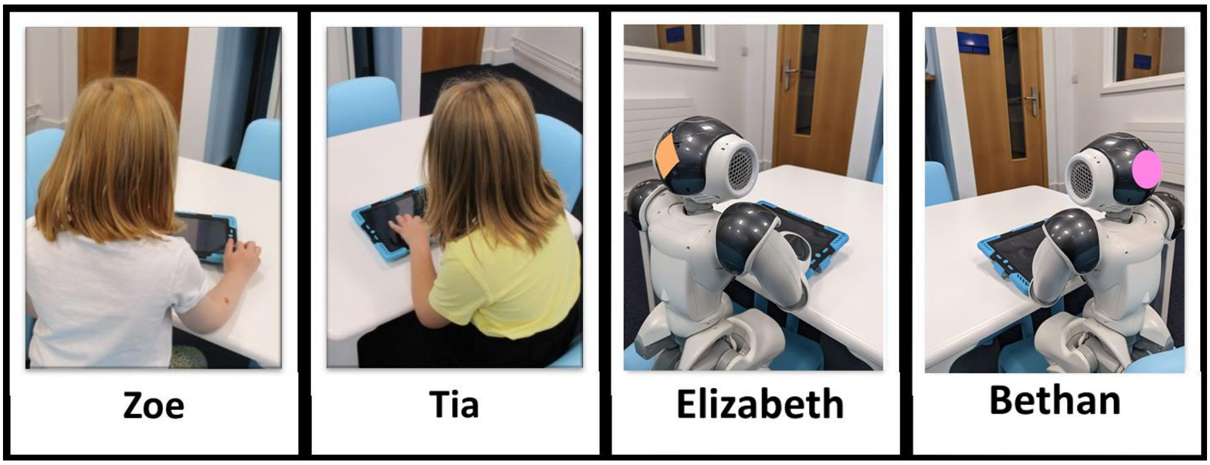
Temporal quality	Simultaneous	Non-Simultaneous
Regular	The high and low sounds play at the same time, on the beat.	The low sound plays on the beat, and the high sound plays 25% of the beat interval later (125 ms delay in the fast condition; 200 ms delay in the slow condition).
Irregular	The high and low sounds play at the same time, at differing intervals from the beat.	The high and low sounds play at different times, at differing intervals from the beat.

Note. Each of the above four conditions had two speed variants – fast (500 ms interstimulus interval) and slow (800 ms interstimulus interval).

Accompanying each auditory stimulus was a photograph of each "partner". Human partners were represented by a photograph of a child holding an iPad, photographed from behind so as to not show the child's face. A photograph of a different child was used for each partner. A name was displayed beneath each photograph to provide the child with an identity (Figure 4.2). Similarly, robot partners were represented by a photograph of a NAO humanoid robot in front of an iPad, photographed from behind. For the photographs used in the task, a different coloured shape was added to the back of each robot's head to differentiate them from one another, and the robot's name was displayed underneath their photo (Figure 4.2). The names of the robots and children were selected from the bottom 20 names from the list of the 100 most common names for boys/girls born in 2012 (Office for National Statistics, 2013a, 2013b). Female participants were shown girls' photos and names, and male participants were shown boys' photos and names. Robots were likewise gendered as male or female. Parents of non-binary participants decided which set of photos/names their child would be shown.

Figure 4.2

Examples of photos used in the girls' version of the Witnessed Interpersonal Synchrony Task



Note. The first two images are two of the photos used in the Human-Human trials of the girls' version of the Witnessed Interpersonal Synchrony Task. The last two images are two of the photos used in the Human-Robot trials of the girls' version of the Witnessed Interpersonal Synchrony Task.

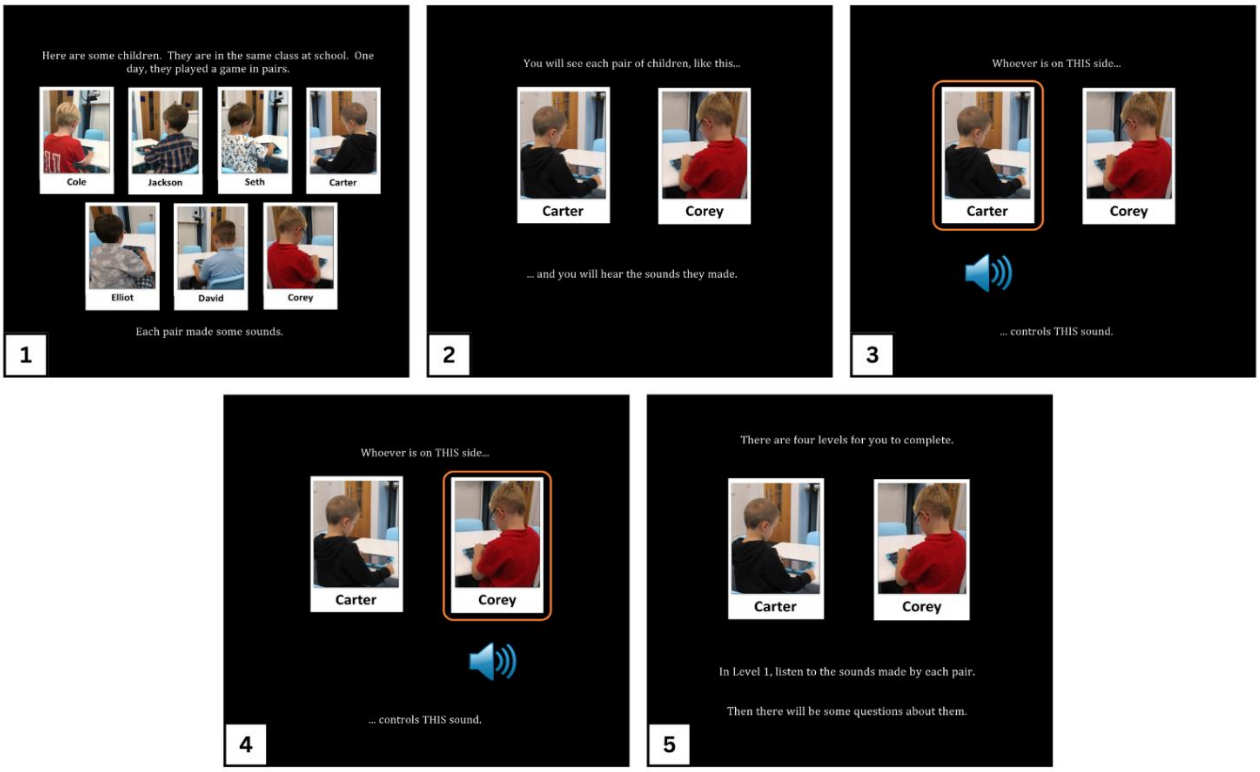
Procedure. The task was completed on a laptop computer via PsychoPy (Peirce et al., 2019). A short audio clip of a series of beeps was first played to ensure that the laptop's speakers were set to an appropriate volume level. All instructions were displayed on the screen and read aloud by the researcher. Participants were assigned one of two orders in which they completed the four phases of the task.

All participants experienced the same 10 trials (eight audible tapping trials and two silent control trials). There were four fixed orders in which the trials could appear. Trials in the Human-Human phases appeared in one of the four orders, and trials in the Human-Robot phases appeared in one of the remaining three orders. Silent trials were omitted in the Togetherness phases.

Human-Human Affiliation Phase. The screen displayed the photographs of seven children and explained that the children were all in the same class and had played a tapping game together in pairs. An example pair of children was displayed on the screen. The participant was told that they would listen to the sounds made by each pair, and then they would be asked some questions about what they heard (Figure 4.3).

Figure 4.3

Instructions for the boys' version of the Human-Human Affiliation Phase

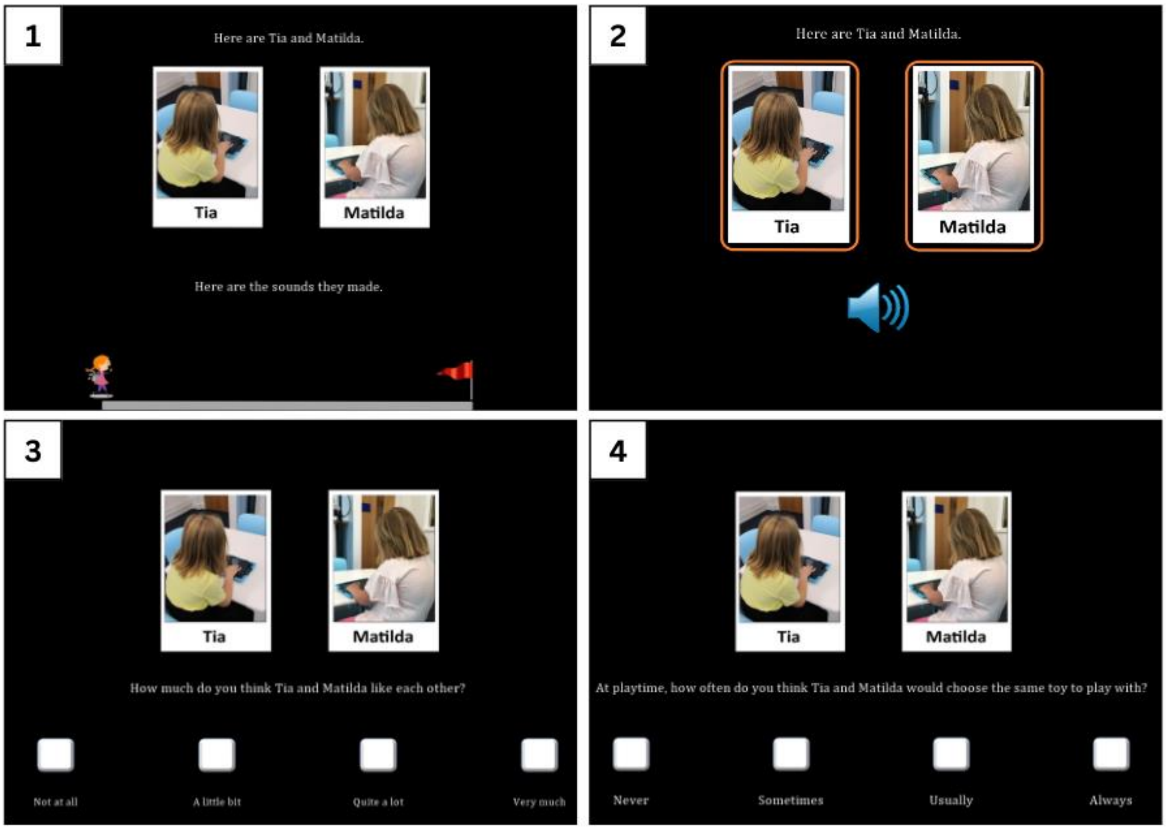


Note. 1) The text reads, "Here are some children. They are in the same class at school. One day, they played a game in pairs. Each pair made some sounds." Photos of seven children are displayed, captioned by their names. 2) The text reads, "You will see each pair of children like this … and you will hear the sounds they made." Photos of two children are displayed, representing the pair. 3) The text reads, "Whoever is on THIS side … controls THIS sound." The photo of the child on the left is highlighted with an orange rectangle, and a picture of a speaker is displayed underneath their photo. Clicking on the speaker will play the "high" glockenspiel sound. 4) The text reads, "Whoever is on THIS side … controls THIS sound." The photo of the child on the right is highlighted with an orange rectangle, and a picture of a speaker is displayed underneath their photo. Clicking on the speaker will play the "low" piano sound. 5) The text reads, "There are four levels for you to complete. In Level 1, listen to the sounds made by each pair. Then there will be some questions about them." The photos of the pair of children are displayed.

For each trial, a pair of children was displayed on the screen along with their names (Figure 4.4). For silent trials, participants were told that they would not be able to hear the sounds made by that pair. After listening to the stimulus (or silence of equal duration), the participant was asked “How much do [Partner 1] and [Partner 2] like each other?” with the options “Not at all”, “A little bit”, “Quite a lot”, and “Very much” appearing at the bottom of the screen as a 4-point Likert scale. The participant was then asked, “At playtime, how often do you think [Partner 1] and [Partner 2] would choose the same toy to play with?” with the options “Never”, “Sometimes”, “Usually”, or “Always” as a 4-point Likert scale. For both questions, the participant could answer verbally or point to their answer if they wanted the researcher to input their choice for them, or they could click on their answer themselves using the laptop trackpad. When both questions had been answered, a progress bar along the bottom of the screen incremented. This was repeated for each of the 10 trials.

Figure 4.4

Example of a trial in the Human-Human Affiliation Phase of the Witnessed Interpersonal Synchrony Task



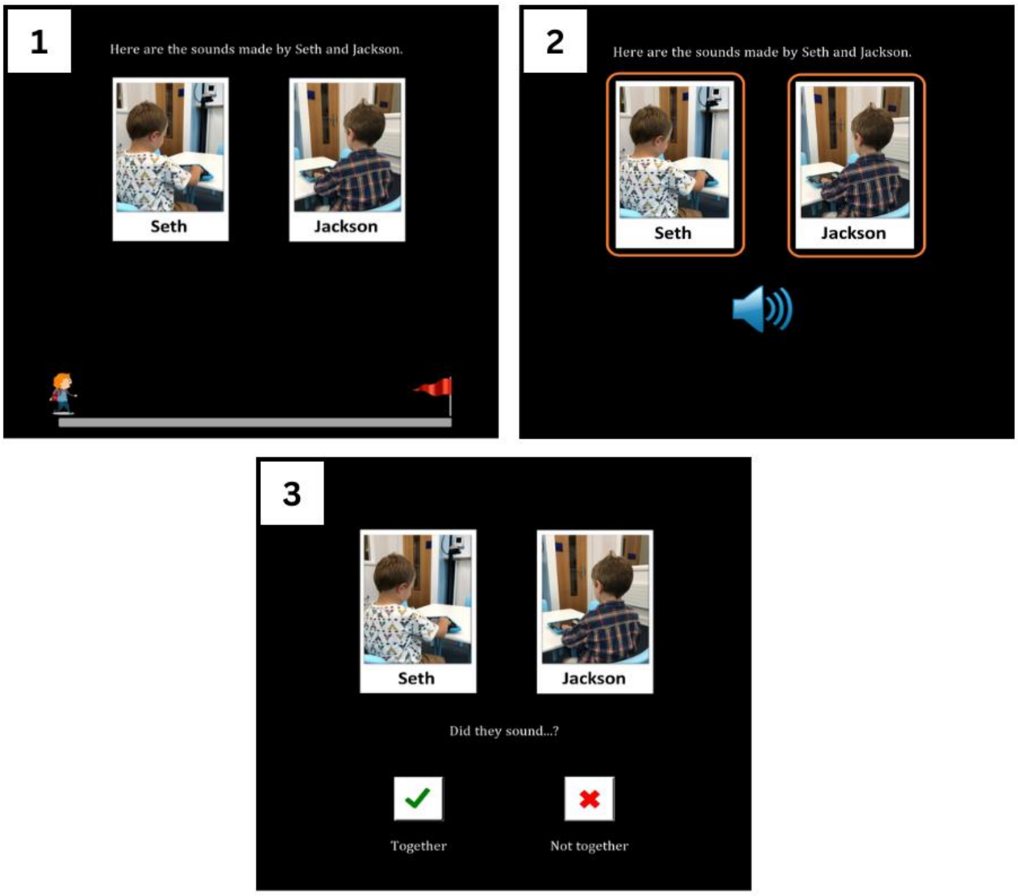
Note. 1) The text reads, “Here are Tia and Matilda. Here are the sounds they made.” 2) The trial’s audio plays. 3) The text reads, “How much do you think Tia and Matilda like each other?” with the options “Not at all”, “A little bit”, “Quite a lot”, and “Very much”. 4) The text reads, “At playtime, how often do you think Tia and Matilda would choose the same toy to play with?” with the options “Never”, “Sometimes”, “Usually”, and “Always”.

Human-Robot Affiliation Phase. If the Human-Robot Affiliation Phase occurred first, the photos of the seven children were first displayed, and the children were introduced as being in the same class. If the Human-Human Affiliation Phase had already been completed, the children were not re-introduced. Next, the screen displayed the photographs and names of seven robots and explained that the children decided to play a tapping game in pairs with some robots. The rest of the phase was carried out in the same manner as the Human-Human phase, with the only difference being that one of the partners' images was always a robot.

Togetherness Phases. The researcher explained that they would again listen to all of the pairs from the first Affiliation Phase, and the participant would be asked whether the members of each pair played their sounds together or not. The researcher explained that the sounds would be considered "together" if the sounds played at exactly the same time as each other. The participant saw and listened to each pair from the first Affiliation Phase again in the same order, answering "Together" or "Not Together" for each trial. The silent trials were omitted, resulting in eight trials. A progress bar on the screen incremented after each trial (Figure 4.5). This was repeated with the pairs from the second Affiliation Phase.

Figure 4.5

Example of a trial in the Human-Human Togetherness Phase of the Witnessed Interpersonal Synchrony Task



Note. 1) The text reads, "Here are the sounds made by Seth and Jackson." Images of two children and their names are displayed. 2) The trial's audio plays. 3) The text reads, "Did they sound…" with the options "Together" (accompanied by a green tick) and "Not together" (accompanied by a red X).

4.2.2.2 Experienced Interpersonal Synchrony

In the Experienced Interpersonal Synchrony Task, participants completed a tapping game with a series of robot partners by listening to a pacing stimulus and then repeating what they heard by tapping. The way in which the robot partners tapped varied depending on the trial, as further described below. This task was adapted from an online version in which participants tapped with a virtual human partner (Bowsher-Murray et al., 2023). To reduce any potential anxiety the participant might have about the robots, each participant completed a brief familiarisation phase with a robot before beginning the task.

Familiarisation Phase. The familiarisation phase was developed based on the findings from Chapter 2. First, the participant was shown a photograph of a NAO robot to remind them what the robot looked like, as they would have seen the robot in the storyboard that they received prior to the laboratory visit (as described in section 3.2.2.1). After confirmation from the participant that they were ready to meet the robot, the researcher left the room and returned with a NAO robot that appeared turned off. The researcher set the robot on the table and introduced it as “Russell”. When the participant was ready, the researcher began the robot’s wake-up sequence and the Guided Exploration familiarisation technique (both developed in Chapter 2 and described in detail in Appendix A). Once complete, the researcher explained that they would put the robot away temporarily so that they could learn how to play the next game. They then removed the robot from the room.

Stimuli. The pacing stimuli for each trial consisted of eight 440 Hz beeps. The participant’s taps produced a “low” piano sound, and the robot’s “taps” produced a “high” glockenspiel sound. The robot’s taps either occurred synchronously with the participant’s taps, at a regular interval after the participant’s taps, or at irregular intervals after the participant’s taps (Table 4.2). Each of the three conditions had a fast trial (500ms ISI pacing track) and a slow trial (800ms ISI pacing track). There were also two silent trials used as controls, resulting in eight total trials.

Table 4.2

Tapping conditions in the Experienced Interpersonal Synchrony Task

Trial type	Description	Amount of latency
Simultaneous	Robot's taps occurred simultaneously with the participant's.	0ms
Non-Simultaneous/Regular	Robot's taps occurred at a regular interval after the participant's.	25% delay from pacing stimulus (125 ms delay in fast tempo; 200 ms delay in slow tempo)
Non-Simultaneous/Irregular	Robot's taps occurred at irregular intervals after the participant's.	Delays were quasi-randomised such that they followed a normal distribution and had a mean delay equal to that of the Non-Simultaneous/Regular trials (i.e., 125 ms delay in fast tempo; 200 ms delay in slow tempo)

Note. Each of the above three conditions had two speed variants – fast (500 ms interstimulus interval) and slow (800 ms interstimulus interval).

The names of the robots were the same as the seven given to robots in the Witnessed Interpersonal Synchrony Task, plus one additional name for the eighth robot, which was taken from the bottom 20 names from the same list of the 100 most common names for boys/girls born in 2012 (Office for National Statistics, 2013a, 2013b). Female participants were shown the girls' names, and male participants were shown the boys' names. Parents of non-binary participants decided which set of names their child would be shown. Names of robots were presented in a random order for each participant.

Procedure. The researcher told the participant that they would play a tapping game with a robot partner. The participant was told to listen to a series of beeps (the pacing stimuli) and then repeat what they heard as accurately as possible by tapping on a picture of a drum on the iPad with their finger. They were told that the robot would complete the task with them and would be seated in front of the laptop across from the participant. The laptop also had an image of a drum on its screen, indicating the robot would be engaged in the same activity. The participant was told they would hear the low sound when they tapped, and the high sound when the robot tapped. They were instructed to keep tapping until the picture of the drum was replaced by a green tick, indicating the end of the trial. All sounds came out of a speaker on the table. The researcher first demonstrated how to do the task twice, then the participant completed three practice trials without a partner before starting the main task.

In each trial, the child's iPad displayed the name of the robot partner. A researcher brought a NAO robot into the room that had a coloured shape on its chest to distinguish it from the other robots. They told the child the robot's name and placed it in front of the laptop with its hand on the trackpad (Figure 4.6). For the silent trials, the participant was told that they would only hear their own taps for that trial. The speaker played the pacing stimulus, then the participant tapped on the drum on the iPad. The robot's tapping was dependent on the condition, and the sound was produced by the iPad via the speaker with the illusion that it was being produced by the robot tapping on the laptop. When the participant tapped on the iPad, the audio file that played included both their own tap sound and the robot's tap sound (either simultaneously or in sequence, depending on the trial as described in Table 4.2). The robot remained stationary during the task, but with its tapping hand occluded by the laptop and not visible to the participant. After the participant tapped on the drum 21 times, the green tick was presented and indicated that they had completed the trial. The participant then rated how much they liked the robot (4-point Likert scale: "Not at all", "A little bit", "Quite a lot", "Very much"), and how often they thought that the robot would choose the same toy as them during playtime (4-point Likert scale: "Never", "Sometimes", "Usually", "Always"). Afterwards, the robot was removed from the room and replaced by a different robot with a different coloured shape on its chest. Participants completed eight trials, one per robot. Only two robots were used during the trials, with the illusion of there being a total of eight robots. Because the task required participants to follow a pacing track, which was always a steady beat with either 500 ms or 800 ms ISI, it was not possible to have the participant and robot tap in a way that was both simultaneous and irregular as doing so would require the participant to tap differently than in the other trials. As such, there was no Simultaneous/Irregular trial for the Experienced Interpersonal Synchrony task.

Figure 4.6

Experienced Interpersonal Synchrony Task trial setup

Note. The setup of the equipment for the Experienced Interpersonal Synchrony trials. A laptop and iPad are plugged into a speaker. The image on the left is a side view of the setup, and the image on the right shows the setup from the participant's end of the table.

4.2.3 Statistical Analysis

Data were inspected to ensure parametric testing assumptions were met. Shapiro-Wilk tests showed that the majority of affiliation scores were normally distributed within each trial type, and histograms revealed that all trial types showed an approximately normal distribution.

4.2.3.1 Witnessed Interpersonal Synchrony

Calculating affiliation scores. Each of the participants' responses to the affiliation questions were converted into numerical values between 1 and 4, with higher values indicating greater affiliation. Responses to the two affiliation questions for each trial were significantly positively correlated, r (1080) = .483, $p < .001$. Therefore, within each trial, each participant's responses to the two questions were averaged to provide a total affiliation score. The fast and slow trials were also significantly positively correlated (r (397) = .429, $p < .001$), so affiliation scores were also averaged across speed, giving each participant one composite score for each tapping condition.

In the Human-Human trials, 18 participants (9 autistic, 9 non-autistic) were erroneously shown the fast version of the simultaneous/regular trial twice instead of one fast and one slow trial. These participants did not have significantly different calculated composite affiliation scores for the simultaneous/regular trial type than the rest of the rest of the participants, t(52) = .60. The same error occurred for 17 participants (8 autistic, 9 non-autistic) in the Human-Robot trials, and their composite affiliation scores for the simultaneous/regular trial type were also not significantly different from the other participants', t(52) = .81. As such, all participants were retained in the dataset.

Effect of synchrony, simultaneity, and regularity on affiliation scores. To determine the effect of synchrony on perceived affiliative effects when autistic and non-autistic children witness synchrony in Human-Human pairs (H1), a mixed ANOVA (2 x 3) was conducted for autistic and non-autistic children that compared their affiliation scores across three conditions: silent pairs, fully asynchronous (non-simultaneous and irregular) pairs, and fully synchronous (simultaneous and regular) pairs. This was repeated for Human-Robot pairs (H2). Another mixed ANOVA (2 x 2 x 2) was then conducted for autistic and non-autistic children that explored the separable effects of simultaneity (simultaneous versus non-simultaneous) and regularity (regular versus irregular), which was repeated for Human-Robot pairs (H3).

These analyses were repeated as separate repeated measures ANOVAs for each group (1 x 3 ANOVA to examine how each group responded to silent, fully asynchronous, and fully synchronous conditions; 2 x 2 ANOVA to examine how each group responded to simultaneity and regularity) to further examine patterns within each group. ANCOVAs were also conducted to control for covariates of no interest. These steps were repeated for the Human-Robot pairs to investigate how synchrony affects perceived affiliation when autistic and non-autistic children witness a dyad that includes a robot.

Ability to detect togetherness. The percentage of trials that each participant identified correctly as including partners that tapped together was calculated to create a Togetherness Score. Answers were considered correct if participants said simultaneous pairs were together, or non-simultaneous pairs were not together. A score of 1 indicated the participant answered all togetherness measures correctly, and 0 showed they answered all measures incorrectly. To compare how accurately autistic and non-autistic participants were able to tell whether each dyad tapped together, Togetherness Scores were compared between groups with a *t*-test, followed by an ANCOVA to account for covariates of no interest (H6).

Effects of simultaneity and regularity on perceived togetherness. GLMMs with a binomial distribution and a logit link function were used to examine the separable effects of simultaneity and regularity on whether a pair was perceived as tapping together. Simultaneity and regularity were used as binary predictor variables, and participant was used as a random effects variable. Perceived togetherness was the binary outcome variable.

Effects of perceived togetherness on affiliation ratings. Mediation analysis was conducted to determine whether the perceived togetherness of a pair mediated the effects of simultaneity or regularity on affiliation scores (H4). Linear regression models were used to determine path estimates.

Participants' sensitivity to witnessed interpersonal synchrony. Each participant's Overall Witnessed Sensitivity Score was calculated by subtracting their averaged affiliation score for the fully asynchronous trials from the averaged affiliation score for the fully synchronous trials. Higher scores indicate a stronger sensitivity to the social effects of interpersonal synchrony. This score was used to examine the relationship between social sensitivity to witnessed interpersonal synchrony and how accurately participants could temporally perceive non-social synchrony by calculating the Pearson's correlation coefficient for participants' Overall Witnessed Sensitivity Scores and Synchrony Perception Thresholds (Chapter 3) (H5).

4.2.3.2 Experienced Interpersonal Synchrony

Calculating affiliation scores. Composite affiliation scores were generated using the same method as in the Witnessed Interpersonal Synchrony Task. The two affiliation questions were significantly positively correlated $r(382) = .456$, $p < .001$. The scores from each of the two speeds were significantly positively correlated $r(190) = .68$, $p < .001$.

Effects of synchrony, simultaneity, and regularity on affiliation.

To determine the effects of synchrony on affiliation in autistic and non-autistic children (H7), a mixed ANOVA (2 x 3) was conducted to compare the affiliation scores across three conditions: silent robots, fully asynchronous robots, and fully synchronous robots. To compare how simultaneity and regularity impacted autistic and non-autistic children's affiliation ratings, a mixed ANOVA (2 x 3) was conducted that compared the affiliation scores across three conditions: synchronous/regular robots, non-synchronous/regular robots, and non-synchronous/irregular robots.

As with the Witnessed Synchrony task, these analyses were repeated as separate ANOVAs for each group (1 x 3 ANOVA for silent robots, fully asynchronous robots, and fully synchronous robots; 1 x 3 ANOVA for synchronous/regular robots, non-synchronous/regular robots, and non-synchronous/irregular robots) to further examine differences within the autistic and non-autistic groups. These analyses were also repeated as ANCOVAs to control for covariates of no interest.

Participants' sensitivity to experienced interpersonal synchrony. Each participant's Overall Experienced Sensitivity Score was calculated by subtracting their averaged affiliation score for the fully asynchronous trials from the averaged affiliation score for the fully synchronous trials. Higher scores indicate a stronger sensitivity to the social effects of interpersonal synchrony. This score was also used to examine the relationship between social sensitivity to experienced interpersonal synchrony, how accurately participants can temporally perceive non-social synchrony, and their motor skills (Chapter 3) (H8). This was done by calculating the Pearson's correlation coefficient for participants' Overall Experienced Sensitivity Scores and their Overall Motor Synchrony Scores, followed by the correlation between Synchrony Perception Scores and Overall Experienced Sensitivity Scores.

4.3 Results

4.3.1 Witnessed Interpersonal Synchrony

4.3.1.1 Sample Characteristics

Twenty-seven autistic children and 27 non-autistic children successfully completed the Witnessed Interpersonal Synchrony Task (see Table 4.3 for participant exclusions). Of the 27 autistic children, 26 (96.30%) scored above the ASDQ threshold of 2.7. Of the 27 non-autistic children, 1 (3.70%) scored above the ASDQ threshold. Fisher's Exact Test showed there was not a significant difference in the gender distribution between groups (p = .60). As expected, levels of autistic traits and ADHD traits were significantly higher in the autistic group than the non-autistic group, and general ability (WASI-II) was significantly lower (Table 4.4). Because this thesis is focused on the potential factors that influence children's social responses to interpersonal synchrony, gender was reported instead of sex to prioritise socialisation over genetics.

Table 4.3

Participant exclusions for Witnessed Interpersonal Synchrony Task

Reason for Exclusion	Number of Participants	
	Autistic (n = 29)	Non-Autistic (n = 27)
Participant did not complete task correctly.	1	0
Participant noncompletion of task.	1	0
Number of valid participants	27	27

Table 4.4

Demographic information of participants who completed the Witnessed Interpersonal Synchrony Task

	Autistic Children n = 27				Non-Autistic Children n = 27				*t*-test
Sample Characteristics	n	Mean	SD	Range	n	Mean	SD	Range	
Gender									
Male	21				14				
Female	5				12				
Other	1				1				
Race/Ethnicity									
White British	22				19				
Other White background	1				5				
Asian	0				2				
African	0				1				
Mixed Race	4				0				
Age (years)		9.25	1.58	6.50 - 11.75		9.00	1.43	6.67 - 11.83	.55
General Ability (WASI-II)[a]		94.30	16.51	70 - 121		106.10	13.61	85 - 142	**.01***
Autistic Traits (ASDQ)[b]		3.65	0.44	2.46 - 4.28		1.66	0.47	1.10 - 2.92	**< .001*****
Inattentive-Type ADHD Traits (SWAN)[c]		5.74	2.77	0 - 9		2.70	2.58	0 - 9	**< .001*****
Hyperactive-Impulsive-Type ADHD Traits (SWAN)[c]		6.74	2.55	0 - 9		1.40	1.72	0 - 6	**< .001*****
Total ADHD Traits (SWAN)[c]		12.48	4.90	0 - 18		4.11	3.90	0 - 12	**< .001*****

Note. [a] Wechsler Abbreviated Scale of Intelligence – Second Edition, [b] Autism Symptom Dimensions Questionnaire, [c] Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale.

* $p < .05$, *** $p < .001$

4.3.1.2 Effect of synchrony on affiliation scores

The mean affiliation scores were compared between fully Synchronous trials (simultaneous and regular), fully Asynchronous trials (not simultaneous and irregular), and Silent trials.

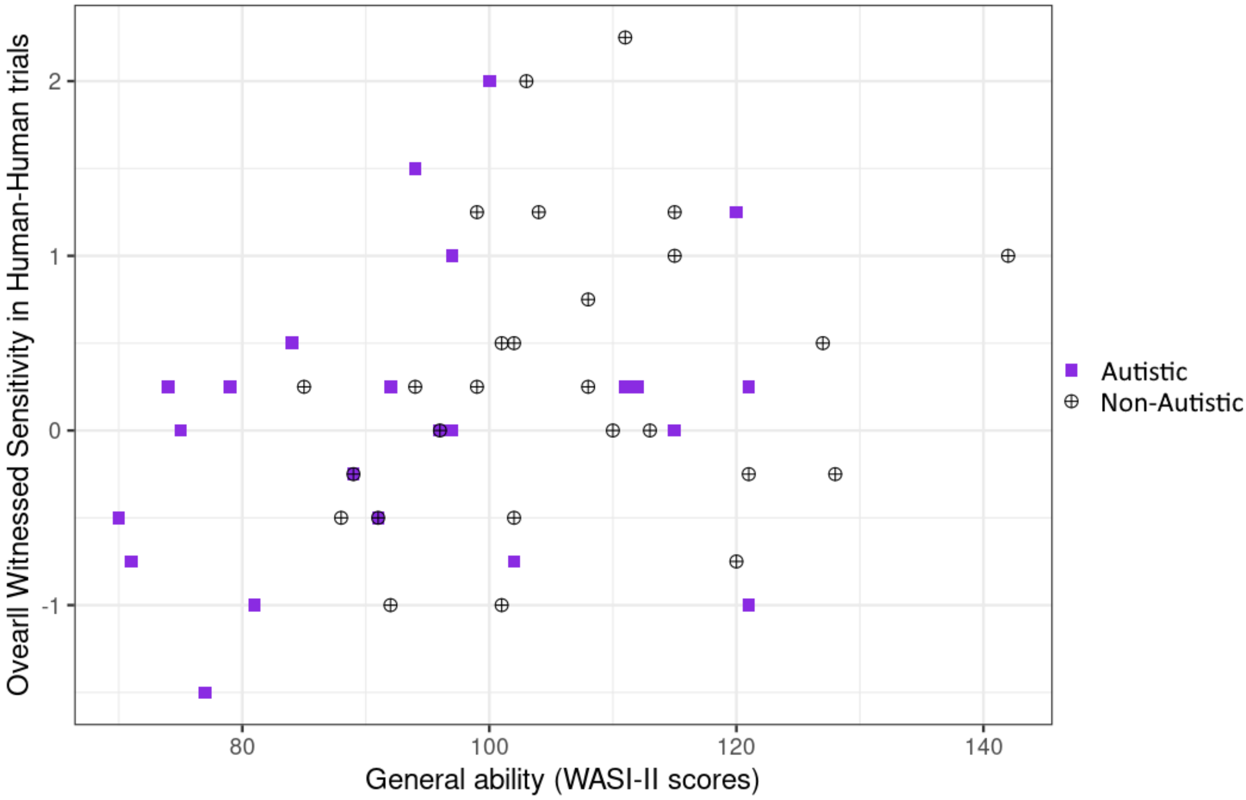
Human-Human Pairs. A mixed ANOVA, to determine the effect of group (autistic versus non-autistic) on affiliation scores, found a main effect of group close to significance with autistic participants giving higher affiliation scores, $F(1, 52) = 4.02$, $p = .0502$, $\eta^2_{partial} = .07$. There was a main effect of tapping condition, $F(2, 104) = 5.42$, $p = .006$, $\eta^2_{partial} = .09$, and post-hoc analysis with a Bonferroni adjustment indicated that Synchronous pairs received significantly higher ratings than Silent pairs ($p = .005$). The interaction of group and condition was non-significant, $F(1, 52) = 1.18$, $p = .28$, $\eta^2_{partial} = .02$. The sample size was not large enough to have the necessary power to detect significant interactions at this effect size, as the total sample size would have needed to be at least 172 for 95% power.

When general ability scores (WASI-II) were included as a covariate, there was no main effect of group, $F(1, 47) = .73$, $p = .73$, $\eta^2_{partial} = .003$, no main effect of tapping condition, $F(2, 94) = 1.19$, $p = .31$, $\eta^2_{partial} = .03$, and no interaction between group and condition, $F(2, 94) = .05$, $p = .96$, $\eta^2_{partial} = .001$. Because the main effect of group was reduced in effect size when ability levels were accounted for, post-hoc analysis investigated the relation between participants' general ability scores on their sensitivity to synchrony. Participants' Overall Witnessed Sensitivity Scores were recalculated using only the affiliation scores from Human-Human pairs. There was a significant correlation between Overall Witnessed Sensitivity and general ability for the sample as a whole, $r(48) = .29$, $p = .04$, although not for the two groups when analysed separately (autistic group, $r(21) = .28$, $p = .19$; non-autistic group, $r(25) = .24$, $p =$

.24) (Figure 4.7). This suggests that those with higher ability levels were more likely to experience the affiliative effects of synchrony.

Figure 4.7

Correlation between Overall Witnessed Sensitivity in Human-Human trials and general ability scores



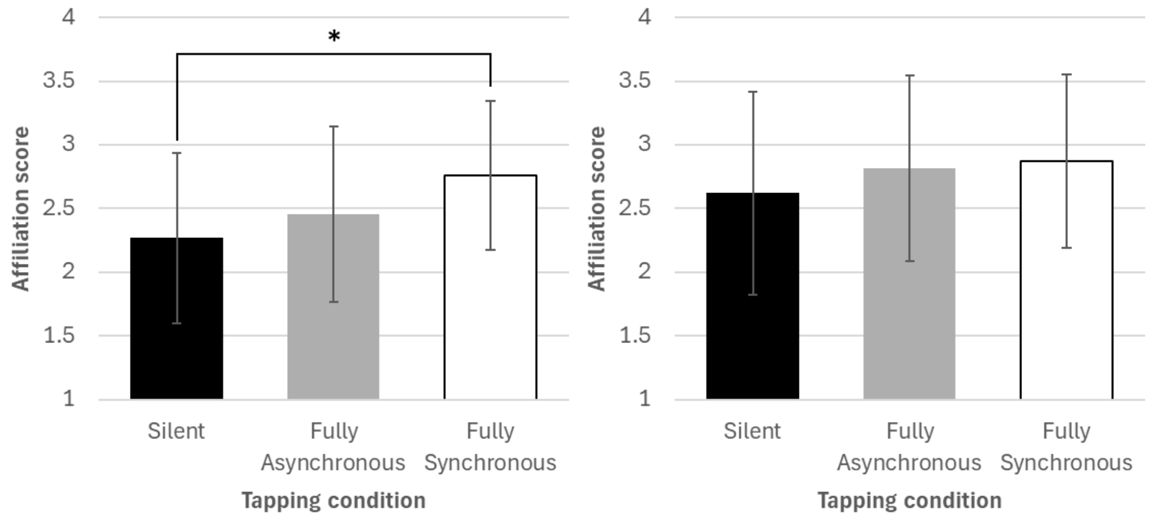
For non-autistic children, there was a main effect of condition for the Human-Human pairs, $F(2, 52) = 4.14$, $p = .02$, $\eta^2_{partial} = .17$. Post-hoc comparisons indicated that the Synchronous pairs received significantly higher affiliation scores than the Silent pairs ($p = .03$) (Figure 4.8a), but the other comparisons were not significant (p's > 0.2).

For autistic children, there was no effect of condition on the affiliation scores for Human-Human pairs, $F(2, 52) = 1.647$, $p = .203$, $\eta^2_{partial} = .06$ (Figure 4.8b).

Figure 4.8

Children's affiliation scores for Witnessed Interpersonal Synchrony with Human-Human pairs

(a) Non-Autistic Children: (b) Autistic Children:



Note. Error bars indicate standard deviation. * p < .05

Human-Robot Pairs. For human-robot pairs, a mixed ANOVA found no main effect of group, $F(1, 52) = .09$, $p = .76$, $\eta^2_{partial} = .002$, suggesting there was no difference in the responses of autistic and non-autistic children. The main effect of condition was significant, $F(2, 104) = 8.71$, $p < .001$, indicating that the way the robot tapped had a significant impact on the affiliation ratings. Post-hoc tests with a Bonferroni adjustment showed that Silent robots received significantly lower affiliation ratings than Fully Asynchronous ($p = .04$) and Fully Synchronous robots ($p < .001$). There was no significant difference in the Fully Asynchronous and Fully Synchronous conditions ($p = .35$). The interaction of condition and group was not significant, $F(2, 104) = 1.70$, $p = .19$, $\eta^2_{partial} = .03$. The sample size was not large enough to have the necessary power to detect significant interactions at this effect size, as the total sample size would have needed to be at least 80 for 95% power.

When WASI-II scores were included as a covariate, there was no effect of group, F(1, 47) = .91, p = .35, $\eta^2_{partial}$ = .02, no effect of condition, F(2, 94) = 2.11, p = .13, $\eta^2_{partial}$ = .04, and no interaction between group and condition, F(2, 94) = .36, p = .70, $\eta^2_{partial}$ = .01.

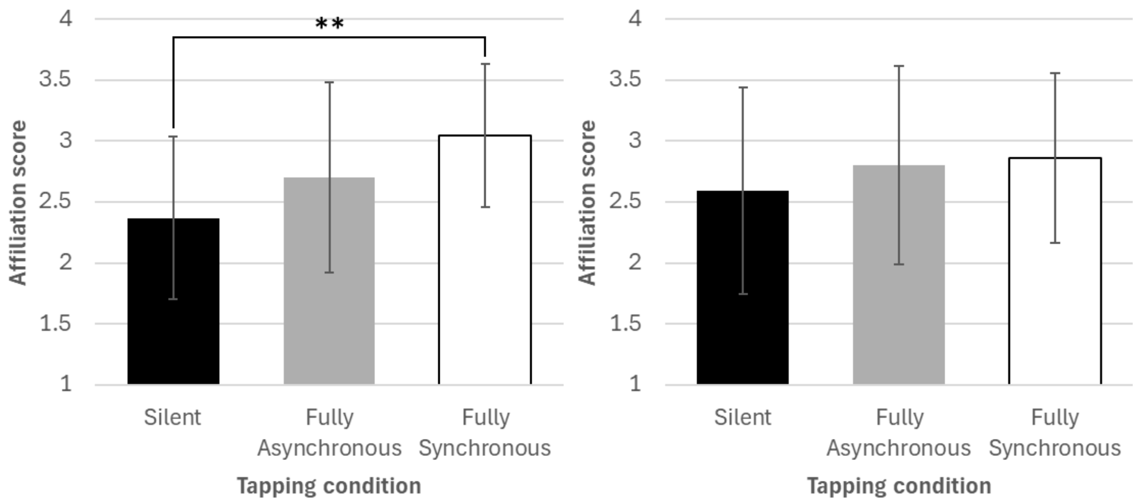
Non-autistic children gave significantly different affiliation scores across conditions, F(2, 52) = 6.36, p = .003, $\eta^2_{partial}$ = .20. Post-hoc analysis with a Bonferroni adjustment indicated affiliation scores were significantly higher for Synchronous partners than Silent partners (p = .001) (Figure 4.9a). The other comparisons were not significant (p's > .2).

Autistic children did not give significantly different affiliation scores across conditions, F(2, 52) = 2.56, p = .09, $\eta^2_{partial}$ = .09 (Figure 4.9b).

Figure 4.9

Children's affiliation scores for Witnessed Interpersonal Synchrony with Human-Robot pairs

(a) Non-autistic Children (b) Autistic Children



Note. Error bars indicate standard deviation. ** $p < .01$

4.3.1.3 Effects of simultaneity and regularity on affiliation scores

Human-Human pairs. A mixed ANOVA with both groups found no main effect of group [F(1, 52) = 1.51, p = .22, $\eta^2_{partial}$ = .03], simultaneity [F(1, 52) = 2.31, p = .14, $\eta^2_{partial}$ = .04], or regularity [F(1, 52) = .82, p = .37, $\eta^2_{partial}$ = .02] on affiliation scores. The interaction of group and simultaneity was the only significant interaction [F(1, 52) = 5.99, p = .02, $\eta^2_{partial}$ = .10]. However, this interaction was no longer significant when WASI scores were included as a covariate [F(1, 47) = 2.75, p = .10, $\eta^2_{partial}$ = .06].

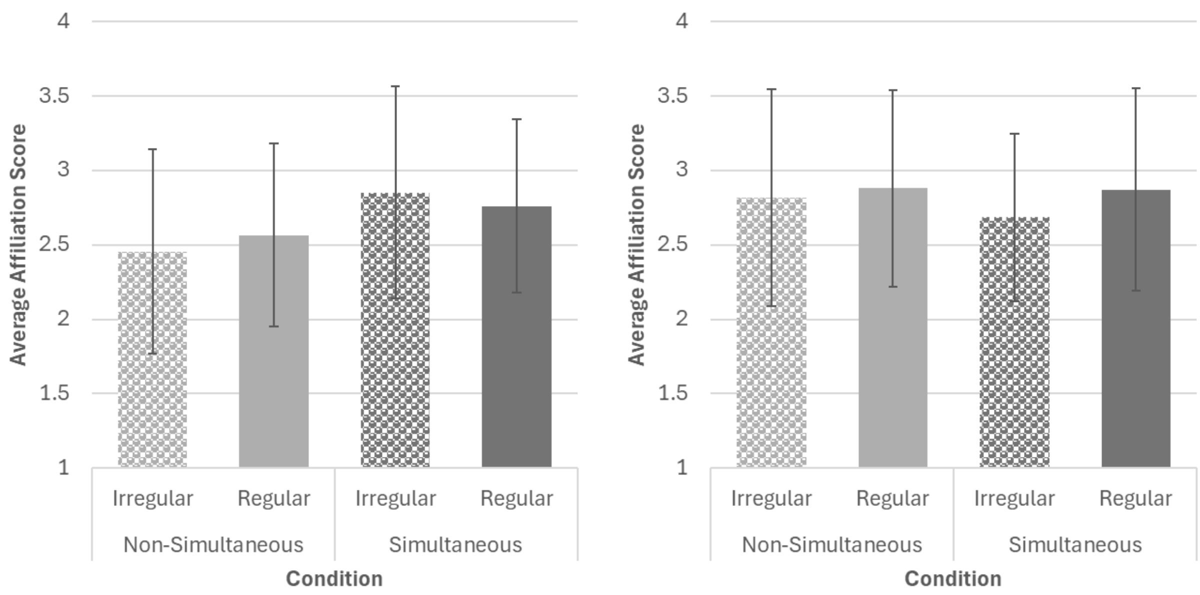
In non-autistic children, there was a main effect of simultaneity, F(1,26) = 6.16, p = .02, $\eta^2_{partial}$ = .19, with simultaneous partners receiving higher affiliation scores. There was no effect of regularity, F(1,26) = .01, p = .93, $\eta^2_{partial}$ < .001, nor was the interaction significant, F(1,26) = .84, p = .37, $\eta^2_{partial}$ = .03 (Figure 4.10a).

In autistic children, there was neither a main effect of simultaneity, F(1,26) = .60, p = .45, $\eta^2_{partial}$ = .02, nor regularity, F(1,26) = 1.46, p = .23, $\eta^2_{partial}$ = .053 on affiliation scores. The interaction between simultaneity and regularity was also not significant, F(1,26) = .50, p = .49, $\eta^2_{partial}$ = .02 (Figure 4.10b).

Figure 4.10

Children's mean affiliation scores for Human-Human trials

(a) Non-autistic children (b) Autistic children



Note. Error bars indicate standard deviation.

Human-Robot pairs. A mixed ANOVA showed no main effect of group [F(1, 52) = .68, *p* = .42, $\eta^2_{partial}$ = .01], simultaneity [F(1, 52) = 1.45, p = .24, $\eta^2_{partial}$ = .03], or regularity [F(1,52) = 1.81, *p* = .19, $\eta^2_{partial}$ = .03] on affiliation scores. There were no significant interactions (all *p*'s > .1). The sample size may not have been large enough to detect significant interactions at this effect size, as the sample size would have needed to be at least 86 to detect a significant three-way interaction at 95% power.

When WASI-II scores were included as a covariate, there was a main effect of group, with non-autistic children giving significantly higher affiliation scores than autistic children F(1, 47) = 4.10, *p* = .048, $\eta^2_{partial}$ = .08. There was not a significant main effect of simultaneity [F(1, 47) = 2.34, *p* = .13, $\eta^2_{partial}$ = .05], regularity [F(1, 47) = 2.22, *p* = .14, $\eta^2_{partial}$ = .05], nor were there any significant interactions (all *p*'s > .2)

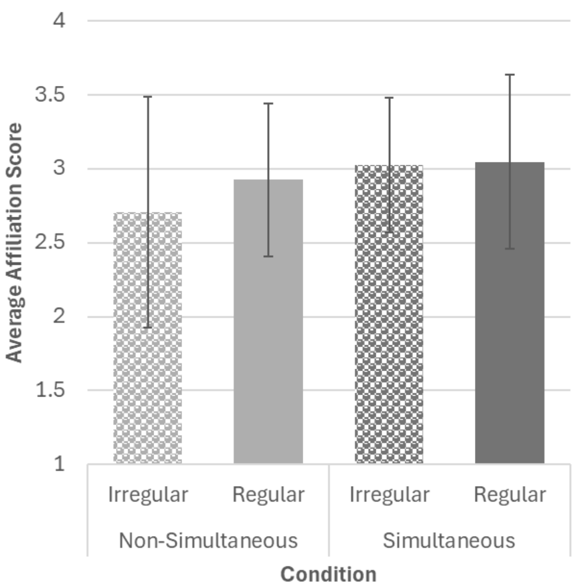
For non-autistic children witnessing Human-Robot pairs, there was no effect of simultaneity [$F(1,26) = 2.83$, $p = .11$, $\eta^2_{partial} = .10$], nor regularity [$F(1,26) = 1.39$, $p = .34$, $\eta^2_{partial} = .04$] on affiliation scores. The interaction of simultaneity and regularity was also non-significant, $F(1,26) = 1.39$, $p = .25$, $\eta^2_{partial} = .05$ (Figure 4.11a).

When autistic children witnessed Human-Robot pairs, there was no effect of simultaneity [$F(1,26) = .14$, $p = .71$, $\eta^2_{partial} = .01$], nor regularity [$F(1,26) = .89$, $p = .36$, $\eta^2_{partial} = .03$] on affiliation scores. The interaction of simultaneity and regularity also non-significant, $F(1,26) = .37$, $p = .55$, $\eta^2_{partial} = .01$ (Figure 4.11b).

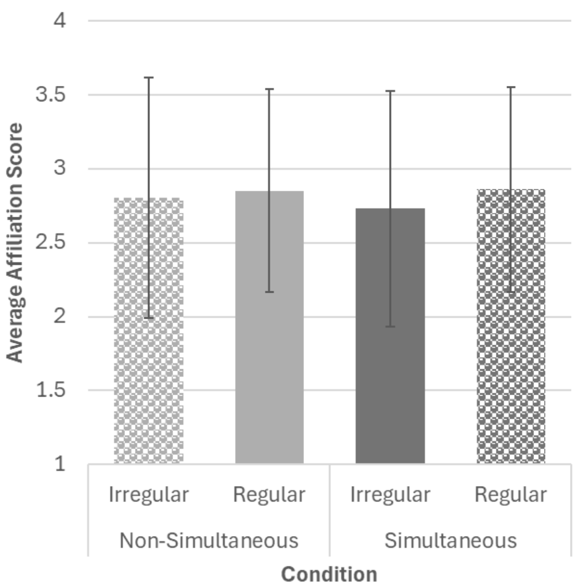
Figure 4.11

Children's mean affiliation scores for Human-Robot trials

(a) Non-autistic children



(b) Autistic children



Note. Error bars indicate standard deviation.

4.3.1.4 Togetherness Scores

Autistic participants had an average Togetherness Score of .70 (SD = .17). Non-autistic participants had an average Togetherness Score of .78 (SD = .17). There was not a significant difference in how accurately groups were able to determine whether witnessed pairs were tapping together, $t(52) = -1.71$, $p = .09$. This remained the same when an ANOVA accounted for the difference in WASI-II scores, $F(1, 47) = 1.78$, $p = .19$. Post-hoc analysis showed that Togetherness Scores were not significantly correlated with participants' Synchrony Perception Thresholds as measured in Chapter 3, $r(44) = -.14$, $p = .34$.

4.3.1.5 Effect of simultaneity and regularity on togetherness ratings

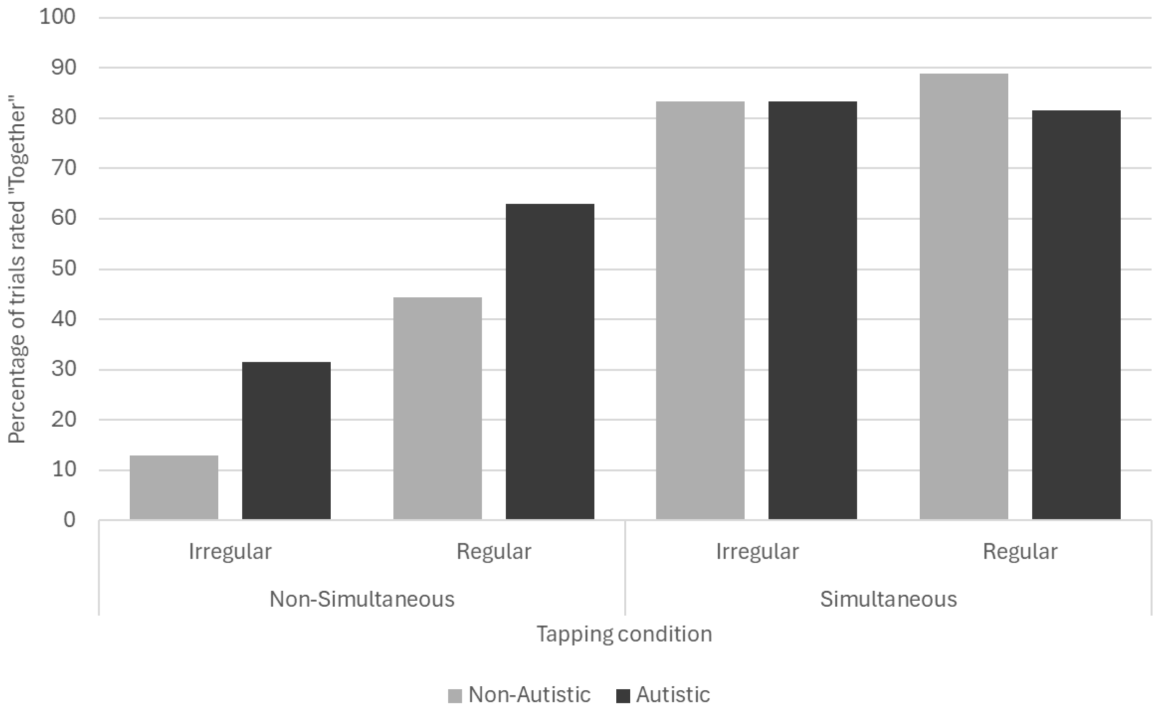
Human-Human Pairs. For non-autistic children, simultaneity had a significant positive effect on the likelihood that pairs were perceived as being "together", $\beta = 2.33$, $t = 4.53$, $p < .001$. The effect of regularity was not significant, $\beta = .473$, $t = .83$, $p = .41$. The interaction between the two variables was also not significant, $\beta = 1.23$, $t = 1.63$, $p = .19$.

For autistic children, simultaneity had a significant positive effect on the likelihood that pairs were perceived as being "together", $\beta = 1.03$, $t = 2.20$, $p = .03$. There was not a significant effect of regularity, $\beta = -0.14$, $t = -0.26$, $p = .80$. However, the interaction of these two variables was significant, $\beta = 1.58$, $t = 2.35$, $p = .02$.

Due to the significant interaction in the autistic group, two more GLMMs were run using regularity as the only predictor variable. Regularity did not predict perceived togetherness when pairs were simultaneous, $\beta = -0.13$, $t = -0.23$, $p = .80$, but it did have a significant effect when pairs were not simultaneous, $\beta = 1.74$, $t = 3.60$, $p < .001$.

Figure 4.12

Percentage of Human-Human trials rated "Together"

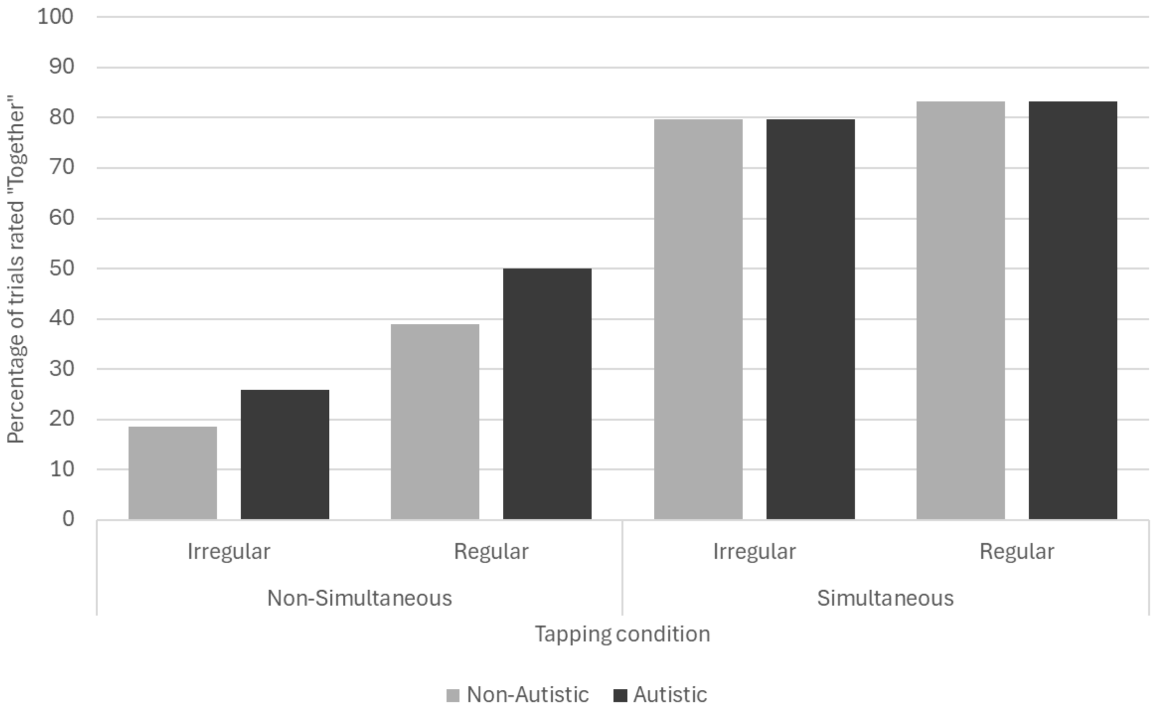


Human-Robot Pairs. For non-autistic participants, analysis indicated that simultaneity had a significant positive effect on the likelihood that pairs were perceived as being "together", β= 2.06, t = 4.48, p < .001. The effect of regularity was not significant, β= .50, t = .50, p = .62, and the interaction between regularity and simultaneity was not significant, β= .78, t = 1.17, p = .24.

For autistic participants, simultaneity had a significant positive effect on the likelihood that pairs were perceived as being "together", β= 1.87, t = 3.79, p < .001. The effect of regularity was not significant, β= .27, t = .52, p = .60. The interaction of simultaneity and regularity was not significant, β= .99, t = 1.42, p = .16.

Figure 4.13

Percentage of Human-Robot trials rated "Together"

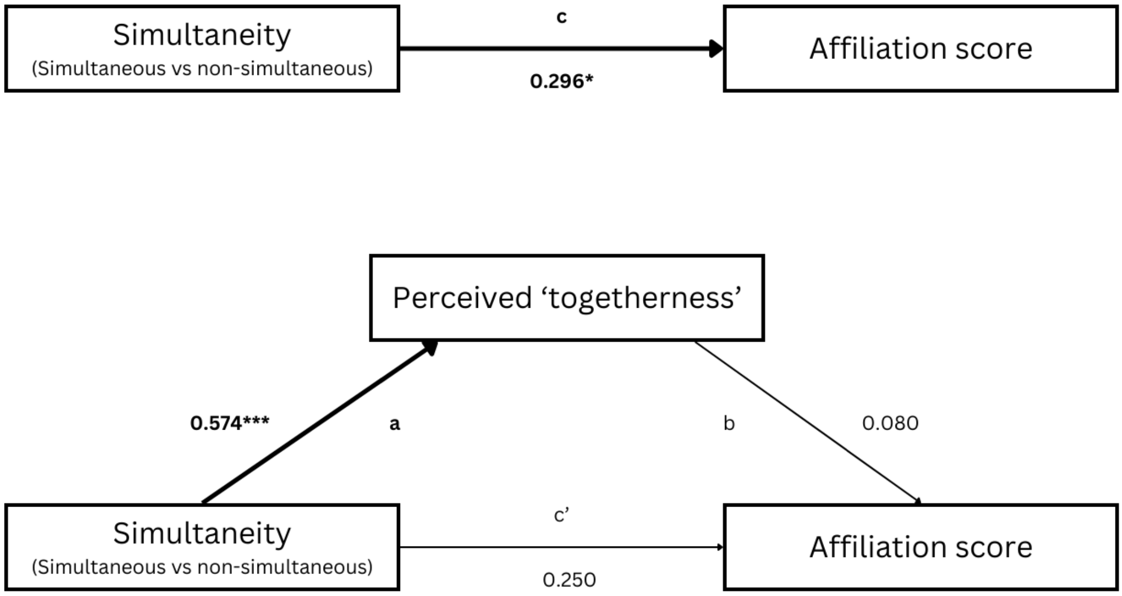


4.3.1.6 Mediating effect of perceived togetherness on affiliation scores

Because there was a main effect of simultaneity on affiliation score for non-autistic children in Human-Human trials, a mediation analysis was run to determine how perceived "togetherness" affected the relationship between simultaneity and affiliation score. Perceived togetherness did not mediate the effect of simultaneity on affiliation scores (Figure 4.14). There were no other significant main effects for non-autistic children, nor any significant main effects for autistic children (section 4.3.1.3), so no other mediation analyses were run.

Figure 4.14

Mediation analysis of the effects of simultaneity and perceived togetherness on affiliation scores for witnessed Human-Human trials with non-autistic children



Note. Significant effects are bolded. Path estimates are unstandardised regression coefficients.
* p < .05, *** p < .001

4.3.1.7 Relationship between Overall Witnessed Sensitivity and Synchrony Perception Threshold

Participants' Overall Witnessed Sensitivity Score was calculated by taking the average affiliation score for fully synchronous pairs in the Witnessed Interpersonal Synchrony Task and subtracting the score for fully asynchronous pairs.

Non-autistic children had an average Overall Witnessed Sensitivity Score of .32 (SD = .87). There was no significant correlation between participants' Overall Witnessed Sensitivity Scores and their Synchrony Perception Thresholds, r(22) = -.25, *p* = .24.

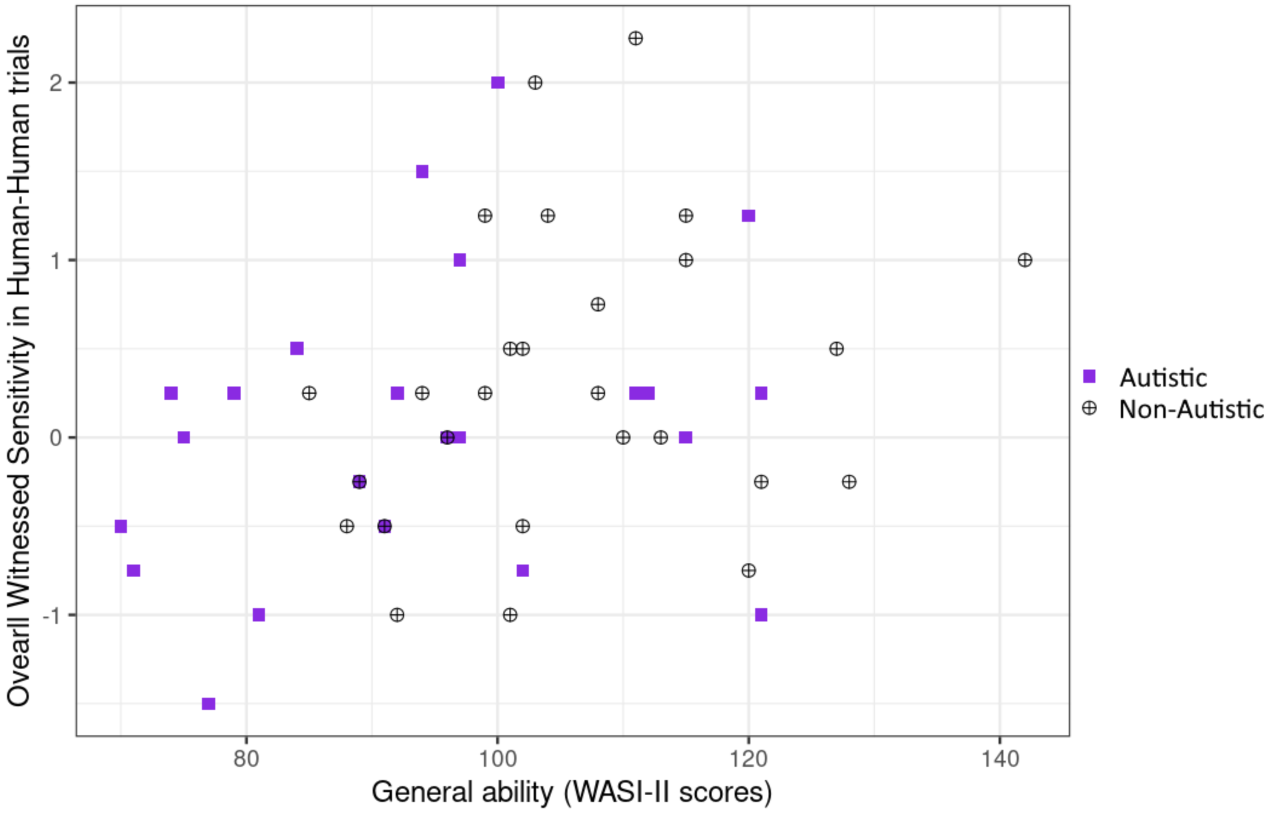
Autistic children had an average Overall Witnessed Sensitivity Score of .06 (SD = .68). There was no significant correlation between participants' Overall Witnessed Sensitivity Scores and their Synchrony Perception Thresholds, r(20) = -.21, p = .35.

These findings suggest that in both groups, participants' sensitivity to the social effects of witnessed interpersonal synchrony were not related to the accuracy with which they can perceive synchrony in simple non-social auditory stimuli.

Post-hoc tests to further investigate sensitivity scores revealed that there was not a significant group difference in Overall Witnessed Sensitivity Scores, $t(52) = -1.26$, p = .21, nor were Overall Witnessed Sensitivity scores significantly correlated with autistic traits (ASDQ), attention (SWAN), or age (all p's > .1). There was, however, a significant correlation between Overall Witnessed Sensitivity Scores and general ability (WASI-II), r(50) = .34, p = .02 (Figure 4.15).

Figure 4.15

Correlation between Overall Witnessed Sensitivity across all trials and general ability scores



4.3.1.8 Manipulation check

Manipulation checks revealed that 20 autistic children (74.1%) and 23 non-autistic children (85.2%) reported that the children/robots were making the sounds presented in the task. Three autistic children (11.1%) and 4 non-autistic children (14.8%) said they did not know or could not remember. Three autistic children (11.1%) gave alternative answers (the sounds were made by a band; the children had been talking instead of tapping, said that sounds were being made but did not specify by whom), and one autistic child did not complete the manipulation checks (3.7%).

4.3.2 Experienced Interpersonal Synchrony

4.3.2.1 Sample Characteristics

Twenty-two autistic children and 26 non-autistic children successfully completed the Experienced Interpersonal Synchrony Task (see Table 4.5 for reasons for participant exclusion). Of the 22 autistic children, 21 (95.45%) scored above the ASDQ threshold of 2.7. Of the 26 non-autistic children, 1 (3.85%) scored above the ASDQ threshold. Fisher's Exact Test showed there was not a significant difference in the gender distribution between groups (p = .53). As expected, levels of autistic traits and ADHD traits were significantly higher in the autistic group than the non-autistic group, and general ability (WASI-II) was significantly lower (Table 4.6). Because this thesis is focused on the potential factors that influence children's social responses to interpersonal synchrony, gender was reported instead of sex to prioritise socialisation over genetics.

Table 4.5

Participant exclusions for Experienced Interpersonal Synchrony Task

Reason for Exclusion	Number of Participants	
	Autistic (n = 29)	Non-Autistic (n = 27)
Participant did not complete task correctly.	5	0
Technical error.	1	1
Participant noncompletion of task.	1	0
Number of valid participants	22	26

Table 4.6

Demographic information of participants who completed the Experienced Interpersonal Synchrony Task

	Autistic Children n = 22				Non-Autistic Children n = 26				*t*-test
Sample Characteristics	n	Mean	SD	Range	n	Mean	SD	Range	
Gender									
Male	16				13				
Female	5				12				
Other	1				1				
Race/Ethnicity									
White British	17				19				
Other White background	1				4				
Asian	0				2				
African	0				1				
Mixed Race	4				0				
Age (years)		9.57	1.53	6.75 - 11.75		9.01	1.46	6.67 - 11.83	0.20
General Ability (WASI-II)[a]		94.57	16.98	70 - 121		105.54	13.58	85 - 142	**0.02***
Autistic Traits (ASDQ)[b]		3.66	0.49	2.46 - 4.42		1.68	0.47	1.1 - 2.92	**<.001*****
Inattentive-Type ADHD Traits (SWAN)[c]		5.45	2.89	0 - 9		2.69	2.63	0 - 9	**0.001****
Hyperactive-Impulsive-Type ADHD Traits (SWAN)[c]		6.32	2.59	0 - 9		1.31	1.67	0 - 6	**<.001*****
Total ADHD Traits (SWAN)[c]		11.77	5.07	0 - 18		4.00	3.93	0 - 12	**<.001*****

Note. [a] Wechsler Abbreviated Scale of Intelligence – Second Edition, [b] Autism Symptom Dimensions Questionnaire, [c] Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behavior Scale.

$p < .05$, ** $p < .01$, *** $p < .001$

4.3.2.2 Effect of synchrony on affiliation scores

A mixed ANOVA showed there was no main effect of group, F(1, 46) = .27, p = .61, $\eta^2_{partial}$ = .01. The main effect of tapping condition was significant, F(1.63, 75.03) = 3.79, p = .04, $\eta^2_{partial}$ = .08, with fully synchronous robots receiving the highest scores and silent robots receiving the lowest scores. However, post-hoc analysis of this simple main was not significant. The interaction of group and tapping condition was also not significant, F(1.63, 75.03) = 1.11, *p* = .33, $\eta^2_{partial}$ = .02. The sample size may not have been large enough to have the necessary power to detect significant interactions at this effect size, as the total sample size would have needed to be at least 102 for 95% power.

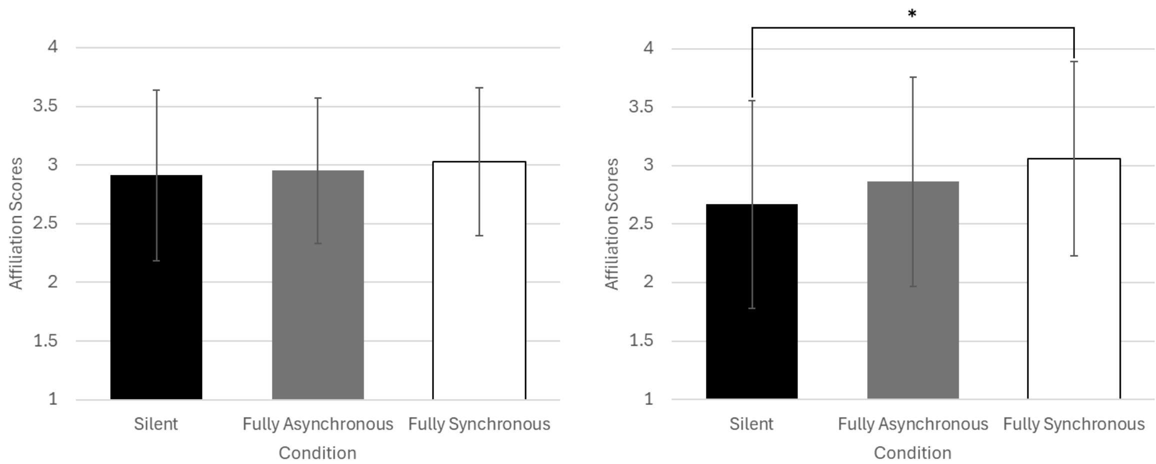
An ANCOVA with WASI-II scores as a covariate found no main effect of group, F(1, 44) = .98, *p* = .33, $\eta^2_{partial}$ = .02, nor tapping condition, F(1.56, 68.31) = 1.55, *p* = .22, $\eta^2_{partial}$ = .03. The interaction was also not significant, F(1.55, 68.31) = 1.79, *p* = .18, $\eta^2_{partial}$ = .04.

For non-autistic children, there was no significant main effect of synchrony on affiliation scores, F(1.50, 37.22) = .34, *p* = .65, $\eta^2_{partial}$ = .01 (Figure 4.16a). Autistic children gave significantly different affiliation ratings across conditions, F(2, 42) = 6.64, p = .003. Post-hoc tests with Bonferroni adjustments showed that autistic children gave significantly higher affiliation ratings to fully synchronous robots than to silent robots, p = .01, $\eta^2_{partial}$ = .24 (Figure 4.16b). The other comparisons were not significant (Silent vs Fully Asynchronous: p = .21; Fully Asynchronous vs Fully Synchronous: p = .17).

Figure 4.16

Effect of fully synchronous tapping on affiliation scores in Experienced Interpersonal Synchrony Task

(a) Non-autistic children (b) Autistic children



Note. Error bars show standard deviations.
* p < .05

4.3.2.3 Effects of simultaneity and regularity on affiliation scores

A mixed ANOVA showed there was no main effect of condition, F(2, 92) = 1.20, p = .31, $\eta^2_{partial}$ = .03, nor was there a main effect of group, F(1, 46) = .24, p = .63, $\eta^2_{partial}$ = .01. The interaction of condition and group was not significant, F(2, 92) = .94, p = .40, $\eta^2_{partial}$ = .02. The sample size may not have been large enough to have the necessary power to detect significant interactions at this effect size, as the total sample size would have needed to be at least 128 for 95% power.

An ANCOVA to control for WASI-II scores similarly found there was no main effect of condition, F(2, 88) = 1.81, p = .17, $\eta^2_{partial}$ = .04, nor group, F(1, 44) = 1.17, p = .29, $\eta^2_{partial}$ = .03. There remained no significant interaction of condition and group, F(2, 88) = 1.97, p = .15, $\eta^2_{partial}$ = 04.

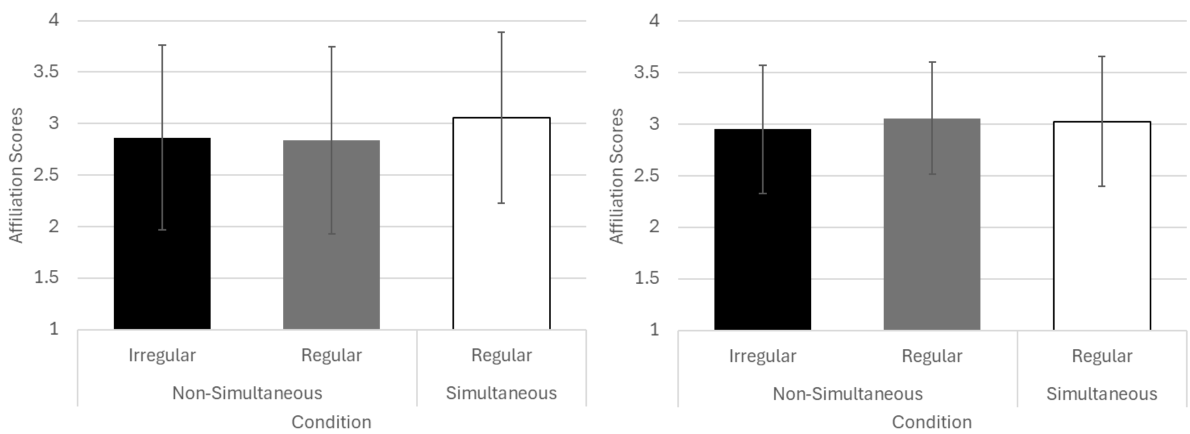
For non-autistic children, there was no difference in affiliation scores between the fully synchronous, non-simultaneous/regular, and non-simultaneous/irregular conditions, F(2, 50) = .29, p = .75, $\eta^2_{partial}$ = .01 (Figure 4.17a).

For autistic children, the difference between conditions was close to significance, F(2, 42) = 3.00, p = .06, $\eta^2_{partial}$ = .13. Post-hoc analysis with a Bonferroni adjustment was conducted to determine which comparisons influenced the result. Scores were highest when the tapping was fully Synchronous (M = 3.06, SD = .83) rather than non-simultaneous/regular (M = 2.84, SD = .91) or non-simultaneous/irregular (M = 2.86, SD = .90), but neither comparison was significant (p = .12 and p = .17, respectively, Figure 4.17b).

Figure 4.17

Effect of simultaneity and regularity on affiliation scores

a) Non-autistic children *b) Autistic children*



Note. Error bars show standard deviations.

4.3.2.4 Relationship between Overall Experienced Sensitivity, Synchrony Perception Threshold, and Overall Motor Synchrony Score

Participants' Overall Experienced Sensitivity Scores were calculated by taking the average affiliation scores for fully synchronous pairs in the Experienced Interpersonal Synchrony Task and subtracting the scores for fully asynchronous pairs.

Autistic children had an average Overall Experienced Sensitivity Score of .19 (SD = .45). There was no significant correlation between participants' Overall Experienced Sensitivity Scores and their Synchrony Perception Thresholds, r(16) = -.20, p = .42, nor their Overall Experienced Sensitivity Scores and Overall Motor Synchrony Scores, r(20) = .33, p = .14.

Non-autistic children had an average Overall Experienced Sensitivity Score of .08 (SD = .74). There was no significant correlation between participants' Overall Experienced Sensitivity Scores and their Synchrony Perception Thresholds, r(21) = .16, p = .48, nor their Overall Experienced Sensitivity Scores and Overall Motor Synchrony Scores, r(22) = -.27, p = .20.

These findings suggest that in both groups, participants' sensitivity to the social effects of experienced interpersonal synchrony was not related to the accuracy with which they can perceive synchrony in simple non-social auditory stimuli, nor their ability to keep time with their finger when tapping along with simple non-social auditory stimuli.

Post-hoc analysis to further investigate Overall Experienced Sensitivity Scores revealed there was not a significant group difference in these scores, $t(46)$ = .64, p = .53, nor were Overall Experienced Sensitivity Scores significantly correlated with autistic traits (ASDQ), attention (SWAN), general ability (WASI-II), or age (all p's > .1). To investigate the relationship between Overall Witnessed Sensitivity Scores and Overall Experienced Sensitivity Scores, a mixed

ANOVA (1 x 2) was run. This revealed there was not a significant difference between these scores [$F(1, 45) = .43$, $p = .52$, $\eta^2_{partial} = .01$], no significant effect of group [$F(1, 45) = .24$, $p = .63$, $\eta^2_{partial} = .01$], and no significant interaction [$F(1, 45) = 1.73$, $p = .20$, $\eta^2_{partial} = .04$].

4.3.2.5 Manipulation checks

When asked how many robots they had met during the task, one autistic child correctly identified that two or fewer robots were being used, with all other participants giving answers of four or more. The average number reported by autistic children was 6.9 (range: 1-10), and the average number reported by non-autistic children was 6.7 (range: 4-12).

When asked whether the robot had been tapping during the task, 15 autistic children (68.2%) and 21 non-autistic children (80.8%) said the robot was tapping. Three autistic children (13.6%) and two non-autistic children (7.7%) believed the robot had not literally been tapping, but had still been completing the task with them and had produced the sounds in other ways (e.g., the robot was communicating with the laptop wirelessly; the robot itself was making the sounds instead of the laptop). One autistic child (4.5%) and 2 non-autistic children (7.7%) did not believe the robot was tapping at all. Two autistic children (9.1%) and one non-autistic child (3.8%) were unsure. One autistic child (4.5%) did not complete the manipulation checks.

4.4 Discussion

4.4.1 Summary of findings

This chapter explored the affiliative effects of witnessed and experienced interpersonal synchrony in autistic and non-autistic children. When non-autistic children witnessed others tapping synchronously, they interpreted the pairs to be more closely affiliated than pairs that did not audibly tap. This was the case when pairs were human-human or human-robot.

However, witnessed interpersonal synchrony did not influence perceived affiliation for autistic participants. Across all participants, the degree to which children were sensitive to the social effects of witnessed interpersonal synchrony was not related to how accurately they could perceive synchrony as measured in Chapter 3. Similarly, when the simultaneity of tapping impacted the pairs' perceived level of affiliation for non-autistic participants, perceived togetherness did not mediate this relationship.

When exploring experienced interpersonal synchrony, tapping synchronously with a robot increased autistic children's sense of affiliation with the robot, but this pattern was not found for non-autistic children. The degree to which participants were sensitive to the social effects of experiencing interpersonal synchrony with a robot was not related to how accurately they could perceive synchrony, nor how accurately they could produce synchrony, as measured in Chapter 3.

4.4.2 Effects of witnessed interpersonal synchrony on affiliation

When non-autistic children witnessed interpersonal synchrony between two children (human-human condition), synchronous pairs had increased perceived affiliation over silent pairs. Because asynchrony did not diminish affiliative effects, this suggests that synchrony actively increases perceived affiliation in non-autistic populations rather than asynchrony having a negative effect. Although synchronous human-human pairs were rated as having higher affiliation than asynchronous pairs, this effect was not significant. Because the ratings that asynchronous pairs received were not significantly different than the synchronous or silent pairs, it is not possible to determine whether the children in this sample were reacting positively to synchrony, or if it was merely that they were reacting to hearing the pairs tap as opposed to listening to silence. This null finding contradicts previous research using the same task, which did find significantly higher affiliation ratings for synchronous pairs (Bowsher-Murray et al., 2023). This difference in findings is unlikely to be solely due to the current study's comparatively small sample size, as my effect size was smaller than Bowsher-Murray et al.'s (2023), with an η^2 of .17 compared to .46. One possible explanation is that because participants in Bowsher-Murray et al.'s study completed the task online, their responses may have been influenced by help or encouragement from their parents. The participants in the current study were 1.5 years older than in Bowsher-Murray et al., so it could also be that additional factors impact on affiliation judgements in older children, making the task less sensitive to synchrony effects. However, because there is no direct evidence to support either of these suggestions, further research in varying contexts with more age groups is needed to develop a deeper understanding of how synchrony influences perceptions of social relationships.

Non-autistic children also assigned higher affiliation ratings to synchronous pairs than silent pairs when observing a child and robot interact. This finding is supported by a study showing that when typically developing adults watched videos of a robot moving in various ways while a researcher completed a task, robots that moved synchronously with the researcher were deemed the most likeable over unmoving robots (Lehmann et al., 2015). This suggests that non-autistic individuals may be sensitive to the social effects of synchrony regardless of whether the interacting partners are human-human or human-robot. However, because asynchronous pairs did not receive significantly different ratings than the synchronous or silent pairs, it is again difficult to determine whether children were responding to synchrony or simply the fact that they could hear the pairs. Regardless of the underlying mechanisms, the fact that the pairs' behaviour impacted their perceived affiliation suggests that the children may perceive the robots as social partners rather than merely as inanimate toys. This aligns with research indicating that children commonly ascribe affective, cognitive, and behavioural characteristics to robots (Beran et al., 2011). The attribution of these traits to the robots may be partially due to the NAO's humanoid appearance. Research indicates that aspects of the physical form of a robot, such as being anthropomorphic instead of zoomorphic, can significantly impact the robot's perceived social presence and degree of similarity to the observer (Barco et al., 2020). As such, it is unknown whether these social attributions would be found in most robots or only in particular types of humanoid robots.

In contrast to the non-autistic children, the autistic participants did not show evidence of being sensitive to the affiliative effects of witnessed interpersonal synchrony. This was the case both when witnessing human-human and human-robot pairs. This suggests that this reduced sensitivity is not caused by autistic children struggling to interpret the complexities of real-world social interactions, but instead still exists when additional social demands, such as attentional load, are stripped away. The Togetherness Scores indicated that there was not a significant difference in autistic and non-autistic children's ability to determine whether dyads were tapping together, which aligns with the finding in Chapter 3 that the groups had comparable abilities to perceive synchrony in the same auditory stimuli used with the Witnessed Interpersonal Synchrony Task. This suggests that even when autistic children consciously and accurately perceive that interpersonal synchrony is occurring, this information does not significantly inform impressions of affiliation. This is further supported by the fact that there was not a significant relation between participants' social sensitivity to synchrony and their ability to perceive synchrony as measured in Chapter 3. This result is unlikely to be due to issues with the believability of the premise of the task, as only three of the autistic children's answers suggested they believed the sounds may not have been made by the children/robots presented on the screen. However, because the ANOVA did not show a significant interaction with group, this apparent difference between autistic and non-autistic children is likely very small as any present group effect would have been quite weak.

The similarity in autistic children's ratings between conditions could also reflect that autistic children often struggle with interpreting the thoughts, feelings, and perspectives of others (Baron-Cohen, 2000; Uljarevic & Hamilton, 2013). They have also been shown to interpret these internal states differently than non-autistic individuals (Chaidi & Drigas, 2020; Milton, 2012), especially when interacting with non-autistic people. The question "How much do [Partner 1] and [Partner 2] like each other?" could therefore either be a difficult question for autistic children to answer, or could yield different results than if it were asked to non-autistic children regardless of what aspect of the interaction was being manipulated. Considering this alongside the absence of a significant interaction, it is possible that synchrony is not the driving force behind these apparent group differences.

4.4.3 Effects of witnessed simultaneity and regularity on affiliation

Simultaneity significantly increased non-autistic participants' affiliation ratings for Human-Human pairs. This finding is consistent with theoretical accounts of interpersonal synchrony which suggest that the social effects of interpersonal synchrony are the effect of perceived similarity that occurs when behaviours occur simultaneously (Dignath et al., 2018; Valdesolo & DeSteno, 2011). Similarly, other studies reporting that synchrony promoted affiliative effects focused primarily on simultaneity rather than regularity (Abraham et al., 2022; Fawcett & Tunçgenç, 2017). However, another study using the same task with children of a similar age range found that both regularity and simultaneity had a significant effect on perceived affiliation (Bowsher-Murray et al., 2023). The influence of regularity may change over development, as it has been shown to increase perceived affiliation in non-autistic adults (Cacioppo et al., 2014) but not in non-autistic infants (Cirelli, Einarson, et al., 2014). If the effect of regularity on perceived affiliation is developmentally sensitive, then this could perhaps explain why findings can differ across studies that focus on children of varying ages.

In contrast to the human-human pairs, simultaneity did not significantly increase non-autistic participants' affiliation ratings for human-robot pairs. This suggests that synchrony with robots may be perceived differently than synchrony with humans, and may align with the findings of a study that found that some children prefer synchronous robots, while others prefer asynchronous robots (Sweezy, 2023). Sweezy proposes that in not moving simultaneously with their partner, robots may appear to move more intentionally or otherwise have a greater sense of agency. The unpredictability produced when a robot is asynchronous with a human partner may also make it more likely for humans to anthropomorphise them (Epley et al., 2007), which could in turn impact the perceived affiliation between the robots and their human partners. As such, some participants in the current study may have perceived simultaneous human-robot pairs to be more closely affiliated due to the social effects of synchrony, while others may have been more likely to anthropomorphise non-simultaneous robots and therefore perceive them as being more similar to their human partners. Further research is needed to disentangle how synchrony and anthropomorphism impact each other and how they interact to influence human-robot relationships.

Given that there were no overall effects of witnessing interpersonal synchrony on affiliation ratings for autistic participants, it is not surprising that neither simultaneity nor regularity significantly influenced their affiliation ratings. This was the case across both human-human and human-robot pairs. These current findings reflect previous research suggesting that autistic individuals are less sensitive to the social effects of interpersonal synchrony (Koehne et al., 2016). The presence of this group difference is supported by the significant interaction with group and simultaneity. This difference in sensitivity to social synchrony does not seem to be driven by a difference in whether the autistic participants subjectively perceived the pairs as tapping together, as simultaneity increased the likelihood that a pair would be rated as tapping together in both participant groups and in both pair types. This is further supported by the finding in Chapter 3 that autistic participants did not have significantly different synchrony perception thresholds than non-autistic participants, as well as studies using non-speech unimodal stimuli which found that autistic and non-autistic participants had similar temporal perceptual acuity in temporal order judgement tasks (Poole et al., 2022; Stevenson et al., 2014). Furthermore, as previously discussed, participants' sensitivity to synchrony was not related to their ability to accurately perceive synchrony as measured in Chapter 3. It is therefore more likely that autistic participants are processing and attending to interpersonal synchrony differently, as supported by the finding that they often display reduced attention to social stimuli relative to non-autistic individuals (Frazier et al., 2017; Hedger et al., 2020).

While simultaneity increased perceived togetherness in both groups and for Human-Human and Human-Robot trials, differences arose in how participants perceived regularity. When Human-Robot pairs tapped in a way that was not simultaneous, autistic children were more likely to rate regular pairs as being "together" than irregular pairs. This pattern was not found in Human-Human pairs, nor in either pair type for non-autistic children. However, it appears that determining whether partners are tapping together is more complicated than merely assessing whether stimuli occurred at the same time. As reported in Chapter 3, autistic and non-autistic children had synchrony perception thresholds of 80.42 ms and 67.65 ms, respectively, which are both shorter than the SOAs used in the regular/non-simultaneous trials (125 ms and 200 ms) in the current study. If evaluating togetherness merely required evaluating the simultaneity of stimuli, it should have been relatively simple for most participants to determine that these pairs did not tap "together" (i.e., at exactly the same time). However, many participants answered this question incorrectly. For example, autistic participants answered that non-simultaneous/regular Human-Human pairs tapped "together" in almost 60% of trials, and non-autistic children made the same error in over 40% of these trials (Figure 4.12 and 4.13). As such, determining togetherness likely involved additional processes beyond merely being able to tell whether two stimuli occurred simultaneously. Indeed, participants' accuracy in determining whether pairs tapped together was not significantly correlated with their ability to differentiate between simultaneous and non-simultaneous auditory stimuli. Additionally, perceived togetherness did not have a mediating effect on the relationship between the simultaneity of partners and affiliation ratings. Further work is needed to determine the extent to which ratings of togetherness rely on a fundamental ability to perceive simultaneity.

A potential limitation of the Witnessed Interpersonal Synchrony task is that baseline affiliation for each pair was not measured prior to the task. As such, it is unclear how other aspects, such as the appearance or names of the pair members, may have influenced their affiliation ratings. However, potential biases in these domains would be unlikely to affect the results as the tapping style of each pair was randomised for each participant.

4.4.4 Experienced interpersonal synchrony

When tapping with a humanoid robot, the way in which robots tapped did not have an effect on non-autistic children's sense of affiliation with the robot. However, autistic children felt a stronger affiliation with robots that tapped synchronously with them compared to robots that did not audibly tap. Neither simultaneity nor regularity significantly influenced either group's affiliation ratings.

The non-autistic participants showed no modulation in how much they felt affiliated with the robot, regardless of whether the robot tapped with them synchronously, asynchronously, or silently. This pattern is unlikely to be due to issues with the believability of the task, as a manipulation check revealed that only two non-autistic children did not believe the robot had been completing the task with them. Similarly, none of the non-autistic children noticed that there were only two robots. While non-autistic children did guess a number of robots on average that was fewer than the number of trials (6.7 robots compared to 8 trials), this is likely to be due to participants' incorrectly remembering how many trials they had completed. Participants were not reminded or told how many trials there had been, nor had they ever been asked to count, and numbers as high as 12 robots had also been reported. A previous study similarly found that acting synchronously with a robot did not impact participants' opinions about how likeable the robot was (Henschel & Cross, 2020). However, in that study, participants completed a task while a robot completed the same task beside them, either synchronously or asynchronously. There was no implication that the task was being completed collaboratively or that participants should pay attention to the robot. Further, a manipulation check showed that a significant proportion of participants were not able to identify whether the robot was moving synchronously or asynchronously with their movements. Therefore, it is possible that the robot's synchrony was not salient enough in that study. This is different that the current study, where participants knew that they were interacting with the robot, and their attention was oriented towards the robot's activity. However, despite being sensitive to the effects of interpersonal synchrony (or, at least, positively responding to active pairs over silent pairs) when observing human-robot pairs, our non-autistic participants did not show equivalent sensitivity when experiencing interpersonal synchrony with a robot for themselves. It could be that the current study's interaction was still too simplistic as it only used auditory stimuli and the robot did not visibly move, but it is unknown whether further increasing the saliency of the synchrony would produce different effects.

Autistic children, however, gave fully synchronous robots significantly higher affiliation ratings than silent robots when they were playing the tapping game with the robots. This suggests that synchrony could be used to strengthen autistic children's positive feelings towards robots. These results were unlikely to have been driven by differences in how much the groups believed that multiple robots were being used, or that the robot was really tapping, as the manipulations were generally believed across both groups. One possible explanation for this finding is that compared to non-autistic children, autistic children are often more interested in non-social activities and mechanical systems (Othman & Mohsin, 2017). In this way, interacting with an active humanoid robot (i.e., a mechanical system with a limited social presence) could be more engaging and rewarding for autistic children than non-autistic children. The silent robot, by comparison, may have more closely resembled an inanimate toy rather than a mechanical system. However, because the asynchronous robots did not receive significantly different ratings than the synchronous or silent robots, it is not possible to determine whether the children were reacting positively to synchrony, or merely to interacting with an active robot rather than an inactive one. Similarly, the absence of a significant interaction with group suggests that differences between groups are quite small as effects were very weak.

The finding that autistic children developed a greater sense of affiliation for fully synchronous robots than silent robots does not align with the Witnessed Interpersonal Synchrony Task, where autistic children did not give fully synchronous human-robot pairs higher affiliation scores than silent pairs. However, autistic children struggle with interpreting other's internal states (Jones et al., 2018; Baron-Cohen, 2000; Bamicha & Drigas, 2022; Siller et al., 2014) and may find it particularly challenging to interpret how other people would experience a partnered tapping game. In contrast, in the Experienced Interpersonal Synchrony Task, they are asked to express their own opinions rather than interpret someone else's. This may have been an easier question to answer.

A limitation of this study is the absence of a human condition in the Experienced Interpersonal Synchrony Task. While we were able to compare the Human-Robot trials in the Witnessed Interpersonal Synchrony Task with the results of the Experienced Interpersonal Synchrony Task, this was not possible for the Human-Human trials. Because humans often unconsciously project additional social information through their gaze (Schütz et al., 2020) and facial expressions (Dimberg et al., 2000) in ways that are difficult to control in experimental settings, the addition of this trial type was deemed to not be logistically viable within the scope of this study. However, this did limit the comparisons that could be made between witnessed and experienced synchrony, and between human-human and human-robot dyads.

4.5 Conclusion

The results of this chapter indicated that non-autistic children interpret synchronous Human-Human and Human-Robot pairs to be more highly affiliated than silent pairs. Probing further, it was the simultaneity of synchronous sounds that increased affiliation, rather than the regularity. However, for autistic children, the ways in which the observed pairs tapped did not influence the partners' perceived affiliation. This suggests that witnessed interpersonal synchrony is not indicative of closely affiliated partners for autistic children in the way that it is for non-autistic children. However, there were few significant interactions with group, suggesting that differences in the groups' responses were quite small.

When experiencing synchrony with a robot, autistic children developed more affiliation with synchronous robots than with silent robots, but non-autistic children showed no difference in their affiliation across conditions. This suggests that experiencing synchrony may improve autistic children's perceptions of robots, but that this may not be the case in the general population. However, these group differences were again rather weak.

Participants' abilities to perceive and produce synchrony, as measured in Chapter 3, did not impact how sensitive they were to the social effects of interpersonal synchrony. This suggests that the differences in the affiliative effects experienced by autistic and non-autistic children are not driven by fundamental differences in synchrony perception or production. Furthermore, differences in how participants responded to witnessed and experienced interpersonal synchrony suggest that these forms of synchrony, and the social effects that arise from them, may be distinct from one another.

Chapter 5

General Discussion

5.1 Overview

Engaging in interpersonal synchrony with another person has been shown to impact how synchronous partners feel about and behave toward each other (Hove & Risen, 2009; Knoblich et al., 2011; Launay et al., 2013). These social effects seem to be reduced in autistic individuals (Koehne et al., 2016). Furthermore, autistic children's interpersonal synchrony is thought to be reduced in its accuracy and its frequency (Bowsher-Murray et al., 2022; McNaughton & Redcay, 2020). While the social benefits of interpersonal synchrony are considered to result from motor, perceptual, and social skills (Trainor & Cirelli, 2015), it is not yet clear which of these factors drive autistic children's reduced sensitivity to the social effects of interpersonal synchrony. Because autistic individuals perform more similarly to non-autistic individuals on synchrony-related tasks when motor and perceptual demands are reduced and stimuli are simplified (Kaur et al., 2018; Stevenson et al., 2014; Zhou et al., 2021), it is possible that reducing the social demands of interpersonal synchrony may be similarly beneficial for autistic individuals. In relation to this, robots can be used to create a limited and controlled social presence, but there is conflicting evidence regarding how people respond to synchrony from a robot (Henschel & Cross, 2020; Lehmann et al., 2015; Sweezy, 2023).

This thesis was structured around four key questions:

1) To effectively utilise robots in studies with autistic children, how can researchers first familiarise autistic children with robots during a laboratory visit? Chapter 2 used quantitative and qualitative measures with autistic children and their parents to evaluate the

effectiveness of various familiarisation techniques to help autistic children feel comfortable and supported when meeting a humanoid robot in a laboratory setting.

2) Compared to non-autistic children, how accurate are autistic children's perceptual and motor synchrony abilities in the absence of confounding demands such as action prediction and social cues? Chapter 3 investigated this by measuring the threshold at which children could differentiate between synchronous and asynchronous sounds through the use of a simultaneity judgement task and by measuring how accurately children could tap along to rhythmic auditory stimuli.

3) When witnessing a human-human dyad, to what degree are autistic children sensitive to the social effects of synchrony compared to non-autistic children? Is this different when they are instead witnessing a human-robot dyad? Chapter 4 explored this by measuring the degree to which children thought human-human and human-robot pairs were affiliated after listening to them tap in ways that varied in their simultaneity and regularity.

4) Do autistic and non-autistic children experience the social effects of interpersonal synchrony when synchronising with a humanoid robot? This was investigated in Chapter 4 by comparing children's sense of affiliation with robots during a tapping game in which robots either tapped synchronously, asynchronously, or silently with the child.

5.2 Summary of findings

In Chapter 2, I sought to determine the efficacy of various familiarisation techniques for helping autistic children feel comfortable interacting with robots in a research setting. Five themes were generated from parent interviews regarding how to promote the comfort of autistic children when meeting humanoid robots:

1) **Preparation is key:** Getting to know the participant prior to the study visit enables researchers to prepare themselves to support children with different communication styles, sensory sensitivities, and unique anxieties. Providing parents and children with additional information before their visit helps participants understand what to expect and what will be expected of them.

2) **Consideration of environmental factors:** Aspects of the physical environment, such as being in an unfamiliar space or the room appearing overly clinical, can cause anxiety in autistic children. Similarly, social aspects of the environment, such as meeting new people or being separated from their parents, can also make children nervous.

3) **Using familiarisation:** Effective familiarisation methods should be fun and engaging ways to build the child's understanding of the robot. This also gives the child time to "warm up" to the robot, as some may initially feel nervous around it.

4) **A supportive and engaged researcher:** Leading children through interactions and demonstrating how to complete tasks can help build the child's trust and confidence. Providing explicit permission and clear boundaries regarding what children are meant to do can also help them feel less anxious or reserved.

5) **Individualised approaches:** Depending on a child's age and abilities, some methods may not be appropriate for every child. The time or number of activities it takes for children to feel fully comfortable around the robot may also vary between individuals. It is beneficial to give children choices when possible, as many children are capable of communicating their needs and preferences.

Because many of the themes were not specific to human-robot interaction studies, general guidelines for supporting autistic children in lab-based studies were also generated. Quantitative measures showed that the familiarisation approaches were effective in promoting children's comfort and enjoyment when meeting the robot.

In Chapter 3, I compared how autistic and non-autistic children performed at fundamental perceptual and motor processes that contribute to interpersonal synchrony. Findings showed that autistic and non-autistic children did not significantly differ in their abilities to perceive auditory synchrony or produce motor synchrony with auditory stimuli. The tasks that measured these abilities were completed in the absence of additional social factors, used simple unisensory stimuli, and the motor synchrony task was based on finger tapping. These findings align with other research that has measured synchrony using tasks with reduced demands and stimulus complexity. Autistic and non-autistic individuals performed similarly on tasks measuring motor synchrony in adolescent and adult populations (Gowen & Miall, 2005; Morimoto et al., 2018; Tryfon et al., 2017) and on temporal order judgement tasks measuring auditory synchrony perception (Stevenson et al., 2014; Zhou et al., 2021). Taken together, this suggests that the experiential differences autistic and non-autistic children have with interpersonal synchrony are unlikely to stem from differences in basic perception and production of synchrony, but arise when stimuli are more complex, movements are more complex, and/or when there is a social presence.

In Chapter 4, I explored how autistic and non-autistic children experience the potential social effects of interpersonal synchrony. This was achieved by measuring the perceived affiliative effects of witnessed synchrony between human-human and human-robot pairs, and what affiliative effects they experience when a humanoid robot taps with them either synchronously or asynchronously. Non-autistic children perceived synchronous human-human and human-robot pairs to be more closely affiliated than silent pairs, which is consistent with previous research on both human-human (Bowsher-Murray et al., 2023) and human-robot pairs (Lehmann et al., 2015). However, the absence of significant differences in responses for synchronous and asynchronous pairs makes it difficult to determine whether children were responding to synchrony or merely the fact that they could hear the pairs. An increase in perceived affiliation in response to witnessed synchrony was not found in autistic children, although the interaction with group was weak, suggesting any true differences between the groups would be small. However, when experiencing synchrony themselves, autistic children preferred synchronous robots over silent robots, while non-autistic children did not. Although this suggests that autistic children are sensitive to the social effects of synchrony when experiencing it with a robot, even if they are not sensitive to the social effects of synchrony when observing it in human-human or human-robot pairs, non-significant differences between synchronous robots and asynchronous robots makes it difficult to determine whether children were responding to synchrony or animacy. While observing synchrony led to increased perceived affiliation between humans and robots for non-autistic children, such affiliative effects were not generated when the children engaged in synchrony with a robot themselves. Participants' social sensitivity to synchrony was also not related to their ability to perceive or produce synchrony as measured in Chapter 3. Together, these findings suggest that the affiliative effects of synchrony may be different for autistic and non-autistic individuals, that these differences are not driven by fundamental differences in how accurately they can perceive and produce synchrony, and that children's social sensitivity to synchrony can be context-dependent.

5.3 Implications of findings

5.3.1 Theoretical implications

The results of Chapter 4 supported previous findings that witnessing interpersonal synchrony in others informs non-autistic children's understanding of the pair's relationship (Abraham et al., 2022; Bowsher-Murray et al., 2023). The significant impact of the simultaneity of stimuli, but not regularity, aligns with research which has conceptualised the degree of simultaneity to be the driving force behind the affiliative effects of synchrony (Dignath et al., 2018; Hove & Risen, 2009). This suggests that the simultaneity of actions drives the social effects of interpersonal synchrony, rather than a general sense of temporal interconnectedness. This may be because many of the processes underpinning interpersonal synchrony that would be made easier with rhythmic stimuli are unnecessary or absent when merely witnessing synchrony in others. For example, achieving synchrony requires an individual to temporally anticipate their partner's actions (Bowsher-Murray et al., 2022), which is likely to be easier when movements are rhythmic. However, this process is not necessary when witnessing synchrony in others, nor is there the need to monitor one's own movements and adjust them accordingly. While my results suggest that simultaneity is the primary component of synchrony that influences non-autistic children's understanding of others' relationships, an online study investigating the effects of synchrony in this population found that both simultaneity and regularity had a significant impact on perceived affiliation (Bowsher-Murray et al., 2023). Therefore, converging evidence supports a central role for simultaneity, but more work is necessary to explore how regularity contributes to the social impact of interpersonal synchrony.

Autistic and non-autistic children performed similarly in tasks that measured how accurately they could perceive and produce synchrony (Chapter 3), and there was no relationship between children's performance on these tasks and how sensitive they were to the social effects of interpersonal synchrony (Chapter 4). This suggests that autistic children's reduced sensitivity to the social effects of interpersonal synchrony is not the result of fundamental differences in how accurately they can produce or perceive synchrony. However, while autistic individuals have been shown to have reduced social sensitivity when tapping with a virtual human partner (Koehne et al., 2016) and research suggests that synchrony is less important to autistic individuals when forming social bonds (Efthimiou et al., 2025), I found that autistic children may have been sensitive to the effects of synchrony when interacting with humanoid robots. Together, these findings suggest that the ability to engage in interpersonal synchrony and the social effects that come from it are not entirely absent in autistic children, but may only arise in certain circumstances, such as when motor, perceptual, and social demands are reduced. These demands were reduced in the current study by only requiring participants to tap on a screen with one finger, using simple unisensory auditory stimuli instead of multisensory or speech-based stimuli, and using a robot instead of a human. In essence, while it has been established that autistic individual's produced interpersonal synchrony is often less accurate than non-autistic individuals' (Fitzpatrick et al., 2016) and that they are less sensitive to its social significance (Koehne et al., 2016), the findings of this thesis suggest that this may be context-specific rather than a universal truth. However, given the absence of significant differences between ratings for synchronous robots and asynchronous robots, more research is needed to confirm whether the children's responses were truly being driven by how synchronous the robot was or whether they were merely reacting to the robot being responsive.

The current finding that autistic children's ability to perceive and produce synchrony was similar to non-autistic children's when demands were reduced has implications for understanding which underlying processes of interpersonal synchrony may be impacted in autistic individuals. One candidate process is social orienting, which is the tendency to attend to social stimuli (S. Fletcher-Watson et al., 2008; Gluckman & Johnson, 2013). This process enables individuals to attend to cues such as mutual gaze and relevant body movements, and is considered a necessary process for interpersonal synchrony to take place (Bowsher-Murray et al., 2022). Autistic individuals typically display reduced attention to social stimuli (Brezis et al., 2017; Fitzpatrick et al., 2016; McNaughton & Redcay, 2020), which could contribute to the different ways in which they experience synchrony. As such, it may be that while social cues help non-autistic individuals achieve interpersonal synchrony and experience its social effects, these cues are less salient for autistic individuals. Interacting with a robot is an atypical situation in which participants interact with an entity that often displays almost no social cues, which could explain why autistic children appeared to be sensitive to the social effects of experienced synchrony but non-autistic children were not. However, the validity of this group difference is unclear as there was not a significant interaction.

It is also relevant to reflect on an important discrepancy uncovered in my thesis; autistic children were sensitive to synchrony (or, at least, sound versus silence) when they themselves were interacting with the robots, but they did not perceive the relationships of human-robot or human-human pairs differently based on their degree of synchrony (Chapter 4). This could relate to the idea that autistic individuals struggle to understand other people's minds, with regard to their feelings, thoughts, beliefs, and other mental states (Baron-Cohen, 2000; Kimhi, 2014; Senju, 2012). Similarly, research has indicated that autistic individuals have significantly more difficulty interpreting and understanding others' emotions (i.e., cognitive empathy; Mazza et al., 2014). Furthermore, the difficulties that many autistic individuals have with engaging in imaginative play (American Psychiatric Association & American Psychiatric Association, 2013) may have made it more difficult for the autistic participants to imagine the children in the photos playing the game together. Considering these factors, autistic children may be able to answer how they themselves feel about the robot after it tapped either synchronously or asynchronously with them, but would find it difficult to interpret or imagine how others would experience this. This would suggest that autistic children's lack of sensitivity to witnessed interpersonal synchrony is, in part, the result of the different ways in which they interpret the feelings and relationships of others more broadly.

5.3.2 Practical implications

The generalisability of the themes and recommendations identified in Chapter 2 suggests that familiarisation techniques should be used when working with autistic children, even outside of HRI studies. Many of the parents' concerns were largely unrelated to the NAO robot, but instead focused on other aspects of the experience such as their child being in a new space and meeting new people. These situations are not exclusive to HRI and are likely to occur in nearly any laboratory-based study. Indeed, the recommendations provided in Chapter 2 to provide autistic children and their families with preparation materials before the study complements previous guidance stressing the importance of providing autistic participants with as much information about the venue as possible in advance of the study visit (Gowen et al., 2019). Similarly, the recommendations to be mindful of the physical testing environment and be active in supporting the participant mirror other guidance to adjust one’s behaviour and the testing environment accordingly in response to the autistic participant’s specific needs (Pellicano et al., 2017). As such, it is likely that some of the proposed solutions and aids (e.g., storyboards, video walkthroughs, using personalised approaches) will be useful in other study paradigms. For example, researchers who use MRI machines have also found success using storyboards with autistic children as a means of increasing participant comfort (Tziraki et al., 2021).

Familiarisation methods can also be used outside of research contexts. The aspects of research studies that can make autistic children uncomfortable, such as unfamiliarity and uncertainty, are not exclusive to research settings. Autistic children are also likely to encounter unfamiliar places and people in education settings, healthcare settings, and other public spaces. Given the generalisability of parents' concerns and the provided recommendations, familiarisation should not be considered exclusively when conducting research, but rather utilised whenever one is working with autistic children. For example, many theatres have started providing visual guides that explain what can be expected before and during a performance, and some have begun to offer familiarisation visits for patrons who may benefit from seeing the venue ahead of time (B. Fletcher-Watson, 2015; OfficialLondonTheatre, 2022). Other organisations may have general guidelines for how to support autistic individuals, but they may not have explicit recommendations for how this should be achieved in practice. For example, the NHS guidance for improving inpatient settings for autistic individuals recommends creating a predictable environment by informing patients of what and who to expect, but it does not make any suggestions regarding how or when this should be communicated (NHS England, 2023). This could be achieved through the use of familiarisation materials like the storyboards and video walkthrough recommended in Chapter 2.

Autistic and non-autistic children had similar motor synchrony production abilities (Chapter 3) but responded to interpersonal synchrony differently (Chapter 4). This suggests that the differences in autistic and non-autistic children's sensitivity to the social effects of synchrony are unlikely to be related to how accurately they can produce simple motor synchrony. This is supported by the finding that there was not a significant relationship between participants' motor synchrony abilities and their sensitivity to experienced synchrony (Chapter 4). While improving autistic children's motor skills does increase the likelihood that children will participate in physical activity and active play, which in turn creates more opportunities for social development (Busti Ceccarelli et al., 2020; Colombo-Dougovito & Block, 2019), these results suggest it is unlikely that improving motor skills would have a significant effect on the social effect children receive from experiencing interpersonal synchrony. However, this may only be the case for this specific lab-based scenario and may not remain true in real-world interactions. Research has shown that many autistic people feel that coordinating their movements takes a considerable amount of concentration (Gowen et al., 2023), which could reduce their sensitivity to the social effects if attention plays a more important role in real-world interpersonal synchrony than it appeared to in this study. Given that most real-world interactions are more complex than the simple finger tapping used in the current study, further research is necessary to determine whether the ability to coordinate complex movements is related to social sensitivity to interpersonal synchrony.

Regarding human-robot interactions, my findings suggest that synchrony could be used to positively impact autistic children's attitudes towards robots. Because robots are becoming common in healthcare, education, work, public spaces, and the home (Leite et al., 2013), ensuring that autistic children feel safe and comfortable around robots has become increasingly important. As discussed in Chapter 2, autistic children are often initially nervous around robots, but various familiarisation techniques can be used to increase their comfort. Because autistic children reported a stronger sense of affiliation toward robots with whom they were tapping synchronously than robots which tapped silently in Chapter 4, this demonstrates that having autistic children act synchronously with robots can improve autistic children's opinions of robots. One possible use for this is to incorporate aspects of synchrony within familiarisation phases. For instance, synchrony could be incorporated into the Capability Demonstration approach described in Chapter 2 in order to increase the child's affiliation with the robot. For example, if the robot sings a nursery rhyme and performs the relevant actions, the child could be encouraged to sing and dance along with them. One study used a familiarisation technique similar to this in which they invited participants to join the robot in dancing to "Gangnam Style" and the "Macarena", which both have choreographed dances that children are likely to know (Arent et al., 2022). Similarly, researchers could have the child and robot clap in time with a song. Depending on the capabilities of the robot, this could also be implemented in the Stimulus and Response approach by having the robot follow the child's movements. Further research is needed to understand how to best utilise synchrony in ways that are both effective and engaging. However, given that the only true significant difference in the affiliation ratings was that of the synchronous robot compared to the silent robot, it is uncertain whether synchrony itself drove the results, or whether children simply did not like the silent robots. In either case, it is clear that autistic children significantly preferred robots that were obviously active and engaged with them compared to robots which were not. This aligns with the findings in Chapter 2 which showed that the Stimulus and Response activities, which demonstrated the robot's interactive capabilities, were preferred over the Static Exploration activities, in which the robot was stationary and unresponsive.

For non-autistic children, my results suggest that synchrony should be implemented differently than for autistic children to improve positive feelings about robots. In Chapter 4, it was demonstrated that non-autistic children were sensitive to the social effects of synchrony (or, at least, animacy) when witnessing it in human-robot pairs, but not when they themselves were interacting with a robot. Social effects from witnessed synchrony in human-robot dyads were also seen in Lehmann et al. (2015). Therefore, for non-autistic children, watching a robot synchronise with someone else, such as a researcher, teacher, or parent, may be a more effective way of increasing positive regard towards robots. This could similarly be implemented into the Capability Demonstration approach, for example, by having the researcher and robot perform a nursery rhyme dance together. While convincing children that the robot has a positive relationship with a trusted adult may not be as impactful as directly influencing children's opinions about the robot, structural balance theory (i.e., the idea that people are motivated to avoid cognitive dissonance in their interpersonal relationships; Cartwright & Harary, 1956; Goodreau et al., 2009; Heider, 1958) shows that two individuals are more likely to develop a positive relationship with each other if they both have a positive relationship with a shared third individual. This suggests that demonstrating that the robot is affiliated with a trusted adult will encourage children to develop a positive relationship with the robot. However, further research is needed to determine whether structural balance theory maintains its validity when one member of the triad is a robot. It is also possible that achieving synchrony in this thesis through tapping with a robot that was not visibly moving was not salient enough. Visibly synchronising movements could have generated a stronger social response from non-autistic children, but this is not confirmed.

5.4 Strengths and limitations

5.4.1 Strengths

One particular strength of the study conducted in Chapter 2 is that the familiarisation approaches are likely generalisable to many types of robots and a wide range of study paradigms. The approaches were developed based on literature that analysed familiarisation techniques with 28 different models of robots, which had a wide range of designs including anthropomorphic, zoomorphic, and caricatured (Wallbridge et al., 2024). This suggests that the approaches may also be effective with robots other than the NAO, although further research is needed to provide corroborating evidence. Furthermore, the majority of the qualitative themes that captured approaches for introducing autistic children to research environments were not specific to HRI studies. Rather, the themes included aspects of participating in research that are present in many different study paradigms (e.g., unfamiliar people and places, potential triggers of sensory sensitivity, considering children's abilities and preferences). As such, the recommendations generated from the themes are likely to be useful in promoting autistic children's comfort regardless of whether robots are involved.

The study in Chapter 2 also enabled us to get parents' and children's feedback on a real-world example. While some guidelines regarding how to appropriately conduct research with autistic individuals rely on participants' memories of past experiences (e.g., Gowen et al., 2019,) or rely on researchers' opinions regarding what methods they found suitable (e.g., Lewis et al., 2023), we were able to ask parents and children for feedback using a real example they had just witnessed/experienced. We were also able to ask autistic children directly about their preferences rather than solely relying on feedback from their parents or other adults.

Another strength of the thesis was that the work developed in Chapter 2 informed the familiarisation approaches used in the studies reported in Chapters 3 and 4. Thus, within the lifetime of this thesis, I was able to observe the positive impact of the recommendations I developed, which were based on feedback from parents and autistic children. For example, the pre-familiarisation materials used in Chapters 3 and 4 (i.e., the storyboard and video walkthrough) were recommendations made by parents from Chapter 2. Children's feedback from Chapter 2 also informed how the robot was programmed – one child expressed discomfort when the robot's head followed their movements, so this feature of the robot was not used in the studies presented in Chapters 3 and 4.

When investigating synchrony, all four tasks – motor synchrony, synchrony perception (Chapter 3), witnessed synchrony, and experienced synchrony (Chapter 4) – used the same auditory stimuli. Exclusively using simple auditory stimuli helped to eliminate additional confounding processes that autistic children often struggle with, such as multisensory processing (de Boer-Schellekens et al., 2013; Foss-Feig et al., 2010; Kwakye et al., 2011). Non-speech stimuli were used because autistic children typically have more difficulty temporally processing speech-based stimuli (Bebko et al., 2006; de Boer-Schellekens et al., 2013; Zhou et al., 2021). Similarly, the motor synchrony task and the experienced synchrony task required participants to make the same movements (i.e., tapping on the iPad). This limited extraneous additional demands, as autistic children typically struggle more with actions that require complex actions or core balance (Whyatt & Craig, 2012). Consistency between tasks also allowed for a more accurate comparison of results.

The use of robots in the Experienced Interpersonal Synchrony Task helped eliminate possible impacts caused by whether participants had the same neurotype as a human partner. The "double empathy problem" suggests that people find it easier to relate to and interact with one another if they have the same neurotype (e.g., two autistic people or two non-autistic people; Milton, 2012). Similarly, research suggests that whether one child in a dyad has the same neurotype as the other can impact the frequency with which the children spontaneously synchronise (McNaughton et al., 2024). By having children synchronise with a robot, which is not inherently autistic or non-autistic, this helped reduce unintentional impacts on the quality of the synchrony and its social effects.

Many autistic children who participated had additional neurodevelopmental conditions. This reflects the heterogeneity of the real-world autistic community, considering that autistic individuals have an increased likelihood of having additional neurodevelopmental, psychiatric, and medical conditions compared to the general population (Leyfer et al., 2006; Mannion & Leader, 2013; Rosen et al., 2018). For example, 12 of 29 participants (41.4%) who took part in Chapters 3 and 4 either had or were under assessment for ADHD. This high prevalence of ADHD is thought to be representative of the broader autistic community, with recent estimates showing that the prevalence of ADHD among autistic individuals is approximately 40.2% (Rong et al., 2021). This condition may additionally impact how children perceive and produce synchrony, as features of ADHD, such as difficulties with attention (American Psychiatric Association & American Psychiatric Association, 2013), are known to be relevant to interpersonal synchrony (Bowsher-Murray et al., 2022). Children and adults with ADHD have also been shown to have poorer performance on temporal order judgement tasks that use unisensory auditory stimuli (Fostick, 2017; Oram Cardy et al., 2010). Furthermore, adults with ADHD have been shown to synchronise with others less accurately than adults without ADHD (Gvirts Problovski et al., 2021). By including children with a range of needs and diagnoses rather than focusing on the small subset of autistic children who have no co-occurring conditions, the study results become more generalisable to a broader population of autistic children (Yazdani et al., 2020).

5.4.2 Limitations

While the autistic children who took part in the studies had a wide range of additional neurodevelopmental diagnoses, all children were capable of some speech. Additionally, the autistic participants were unlikely to have had an intellectual disability – the participants in Chapters 3 and 4 had an IQ range of 70-121, while an IQ score of below 70 is considered to be indicative of an intellectual disability (Committee to Evaluate the Supplemental Security Income Disability Program for Children with Mental Disorders et al., 2015). As such, there may be limited generalisability for non-speaking children or those with more significant intellectual difficulties. Some of the familiarisation approaches may not be suitable for this population, and it is similarly unknown how they experience synchrony in comparison to verbal autistic children. This limitation is unfortunately common in the field of autism research. Although an estimated 50-55% of autistic people have a co-occurring intellectual disability (Charman et al., 2011; Loomes et al., 2017), selection bias that ultimately excludes or underrepresents autistic individuals with intellectual disabilities has been found throughout all fields of autism research (Russell et al., 2019). While children with intellectual disabilities are sometimes intentionally excluded from studies due to concerns regarding the child's ability to consent, this underrepresentation can also be due to the existence of additional barriers to participation for these children and their carers (e.g., limited time and resources) or the absence of appropriate measures and tasks to use with these children (Russell et al., 2019). The studies used in this thesis were in-person, laboratory-based experiments that often lasted up to two hours, which may not have been suitable for children with an intellectual disability.

Another limitation is that I only studied a very particular type of motor and perceptual synchrony. Stimuli were always non-speech unisensory auditory beeps, and motor tasks only involved tapping with one finger. As discussed in the previous section (5.4.1), this narrowness afforded certain advantages, such as reducing extraneous demands and making tasks more comparable. However, as a result, my findings may not be generalisable to visual, multisensory, or speech-based stimuli. Similarly, results may differ when children are required to do more complex movements or coordinate multiple body movements. Autistic children typically have less sensory acuity for audiovisual stimuli (Bebko et al., 2006; de Boer-Schellekens et al., 2013; Foss-Feig et al., 2010; Stevenson et al., 2014) and often struggle with motor tasks involving balance (Whyatt & Craig, 2012). As such, the results found using reduced task demands in this thesis are likely not representative of how autistic children will experience many real-world social interactions.

While results from synchronous conditions were sometimes significantly different from silent conditions, asynchronous conditions were never significantly different from the synchronous or silent condition. This makes it difficult to determine whether participants were reacting to the social effects of synchrony, or merely active pairs/robots versus inactive ones. This limits the interpretation of the significant results, as it is unclear what underlying mechanisms are driving these differences.

The gender imbalance and size of the samples prevented me from fully investigating the extent to which participants' gender impacted their synchrony perception, synchrony production, and social sensitivity to synchrony. While there have been a limited number of studies that have investigated gender differences in interpersonal synchrony, results are mixed. Some studies concluded that females were more sensitive to the social effects of interpersonal synchrony than males (Fujiwara et al., 2019; Tschacher et al., 2014), but others found no gender difference (Bowsher-Murray et al., 2023; Cacioppo et al., 2014; Kirschner & Tomasello, 2010). Similarly, studies have shown gender differences in children's motor development, but these differences are often task- and domain-specific, with males performing better than, worse than, or equal to females depending on the particular motor skill that is being measured (Bondi et al., 2022; Liutsko et al., 2020). Given these inconsistent results, it remains unclear how gender/sex impact children's experiences with interpersonal synchrony. However, a study using a similar tasks to those in Chapter 4 with typically developing children the same age as those in the current sample did not find any significant gender effects in their Witnessed Synchrony Task nor their Experienced Synchrony Task (Bowsher-Murray et al., 2023).

While all participants were able to hear, as children with significant physical disabilities that would prevent them from completing the tasks were excluded, another limitation is that no hearing acuity tests were performed during the study. As such, the degree to which participants' general hearing ability impacted their performance on this task is unknown.

Finally, only one type of robot was used in the studies, which may limit the generalisability of the results. While this may not significantly impact the results of the familiarisation study in Chapter 2 as the techniques were developed from studies that used a wide range of robots, it is unknown if participants would respond to synchrony/asynchrony in the same way if another type of robot were used (Chapter 3 and 4). For example, synchrony could be perceived differently if the robot was humanoid, zoomorphic, caricatured, or functional in its design. Indeed, research has indicated that the appearance of a robot can impact its perceived social presence and sociability (Kwak, 2014). As such, the findings regarding how children respond to witnessed and experienced synchrony with robots may not be generalisable to robots which are not humanoid.

5.5 Areas for further research

This thesis focused on the differences in how accurately autistic and non-autistic children perceive and produce synchrony outside of social contexts, as well as their social sensitivity to interpersonal synchrony. While this thesis focused on a narrow age range, it would be beneficial to investigate how children's experiences with synchrony may change as they develop. Research has shown that typically developing individuals become more sensitive to the social effects of interpersonal synchrony as they age (Bowsher-Murray et al., 2023). The degree to which regularity impacted affiliative effects was also positively correlated with participants' ages (Bowsher-Murray et al., 2023). Because autistic individuals may develop social skills later in life than non-autistic people (Ventola et al., 2014), my pattern of findings could change in adolescent and adult populations. Indeed, research has shown that interpersonal synchrony significantly affected perceived self-reported rapport in dyads of autistic adults, although at a level that was reduced compared to dyads of non-autistic adults (Efthimiou et al., 2025). While synchrony may hold less social importance for autistic individuals, it does still impact how they perceive their social interactions in adulthood. People's opinions toward and expectations of robots can also change with age (Cameron et al., 2015, 2017), further suggesting that these findings may change in older groups. For example, because younger children often perceive robots to be more human-like than older children (Cameron et al., 2015), this could impact the robot's perceived social presence. While age did not appear to influence children's sensitivity to the social effects of witnessed or experienced synchrony in the current study, as age was not significantly correlated with either of these measures, it is possible that the sample's age range was too narrow to detect age effects. Beran et al. (2011), for example, which found differences in younger and older children's beliefs about robot's animacy, defined "younger children" as aged 5-11 years old, and "older children" as aged 12-16 years old. Given that the sample in the current study did not include any children over the age of 11, it is possible that the children in this study simply had not yet experienced these developmental shifts in belief. Future research could utilise a longitudinal design to track the ways in which sensitivity to synchrony and feelings towards robots change over time as children enter adolescence and adulthood.

This thesis also provided recommendations for how to promote the comfort of autistic children when meeting a humanoid robot. While many of these recommendations should be broadly generalisable, the methods of familiarisation were only tested with one child at a time. In other settings, such as classrooms where multiple children are present, it may not be logistically viable for each child to have an extended one-on-one introduction to the robot. While relatively passive Capability Demonstration-type familiarisation approaches have been used with groups of autistic children (e.g., Huskens et al., 2013), the efficacy of this approach has not been explicitly tested against one-on-one familiarisation sessions. In group settings, autistic children have been shown to observe how other children first interact with a robot, which then influenced how they later interacted with it (e.g., putting a hat on the robot's head after watching another child do the same; Kozima et al., 2009). In this way, group settings may be beneficial in allowing more confident children to demonstrate and scaffold how to appropriately interact with the robot. However, in instances where robots may need to be introduced to multiple children at a time, it is also likely that the children will have different needs, abilities, sensitivities, and preferences from one another. As such, it would be beneficial to assess the efficacy of these methods in group settings and determine the ways in which they should be adapted.

This Experienced Interpersonal Synchrony Task (Chapter 4) investigated the effects of interpersonal synchrony by utilising a paradigm in which participants and robots synchronised together with an external stimulus, which is a form of synchrony often referred to as “orchestration” (Cacioppo et al., 2014). However, synchrony can also be reciprocal (in which both partners adjust their movements to synchronise with each other) or unilateral (in which there is an explicit leader/follower dynamic where one participant moves and the other is tasked with following them) (Cacioppo et al., 2014). It is important to understand the differences in the social effects generated by these types of synchrony, as orchestration only represents a portion of real-world interpersonal synchrony. Many manifestations of interpersonal synchrony, such as walking in step, shaking hands, and entraining postural adjustments, are often not explicitly guided by external stimuli. Although an obvious avenue for future research is to explore these different types of interpersonal synchrony with robots, many robots will have practical limits regarding which roles they can fill. For example, unilateral synchrony requires asymmetrical behavioural adjustments, as the follower is solely responsible for monitoring how their movements compare to the leader's and adjusting their movements accordingly (Reddish et al., 2020). For NAO robots, which were used in this thesis, it will often be simpler for the robot to lead the interaction rather than have the robot monitor the participant's movements and adjust its own accordingly. This will limit how comprehensively unilateral synchrony can be explored. However, for remotely controlled robots such as Keepon (Kozima et al., 2009), it would be relatively simple for the operator to match the robot's movements to the participant's tempo, match external stimuli, or lead an interaction. For robots that can fill multiple roles, future research regarding whether each of these types of synchrony produces equal social effects would be beneficial.

While I have provided evidence that children's social sensitivity to synchrony is likely not driven by how accurately they can perceive or produce synchrony, it remains unclear what is driving the differences in social sensitivity between autistic and non-autistic people. Several underlying processes remain, including social orienting, social context, and attentional load (Bowsher-Murray et al., 2022). Because differences in these processes are not unique to autistic children, a transdiagnostic approach to this question may be enlightening. Indeed, when using a similar paradigm to the Witnessed Interpersonal Synchrony task in Chapter 4, a study found that children who had emotional, behavioural, and/or cognitive difficulties but no formal diagnoses also had reduced sensitivity to the social effects of interpersonal synchrony (Bowsher-Murray et al., Under review). As such, it may be more beneficial to develop a deeper understanding of how social orienting, social context, and attentional load contribute to social sensitivity in interpersonal synchrony rather than comparing diagnostic categories.

5.6 Conclusion

Within this thesis, I aimed to understand: (1) how autistic and non-autistic children compare in their abilities to perceive and produce synchrony in a non-social context, (2) how autistic and non-autistic children perceive affiliation in human-human and human-robot dyads that tap synchronously or asynchronously, (3) whether autistic and non-autistic children experience the social effects of interpersonal synchrony when synchronising with a humanoid robot, and (4) how to effectively familiarise autistic participants with humanoid robots. To meet this final aim, and to ensure the comfort of participants in later stages of this thesis, I used a mixed-methods approach to evaluate ways to familiarise autistic children with unfamiliar robots in laboratory settings (Chapter 2). This resulted in recommendations for researchers who work with autistic children in laboratory settings. In the next chapter (Chapter 3), I demonstrated that autistic and non-autistic children have comparable motor synchrony and synchrony perception skills when stimuli are simple and task demands are reduced, providing evidence that the differences in how autistic and non-autistic individuals experience synchrony are unlikely to be the result of fundamental deficits in motor control or auditory temporal perception. In my final experimental chapter (Chapter 4), I identified differences in sensitivity to synchrony between autistic and non-autistic children, which arose in the context of a limited social presence that was created through the use of humanoid robots (Chapter 4). More specifically, non-autistic children were socially sensitive to witnessed synchrony in human-human and human-robot pairs, while non-autistic children were not. However, autistic children were sensitive to the social effects of experiencing synchrony with a robot, but non-autistic children were not. This thesis also provided evidence that social sensitivity to synchrony was not dependent on participants' ability to perceive or produce synchrony. Further research is required to establish which underlying processes of interpersonal synchrony drive differences in autistic and non-autistic children's social sensitivity to interpersonal synchrony. Furthermore, it is important to investigate how children's sensitivity to social synchrony changes across development.

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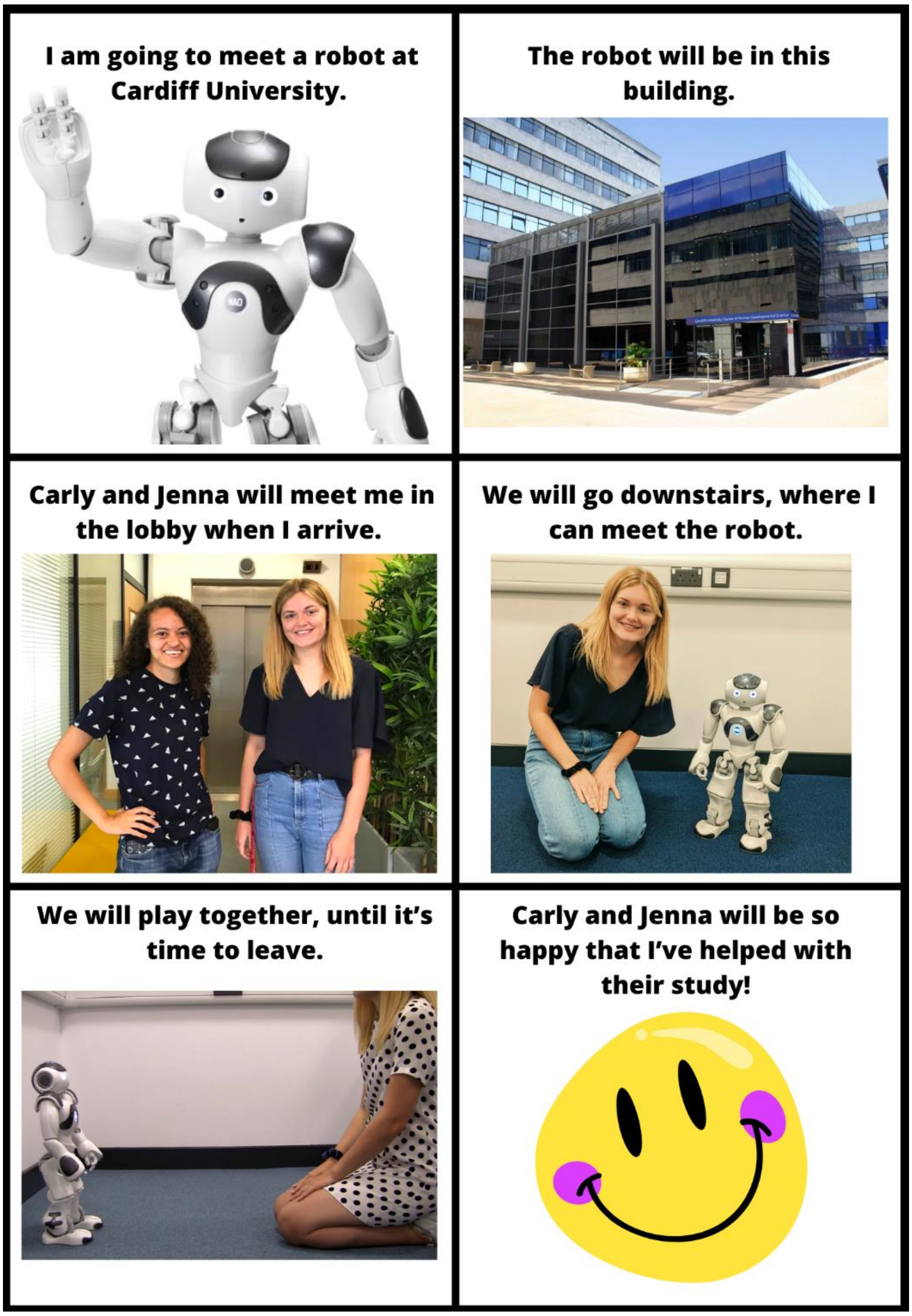
Appendix A – Detailed Familiarisation Procedures

Further explanations of the procedures for the familiarisation approaches can be found below. These include the actions performed by both the robot and the researcher.

Figure A1

Storyboard sent to families prior to lab visit



<u>Capability Demonstration</u>

Wake-Up Sequence

The first portion of the Capability Demonstration presented the robot's basic movement, auditory, and light functions in the context of the robot "waking up". It lasted approximately 70 s.

To mimic the robot being turned off or "asleep", the robot is seated in a kneeling position on the floor. Its LED lights are turned off, and it does not move or make any noise. The researcher and the child enter the room, and the researcher says, "Thank you for coming in to help us today. This is our robot, Russell. We'll have you play some games with Russell, then I'll ask you a few questions at the end when we're done to see what you thought about him. Does that sound okay?" After the child agrees, the researcher asks, "Is it alright if I turn Russell on now?"

Once the researcher has the child's consent to begin, the researcher taps the sensor on the robot's head to trigger the sequence shown in Table A1.

Table A1

Steps of the Wake-Up Sequence

Step	Details
Eye blinking	The robot's LED eye lights "blink" as if warming up, then turn on permanently. This takes approximately 12 seconds.
Musical sequence 1	The robot plays a short musical sequence (E Major arpeggio – E, G#, B, E), starting quietly and gradually becoming louder. This takes approximately 9 seconds.
Head turn	The robot slowly turns its head to the left, then to the right, then looks up, then looks down. This takes approximately 12 seconds.
Hand opening	The robot opens and closes both of its hands twice. This takes approximately 4 seconds.
Musical sequence 2 with hand movement	The robot plays a second short musical sequence (based on the Westminster Quarters). Whilst the music is playing, the robot slowly raises its arms to its face and rotates its wrists as if rubbing its eyes to wake up. The robot then returns its arms to their initial position and the music stops. This takes approximately 14 seconds.
Introduction	The robot raises its right arm, waves, and says, "Hello. My name is Russell. It's nice to meet you." It then lowers its arm again. This takes approximately 7 seconds.
Consent to proceed	The researcher asks the child if Russell (the robot) can stand up and waits for the child to agree before tapping the robot's head sensor to trigger the next movement.
Stand up	The researcher presses the sensor on the top of the NAO's head. The robot then says, "I'm going to stand up now – okay?" and stands up. This takes approximately 6 seconds.

Song and Dance

The second portion of the Capability Demonstration showed the robot's full-body movements and more advanced musical and speech capabilities. The robot then performed either “The Wheels on the Bus” (32 s), “The Itsy Bitsy Spider” (30 s), or a stereotypical Robot Dance accompanied by upbeat electronic music (37 s).

The researcher says, “Russell has a little dance he’s been working on, and he’s really excited to show you. You might know the song, so you can dance along if you want to. Can he show you what he’s been practising?” After getting the child’s permission to continue, the researcher presses the sensor on the robot’s head to trigger the Song and Dance.

Stimulus and Response

Option 1: Question and Answer Session

In this option, the robot asked the child a series of questions. For each question, after the child answered, the robot provided its own answer before asking the next question.

The researcher says, “Now Russell has a few questions he’d like to ask you to get to know you better. He’s really excited to find out about your favourite things. Is that okay?” When the child indicates they are ready to start, the researcher touches the sensor on the top of the robot’s head to begin the activity. The robot asks the following questions, pauses for the child to answer after each one, and does not ask the next question until the researcher on the other side of the one-way mirror prompts it to:

Robot: What’s your favourite colour?

Child: *[Responds.]*

Robot: Cool! I like the colour blue. What is your favourite subject in school?

Child: *[Responds.]*

Robot: Interesting! I like reading. Do you have any brothers or sisters?

Child: *[Responds.]*

Robot: Neat! I have one brother and one sister. What is your favourite food?

Child: *[Responds.]*

Robot: Cool, I like to eat pancakes. How old are you?

Child: *[Responds.]*

Robot: Wow! I was built four years ago. What is your favourite animal?

Child: *[Responds.]*

Robot: Cool! My favourite animal is an elephant. What do you want to be when you grow up?

Child: *[Responds.]*

Robot: Awesome! I want to be a scientist, like my friends. What's your favourite game to play?

Child: *[Responds.]*

Robot: Fun! I like playing checkers. Thank you for answering all of my questions.

The researcher was available to clarify the robot's questions, if required. Parents who selected this option during the Phase 1 interview could choose to have the robot skip over any questions they did not think would be appropriate for their child.

Option 2: Following Game

In this option, the robot asked the child to complete a series of simple tasks and praised the child after they successfully completed its request.

The researcher says, "Now we have a game the two of you can play. Russell will ask you to do some things for him, and all you have to do is follow along. I'll play along with you, too. Does that sound okay?" After the child indicates they are ready to begin, the researcher taps the sensor on the top of the robot's head to start the activity. The robot makes the following requests, and the researcher on the other side of the one-way mirror waits until the child successfully completes the request before triggering the robot to make the next one:

1. Can you clap your hands?
2. Good job! Can you stand up?
3. Awesome! Can you sit back down?

4. Fantastic! Can you pat your head?
5. Great! Can you touch your nose?
6. Hooray! Can you wave at me?

The robot then says, “Great job! Thanks for playing with me!”

The researcher also completed the simple tasks with the child, in case the child was unsure of the instruction. Parents who selected this option during the Phase 1 interview could choose to have the robot skip over any requests they did not think would be appropriate for their child.

Option 3: Mindful Breathing

This option had the robot lead the child through a mindful breathing exercise. The mindful breathing exercise was developed based on exercises that control the duration of the inhale and exhale, which have been shown to effectively regulate stress responses (Brown et al., 2013).The robot first said that they will take some deep breaths with the child by breathing in for four beats and then out for seven beats. Before the robot and child commenced the breathing exercise together, the robot demonstrated the technique by slowly lifting his arms in front of his chest and counting aloud to four while raising his head, then lowering his arms and counting aloud to seven while tilting his head back down. The robot said that the child could do the arm motions with him, if they wished. The robot and the child repeated this together three times at a speed of 75 beats per minute, lasting about 30 s. Then, the robot led the child in gentle stretches in which they slowly looked up and down, and then left and right. This lasted about 45 s. The researcher completed the activity simultaneously.

Static Exploration

The researcher first explained that the robot needed to rest and is going to take a nap. After getting the child's permission to continue, the researcher tapped the robot on the head. The robot then said that he was going to sleep, says goodnight, returns to his initial seated position, and his LED lights turn off. This turned the robot's power off, which meant it would not respond to touch or any other stimuli.

Option 1: Free Exploration

The researcher invited the child to touch the robot by saying, "Would you like to come a bit closer and touch him? He's turned off now, so he won't mind. You'll just have to be gentle with him." The duration of this segment was determined by the child.

Option 2: Guided Exploration

The researcher asked the child to help them give the robot a "check-up". The researcher explained that they would ask the child to touch a certain body part on the robot; they then demonstrated this process by gently touching the robot's knee. After confirming that the child understood, the researcher asked the child to touch the robot's hands, mouth, shoulders, forehead, and elbows in turn. The following script was used:

While he's asleep, can you help me give Russell a quick check-up? I think you'll be really good at it. You can help me by touching different parts of his body when I say their name. So if I ask you to touch his knees, you'll just touch them like this. [The researcher demonstrates.] Does that sound okay? It would really help me out.

Great. Can you touch his hands for me?

Good job. Now can you touch his mouth?

Wonderful. Can you touch his shoulders?

Great. Can you touch his forehead for me?

Brilliant. And last, can you touch his elbows for me?

Great job, thank you! Everything's working perfectly. You did great!

The researcher provided clarification if the child was ever unsure of where the body part was located on the robot.

Appendix B – Phase 1 Parent Interview

Interview for Parents

Hello, thank you for agreeing to take part in our study.

- Let me know if you'd like me to repeat any questions or ask them in a different way.
- If you're not comfortable answering a specific question for any reason, we can always skip it or come back to it later.

<u>Robot interactions</u>

As we mentioned in our information sheet, this study is looking into how autistic children react to robots. There's lots of research being done where autistic children interact with robots – some children respond very positively, whereas others have more negative reactions. Our goal is to find the best ways to introduce robots to autistic children so that we can support them in having a positive experience. First, I'd just like to ask a few questions about your child just to get some basic information. I want to check in with you about your child's communication style, regarding their strengths and difficulties. Can you tell me a bit about that?

(If needs prompting: Some activities we have planned give children the opportunity to talk to the robot, but we have other options for children who are nonverbal or who otherwise find verbal communication difficult. Would you like to see all the options as we go through, or should we focus on the ones that wouldn't require your child to speak?)

Here is a video of our robot, called NAO. He's about two feet tall and he can move, talk and play music. He's been developed for use with children.

(video of robot dancing)

Has your child ever interacted with a robot like this before? Does your child have any experience with any other kinds of robots?

How do you think your child would react to meeting this robot?

Do you think your child would find the novelty of the robot exciting, or do you think it might make them anxious?

When your child becomes anxious or distressed by something new in their environment, what do you do to help them calm down?

As you saw in the video, the NAO has various sensory components, such as colored lights and speakers. We know that children with autism have a wide range of reactions to different sensory experiences. Are there any sensations such as lights, sounds, or textures that your child is particularly sensitive to? Conversely, are there any sensations like these that your child doesn't seem to react to very much?

Are there any sensations like these that your child tends to seek out? Are there any sensations that your child tends to avoid?

<u>Module explanations & choices</u>

We've developed a series of modules designed to gradually introduce our robot to children before a study. We have six modules I'll be asking you about today.

Introduction

For the first module, our goal is to gradually show the child taking part all of the things that the robot does so that nothing comes as a surprise later on. For the first part of this module, we'll wake the robot up and he'll slowly start moving, then give a little wave and introduce himself. This is designed to show off all of his lights, moving parts, and speakers one by one. This is what it will look like: [video of wake-up sequence]

How do you think your child would respond to this?

What do you think about the robot's movements? Do you think that his movements are too fast, or too slow, or about right? [prompt for them to explain their reasoning, if not provided]

And what do you think about the duration of this segment? Do you think this segment is too short, or lasts too long, or is about right? [prompt for them to explain their reasoning, if not provided]

For the second part of this module, the robot will stand up and do a little song and dance.

How do you think your child would respond to this?

We have a few songs prepared for use in the study, and we'll have you choose which one you think would be most appropriate for your child. The options are:

- The Itsy Bitsy Spider
- Wheels on the Bus
- Robot

Which song do you think your child would prefer?

Why would your child particularly like this song?

Do you think any of the options would not be appropriate?

I'll show you a video of the song you chose: (video of chosen song and dance)

Does that seem appropriate for your child, or would you like to pick a different one?

Reflecting on this module as a whole, how comfortable do you think your child would be with the robot after this introduction? Is there anything else we could include in this module to help introduce your child to the robot?

We want to make sure that a child is comfortable to move on to the next stage after having been introduced to the robot. How do you think we could tell if your child was happy to move on to the next stage? Would it be fine to just ask your child if they're ready to move on, or are there nonverbal cues we should be looking out for?

Do you think showing them the dance once would be enough? Or do you think it would be beneficial to show it to them more than once?

What do you think the positive effects of doing this module might be for your child? Can you think of any potential negative effects of doing this module?

Activities

Up next is a module intended to get children used to interacting with the robot. We have three options for this section. I'll explain each option to you and ask you a few questions about each one, and then I'll have you choose which one you think your child would like best.

<u>Breathing</u>

The first is a mindful breathing exercise designed to help children feel calm. [video]

How do you think your child would respond to this?

Do you think his movements are too fast, or too slow, or about right? [prompt for them to explain their reasoning, if not provided]

And do you think this segment is too short, or lasts too long, or is about right? [prompt for them to explain their reasoning, if not provided]

<u>Follow Game</u>

The second option is a game where the robot will ask your child to do various things, like clap or wave. [video]

How do you think your child would respond to this?

I have a list here of some things we might have the robot ask your child to do. I'll read through them, and can you tell me for each one if it's something they'd like doing or if it's something that you don't think would be helpful or appropriate.

- *Clap*
- *Stand up / Sit down*
- *Pat your head*
- *Touch your nose*

- *Wave at the robot*

How many types of actions do you think your child would enjoy doing, or how long do you think they would enjoy doing this activity for?

We could repeat a certain action a few times or give your child lots of different actions. Which do you think your child might prefer?

Q & A

The third option is a question-and-answer session where the NAO asks your child what their favourite colour is, what they like doing at school, et cetera. [video]

How do you think your child would respond to this?

I have a list of questions the robot can ask your child. I'll read through them, and can you tell me for each one if it's something they'd like to answer or if it's something that you don't think would be suitable for your child.

- What is your favourite colour?
- What is your favourite subject in school?
- Do you have any siblings?
- What is your favourite food?
- How old are you?
- What is your favourite animal?
- What do you want to be when you grow up?
- What's your favourite game to play?

How many questions do you think your child would enjoy answering, or how long do you think they would enjoy doing this activity for?

Out of those three – the mindful breathing exercise, the following game, and the question-and-answer session – which do you think would be most suitable for your child?

What do you think the positive effects of doing this module might be for your child? Can you think of any potential negative effects of doing this module?

Touch

For this next module, we'll set the robot to an idle mode where it no longer moves or makes any noise, and your child is free to explore and touch it. While the robot is designed for use with children, they will still need to be gentle with it.

We have two options for this module. One is Guided Exploration, where the participant will be asked to point out and touch specific parts of the robot. The other is Free Exploration, where the participant can explore the robot however they like.

Do you think your child would prefer specific guidance, or if they were allowed to explore the robot however they liked?

Can you think of anything we should try for next time to encourage children to touch the robot that we haven't considered?

What do you think the positive effects of doing this module might be for your child? Can you think of any potential negative effects of doing this module?

Initial Session

For other studies, we're considering having children use practice runs of study procedures as a familiarization phase. For example, if the study requires the child to clap in sync with the robot, we would have them practice clapping with the robot at the beginning of the session before we start collecting any data.

How do you think your child would respond to this?

Do you think practising study protocol before the study starts would be beneficial for your child? Or do you think it wouldn't be beneficial, perhaps because your child might get tired or bored of doing the same activity multiple times?

For some studies, we're considering having the parent present for these practice runs, then step away for the real trials. Do you think this is something your child would benefit from? Can you think of any potential negative effects of doing this module (other than those mentioned before)?

Remote Control

In other studies, we might have the children control the robot via a remote control to help them better understand how it operates and demystify the robot. This isn't something we'll be able to do with our NAO robot, as it isn't easily operated by children, but we'd still like to get your opinions about it.

How do you think your child would respond to the opportunity to remote control a robot while meeting it?

Is there anything you think that people should take into consideration when designing remote controls for autistic children?

What do you think the positive effects of doing this module might be for your child? Can you think of any potential negative effects of doing this module?

Pre-Familiarization

The last module I'll be asking you about is a pre-familiarisation phase. In this module, the child's parent would get the opportunity to learn more about the robot the child will be meeting, and share any important information about their child with the researchers—similar to what you're doing right now, but in a much more condensed format. Do you think having the opportunity to share information before the study is helpful?

For studies that use a pre-familiarisation phase, do you think it would be more ideal to have parents read the information and fill out a form online with any information they'd like to share with us? Or do you think it would be better for parents to meet with us over the phone?

We're also planning on showing children a photo of the robot before they meet it so they know what to expect. Do you think this is something your child would find helpful?

In other studies, we're considering having parents be present for the familiarisation phase, then leaving when the actual experiment starts. You will be in the observation room for this experience, but for other studies, do you think your child would find it helpful for you to be in the room with them? Or do you think it would be more beneficial for them to become familiar with the robot on their own?

<u>Wrap-up</u>

Thinking back across all the modules, do you think your child would benefit from experiencing all of the modules, or do you think your child would be comfortable around the robot after just one or two?

Before we wrap up, is there anything that you feel like we've missed or that you'd like to add?

Appendix C – Phase 2 Parent Interview

Now I want to ask a few questions about the answers you gave on the scales while we were in the observation room.

Wake-Up

For the wake-up sequence, you rated it as a ___ out of 5 on comfort and a ___ out of 5 on enjoyment. Could you tell me why you chose those scores?

Having now seen the module in action, what did you think about the length of this module? Is it too long, or too short, or about right?

Is there anything about the module that you think worked particularly well in helping your child become more familiar with the robot?

Is there anything about the module that you think had any negative effects?

Song and Dance

For the song and dance, you rated it as a ___ out of 5 on comfort and a ___ out of 5 on enjoyment. Could you tell me why you chose those scores?

And what did you think about the length of the module?

Is there anything about the module that you think worked particularly well in helping your child become more familiar with the robot?

Is there anything about the module that you think had any negative effects?

Game

For the game, you rated it as a ___ out of 5 on comfort and a ___ out of 5 on enjoyment. Could you tell me why you chose those scores?

And what did you think about the length of the module?

Is there anything about the module that you think worked particularly well in helping your child become more familiar with the robot?

Is there anything about the module that you think had any negative effects?

Touch

For the touch exploration portion, you rated it as a ___ out of 5 on comfort and a ___ out of 5 on enjoyment. Could you tell me why you chose those scores?

And what did you think about the length of the module?

Is there anything about the module that you think worked particularly well in helping your child become more familiar with the robot?

Is there anything about the module that you think had any negative effects?

General

Now just I have a few questions about the experience as a whole.

Do you think it was beneficial to show your child all of the modules? Or do you think they would have been familiar with the robot after just one or two?

Between the song and dance, the game, and the touch exploration -- if researchers only had time to use one of the modules before an experiment, which one do you think would be the best to familiarize children with the robot?