UiT The Arctic University of Norway

Faculty of Health Sciences

Toddlers' imitation and understanding of communicative intentions in various social contexts

The role of social partner type and ostension on toddlers' imitation and their inferences about communicative intentions

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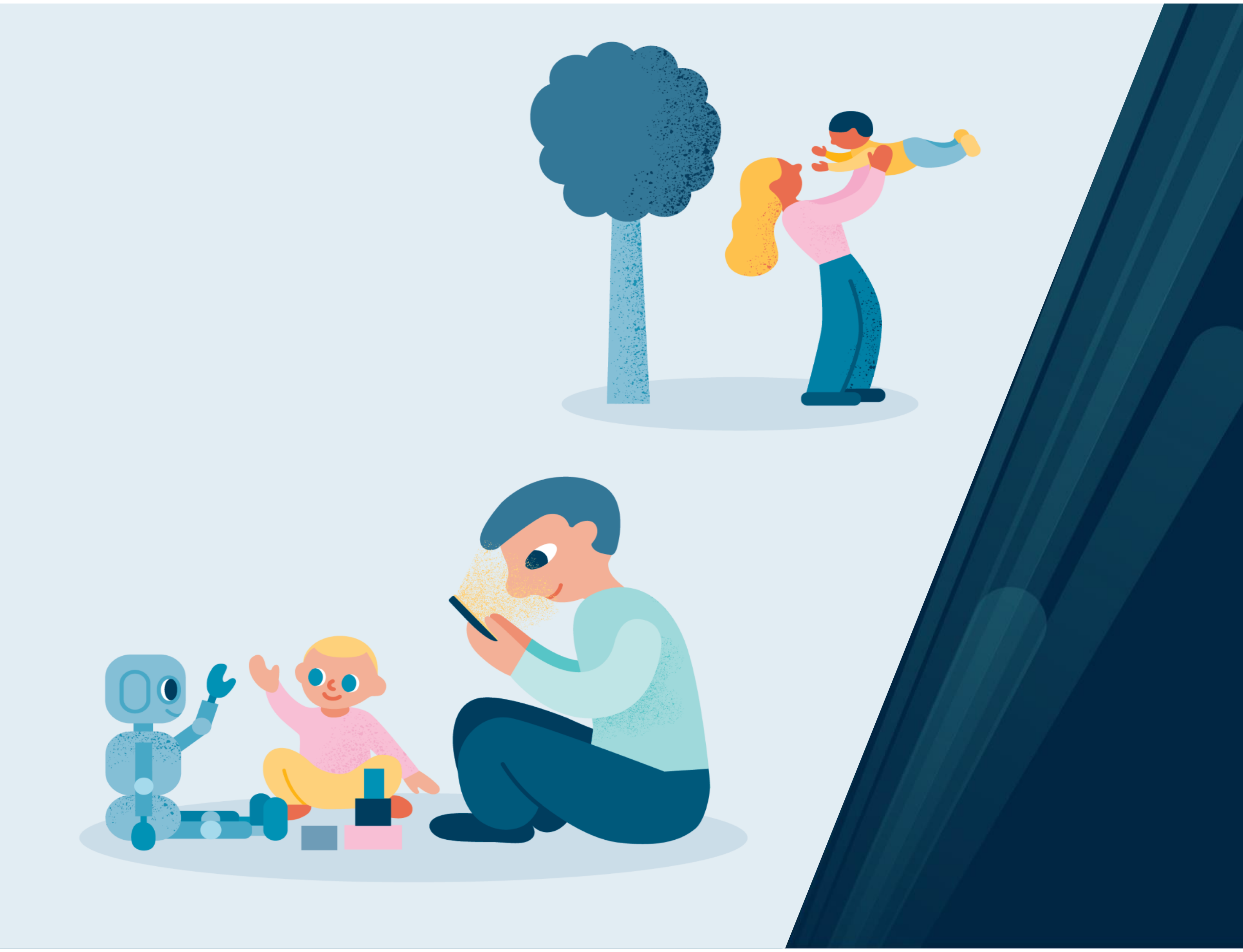

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Acknowledgments

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Preface

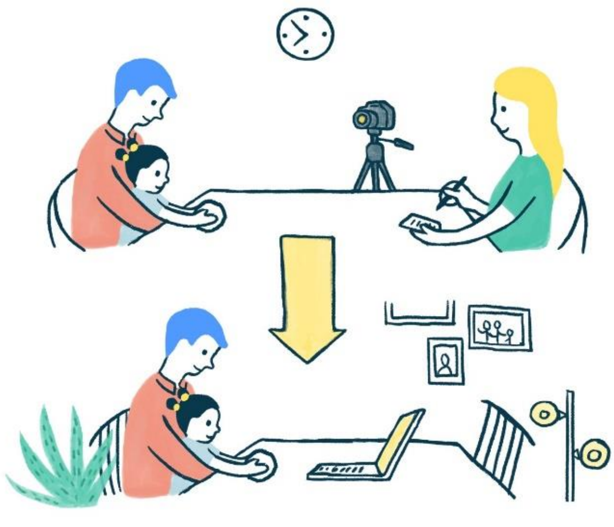
My interest in toddlers' social learning began between 2017 and 2019 when I worked as a research assistant on a project led by Associate Professor Gabriella Óturai, titled "Towards an early detection of delays in social-cognitive development – a new battery of imitation tests." While working on this project, I had several valuable learning opportunities, including developing imitation tests, engaging in scientific communication with the public and at international conferences, recruiting and testing participants, and managing daily lab operations.

While working as a research assistant, I often noticed people distracted by smartphone use during social interactions with toddlers and others. Considering the importance of ostension in toddlers' social learning, I became curious about how a phone-using social partner might impact their imitation. Therefore, I proposed this idea for a research study to Associate Professor Óturai. Together, we wrote a project description that received funding from the university.

«Smartphone use in social interactions." Illustrator: Julian Høgset

I started my Ph.D. position in July 2019 on a project that initially consisted of three experimental imitation studies. These studies were the initial project of Associate Professor Óturai (Study 1) and two studies about the role of smartphone disruptions in toddlers' imitation (Studies 2 and 3). However, the current thesis includes two experimental imitation studies (Studies 1 and 2) and a literature review (Study 3) on the use of social robots in early developmental research.

The trajectory of the PhD project changed due to the COVID-19 lockdown in the spring of 2020, which complicated conducting the planned experiments in the lab. Consequently, we re-planned Study 2 to fit online testing, allowing us to collect data during the pandemic. We also seized this opportunity to improve the study's design. Study 2 comprises two experiments, with data collection spanning from April to November 2021 for Experiment 1 and for Experiment 2 from August to November 2022. Although we successfully conducted our study entirely online, the re-planning resulted in significant delays for the PhD project. It involved several time-consuming tasks, such as developing a new online imitation test, selecting suitable test objects, developing target actions, and conducting a pilot study (October 2020-February 2021). Therefore, in December 2021, both we and the midterm evaluation committee concluded that conducting a third experimental study in the lab was not feasible. Consequently, the third study is a literature review.



“From laboratory to online testing.” Illustrator: Siri Jachlin

The three studies cover many common themes, including toddlers' imitation and their understanding of others' communicative intentions with ostensive and non-ostensive social partners (e.g., lack of or inconsistent use of ostensive cues due to disruptions). Despite these similarities, there are also notable differences in themes and methods, leading to a broad focus that sacrifices some depth. Nevertheless, each paper thoroughly presents the current knowledge and relevant research literature. The thesis thoroughly discusses the topics of imitation, intentions, and ostensive communication, specifically focusing on how each of the three studies contributes to knowledge about socio-cognitive development in toddlers from different angles.

As the literature review study was not originally planned, I had to design and plan it during the Spring semester of 2023. Having experienced the challenges of recreating the same "social context" in experiments with toddlers, I became interested in exploring the potential of using social robots in developmental research. The review paper also initiated my research collaboration with Professor Lars Ailo Bongo and Associate Professor Vi Ngoc-Nha Tran, both from the Department of Computer Science, as well as Professor in clinical psychology Catharina Elisabeth Arfwedson Wang, who all contributed to Study 3.

During my PhD project I have had three supervisors: Professor in clinical psychology Catharina Elisabeth Arfwedson Wang, Associate Professor Gabriella Óturai, and Associate Professor Mikołaj Hernik. Associate Professor Óturai was formally my main supervisor until August 2023 and is also a co-author of two papers in the thesis (Studies 1 and 2). Associate Professor Hernik has been my co-supervisor for the whole duration of the PhD project, with his supervision and contributions focused on Study 2. In August 2023, I formally changed my main supervisor from Associate Professor Óturai to Professor Wang because I needed another type of support to progress. Although challenging, this transition from one supervisor to another has been a valuable learning experience for me as a researcher.

Abstract

Background and aims: From birth, children are attuned to human communication and sensitive to others' ostensive cues, such as direct eye contact, infant-directed speech, and contingent responsivity. These signals help them understand that the information communicated is specifically meant for them. Thus, children often learn and imitate more effectively in ostensive contexts. However, modern challenges such as smartphone disruptions and interactions with technologies like social robots introduce new and less understood social contexts for young children. The main objective of this thesis was to investigate the role of different types of social partners and their various forms of ostension on toddlers' imitation and understanding of communicative intentions. Accordingly, the current thesis comprises three studies employing imitation methods across varied social contexts to enhance our understanding. The purpose of Study 1 was to investigate the consistency and stability of toddlers' selective versus faithful imitation patterns in an ostensive context with both familiar and unfamiliar human social partners. Study 2 aimed to assess toddlers' faithful imitation to investigate if toddlers recognize smartphone disruptions in face-to-face interactions as incompatible with ostensive communication and rely on this representation when making inferences about communicative intent. Study 3 aimed to identify and review publications on toddlers' imitation of and responses to various ostensive cues provided by social robots.

Method: Studies 1 and 2 were experimental imitation studies involving 1.5-year-old toddlers conducted in a lab (Study 1) and online (Study 2). These studies assessed demographic information and imitation behaviors. Specifically, Study 1 measured patterns of selective versus faithful imitation. Meanwhile, Study 2 investigated group differences in faithful imitation of novel means actions and a goal-outcome, comparing conditions where a social

partner disrupted ostensive communication by smartphone use, fiddling with a wristwatch, or did not disrupt at all. Study 3 was a literature review focusing on the toddlerhood period (1-3 years) and aimed to review empirical research on toddlers' imitation of and understanding of social robots' ostensive communication.

Results and discussion: Study 1 found that toddlers' faithful imitation was inconsistent and unstable in the 1.5-year-old period. Study 2 showed no differences in toddlers' faithful imitation across conditions where ostensive communication was disrupted by smartphone use, wristwatch fiddling, or not disrupted at all. Study 3 identified publications assessing toddlers' goal-directed imitation of physically present and on-screen robots, as well as various responses (e.g., looking behavior and verbal responses) to robots' ostensive communication. The results from Study 3 indicate that 1—to 3-year-old toddlers imitate goal-directed actions from social robots but to a lesser degree than from humans. Furthermore, toddlers attributed intentions to robots in some ostensive contexts. The results are discussed in terms of toddlers showing adaptivity in the type of social partners they imitate. Furthermore, that the results demonstrate variability in how ostension influences toddlers' understanding of others' communication in various social contexts. The thesis contributes additional knowledge on toddlers' social learning, including imitation, in various social contexts. Furthermore, it contributes new imitation material for lab and online testing.

Abbreviations

DI	Deferred imitation
E1	Experiment 1
E2	Experiment 2
F/A-test	Functional versus Arbitrary Test
IM	Immediate imitation
NM-test	Novel Means Test
N/UN-test	Necessary versus Unnecessary Test
OSF	Open Science Framework
ToM	Theory of Mind
UiT	UiT The Arctic University of Norway

“For imitation is natural to man from his infancy. Man differs from other animals particularly in this, that he is imitative, and acquires his rudiments of knowledge in this way; besides, the delight in it is universal.”

- Aristotle

List of papers

Paper 1. Flatebø, S., Johansen, L., & Óturai, G. 18-month-olds show neither stability nor consistency in selective vs. exact imitation. Manuscript submitted.

Paper 2. Flatebø, S., Óturai, G., & Hernik, M. (2024). No evidence for adult smartphone use affecting attribution of communicative intention in toddlers: Online imitation study using the Sock Ball Task. *PloS ONE*, *19*(3), e0300874. https://doi.org/10.1371/journal.pone.0300874

Paper 3. Flatebø, S., Tran, V. N.-N., Wang, C. E. A., & Bongo, L. A. (2024). Social robots in research on social and cognitive development in infants and toddlers: A scoping review. *PloS ONE*, *19*(5), e0303704. https://doi.org/10.1371/journal.pone.0303704

1 Introduction

Children are born into this world naturally predisposed to form attachments with their caregivers, which is critical for survival (Bowlby, 1988). Imitation serves as a crucial social-cognitive learning mechanism that enables children to form social relationships with others and learn about the world (Over, 2020; Uzgiris, 1981). Imitation is facilitated by children's inborn sensitivity to ostensive cues—such as direct eye contact, contingent responsivity, and infant-directed speech (e.g., Csibra & Gergely, 2006). These cues help young children to recognize when they are being addressed and that the communication is intended for them, which is essential to facilitate imitation (e.g., Csibra & Gergely, 2006). Although caregivers are the most important figures in children's social world, children also face the challenge of engaging with different social partners and communication styles. They must choose what to imitate and from whom to imitate in different social contexts (e.g., Wood et al., 2013). For example, some newer forms of social interactions that children experience that are less studied involve others' smartphone disruptions and interactions with social robots. Furthermore, children are exposed to various communicative styles, from explicit ostensive communication to more subtle, non-ostensive exchanges. Given the diversity of social interactions and partners they encounter, it is crucial to understand better how children adapt and imitate in these varied social contexts.

The current thesis consists of three studies that employ imitation methods in various social contexts to enhance our understanding of toddlers' socio-cognitive development. These studies have both similarities and differences in their purpose of employing imitation methods (i.e., investigating the underlying nature of imitation vs. communicative intent), social partner type (i.e., human vs. robot), the setting of the imitation test (i.e., lab or online), and whether the demonstrator in the imitation test behaved ostensively (e.g., directly signaling an intention to communicate using eye contact, infant-directed speech, or contingency) or non-ostensively (e.g., lack of or inconsistent use of ostensive cues due to disruptions). The introduction provides an overview of these topics, some from a broader perspective and others more deeply, including imitation, communicative intention, and ostensive communication. Table 1 presents an overview of the variations of the social contexts in three studies of the thesis.

Table 1

The social contexts and the related topics of the three studies in the present thesis

Characteristics	Study 1	Study 2	Study 3
Social partner			
Type	Human female	Human female	Robots and human controls
Social behavior	Ostensive communication	Disrupted vs. non-disrupted ostensive communication	Ostensive vs. non-ostensive communication
Interaction with child	One-to-one	One-to-one	One-to-one, bystander, in pairs or groups
Demonstration format	Physically present	On-screen	Physically present or on-screen
Setting	Lab or controlled setting	Online with participation via a computer in a controlled home-based setting [a]	Lab or controlled settings, naturalistic settings, and ecological settings
Children: age	1.5-year-old period (18 months)	1.5-year-old period (17-19 months)	1 to 3 years (toddlerhood)
Measures			
Imitation	Selective vs. faithful imitation	Faithful imitation of novel means and imitation of goal-outcome	Goals and means
Other measures	Social-emotional development	None	Verbal responses, looking behavior, and other [b]

Note. [a] Although families participated in the online imitation test from their homes, Study 2 was still highly controlled to minimize potential distractions. [b] Other child measures included transcripts of behaviors during social interactions with robots (e.g., bodily movements, facial expressions, and vocalizations), affective behavior, and parent- or robot-oriented behavior (e.g., social initiations).

The first two studies use experimental designs (Studies 1 and 2), while the third is a literature review (Study 3). The main distinction between the experimental studies lies in the application of the imitation methods: whether they were used to investigate imitation itself or communicative competence. More specifically, Study 1 investigates the underlying nature of imitation by examining developmental trends in 18-month-olds' selective versus faithful imitation patterns across different imitation tests and over a short-term period. In contrast, Study 2 employs imitation methods to investigate whether 18-month-old toddlers attribute communicative intent during a social interaction where reading intentions are more challenging due to disrupted ostensive communication. More specifically, the social partner disrupts the ostensive face-to-face communication (i.e., directly signaling an intention to communicate with direct eye contact and verbal signals) and engages with a smartphone. Study 3, the literature review, assesses how social robots have been used as tools in early socio-cognitive developmental research. It specifically investigates whether toddlers aged 1 to 3 years attribute communicative intentions to social robots that engage in ostensive communication and whether they can learn from and imitate these robots.

More specially, the present work seeks to address these knowledge gaps by addressing the following questions: a) Do 1.5-year-olds shift from only considering the goal and situational constraints (i.e., observed through selective imitation) to also considering the social partner's communicative intentions (i.e., observed through faithful imitation) in an ostensive imitation context? Or, more specifically, are 1.5-year-old toddlers' patterns of faithful imitation stable and consistent, and does familiarity with the social partner impact these patterns? (Study 1); b) Do toddlers recognize smartphone use as incompatible with their expectations for ostensive communication, and do they rely on this representation when inferring communicative intent? (Study 2); and c) Do toddlers recognize social robots as social partners that intend to teach and are, therefore, worthy of imitation? (Study 3). To illustrate the importance of these questions, I will begin the introduction by outlining the theoretical framework that guides the thesis, along with some related theories. Thereafter, I will outline relevant concepts and existing research in these areas. Notably, terms introduced in the theoretical framework in section 1.1, such as “imitation” and “selective versus faithful imitation,” will be elaborated upon in section 1.2. Finally, I will present the aims of the present thesis.

1.1 The theoretical framework

This thesis is guided by the Natural Pedagogy Theory, which seeks to explain social learning and understanding of communicative intentions in early childhood (Csibra, 2010; Csibra & Gergely, 2006, 2011; Gergely & Csibra, 2005; Király et al., 2013). Each study within this thesis is grounded in Natural Pedagogy Theory, which posits that ostensive communication from social partners may trigger a pedagogical stance in young children, signaling that the communicated content is intended for them and relevant to learn (Csibra, 2010; Csibra & Gergely, 2006, 2011; Gergely & Csibra, 2005; Király et al., 2013). I will give a detailed presentation of the Natural Pedagogy Theory in the following sections. Lastly, I will outline Uzgiris's (1981) theory, which proposes that both cognitive and social motivations can drive children’s imitation. While Uzgiris's (1981) theory is particularly relevant to Study 1, it is less central to the other studies, so it will be discussed in less detail.

1.1.1 Natural Pedagogy Theory

Natural Pedagogy Theory was introduced by Csibra and Gergely (2006; 2005) about two decades ago. Within this theory, pedagogy is defined as a specialized form of social learning that is facilitated by ostensive communication (Csibra, 2010; Csibra & Gergely, 2006, 2011; Gergely & Csibra, 2005; Király et al., 2013). This theory suggests that humans are innately adapted to learn through social interactions, such as imitation, where a knowledgeable teacher effectively transmits information to a less competent learner (e.g., typically a child) via ostensive communication (e.g., eye contact, infant-directed speech, and contingent responsivity) (Csibra & Gergely, 2011; Gergely & Csibra, 2005). This form of learning is considered *natural* because the theory postulates that the cognitive mechanisms underpinning natural pedagogy are evolutionarily embedded within us to ensure the efficient transmission of new and relevant cultural knowledge across generations (e.g., Csibra & Gergely, 2011). Consequently, a competent teacher naturally communicates their knowledge in an ostensive fashion to a less competent learner who is naturally inclined to learn efficiently through this ostensive communication (e.g., Csibra & Gergely, 2011). For simplicity, the term “child” will be used to refer to the learner henceforth.

1.1.1.1 Ostensive communication and imitation

Ostensive communication involves three important components for knowledge transmission between a teacher and a child: ostension, reference, and relevance (Csibra & Gergely, 2006). *Ostension* involves a teacher’s communication, which serves two intentions: first, to share knowledge with the child (i.e., the informative intention), and second, to signal their intent to teach (i.e., the communicative intent). The teacher uses ostensive cues to indicate that the knowledge is meant for the child (Csibra & Gergely, 2006). These ostensive cues include eye contact, infant-directed speech, contingent responsivity, and the child’s name (Csibra, 2010; Csibra & Gergely, 2006; Gergely & Csibra, 2005). Children recognize the communicative intention because they are sensitive to this ostension (Csibra, 2010). Thus, in an imitative situation, the demonstrator's ostension signals to the children that they are the intended recipients of the message and that the communicated content is relevant and meant for them to learn (Csibra, 2010). Young infants show their sensitivity to ostensive cues through their preferential orientation to eye contact (Farroni et al., 2002), infant-directed speech (i.e., a special intonation pattern used when speaking to infants, which also is called motherese) (Cooper & Aslin, 1990; Fernald, 1992), and contingent responsivity (Masataka, 1993). While sensitivities to eye contact, infant-directed speech, and responsivity are considered innate, a child's sensitivity to their name as an ostensive cue is learned (Csibra, 2010; Csibra & Gergely, 2006; Mandel et al., 1995; Parise et al., 2010). Notably, the Natural Pedagogy Theory aligns with the Relevance Theory, which also states that communicative acts have a dual intention (Sperber & Wilson, 1995, 2002). Furthermore, both theories discuss how humans understand and make inferences about a communicator's intended meaning through ostensive inferential processes (Csibra, 2010; Sperber & Wilson, 1995, 2002).

Reference means that a teacher indicates the specific content of knowledge (Csibra & Gergely, 2006). For example, a teacher can use deictic gestures such as gazing or pointing (referring to) at a tomato (referent) while teaching the word "tomato" (knowledge content). This helps the child to understand and connect the word "tomato" to the actual object and later generalize and apply this knowledge to other situations (Csibra & Gergely, 2006). Thus, reference involves the child's use of referential signals, such as pointing, toward a referent when other ostensive cues are also present (Csibra & Gergely, 2006). *Relevance* refers to the mutual understanding between the teacher and the child that the transmission of new and relevant knowledge is happening. Moreover, the teacher must understand what the child already knows to provide new and relevant knowledge, which the child must then quickly learn (Csibra & Gergely, 2006).

To sum up, ostensive communication involves the teacher first marking to the child that teaching is going to happen by providing ostensive cues (e.g., establishing eye contact and addressing the child by name), followed by using referential signals (e.g., eye gaze or pointing) to refer to the teaching content, and then the presentation of the teaching content itself (e.g., Csibra & Gergely, 2006; Gergely & Csibra, 2005).

In a context with ostensive communication, the child is likely to take the "pedagogical stance," meaning that it is more likely to be receptive and to learn the intended content efficiently (Gergely & Csibra, 2005). Therefore, if a social partner marks these actions as relevant through ostensive communication, children may faithfully imitate even irrelevant means exactly as shown to achieve a goal rather than selectively omitting them (Brugger et al., 2007; Hoehl et al., 2019; Király et al., 2013; Nielsen, 2006; Over & Carpenter, 2012). For example, Meltzoff (1988) found in a study that most 14-month-olds used their foreheads to turn on a push-lamp after observing an adult do so ostensively, even though they could have more easily illuminated the lamp using their hands. Similarly, Király et al. (2013) demonstrated that 14-month-olds were likelier to imitate the inefficient novel means to illuminate the lamp when presented in a rich ostensive context than in a non-ostensive context where actions were observed incidentally. This faithful imitation of novel actions allows children to quickly learn relevant knowledge, even when they do not fully understand the reasons behind those actions (Csibra & Gergely, 2006).

The current thesis investigates further the role of ostensive communication in toddlers' imitation and understanding of communicative intentions. For the experimental studies (Studies 1 and 2), we targeted the 1.5-year-old age group because research suggests that at this stage, toddlers increasingly rely on the model's ostensive cues to recognize when they are being addressed and to understand that the communicated content is relevant to them (e.g., Nielsen, 2006; Southgate et al., 2009). Given that ostension highlights the relevance of demonstrated content, it is theorized that ostension facilitates toddlers' faithful imitation of all modeled behaviors, regardless of their efficiency or relevance in attaining a goal, rather than selectively imitating only the most relevant behaviors (Csibra & Gergely, 2006; Gergely & Csibra, 2005). In Study 1, we examined toddlers' selective versus faithful imitation within a rich ostensive context, where the experimenters consistently provided ostensive cues throughout the imitation test. In Study 2, we assessed faithful imitation of sub-efficient actions to investigate whether toddlers attribute communicative intent to an adult who disrupts ostensive communication with a smartphone. Accordingly, we extended the boundaries of Natural Pedagogy Theory by claiming that toddlers make rich inferences about the model's communicative intentions in a context where ostensive communication is disrupted. Lastly, Study 3 presents a literature review of empirical studies that, among other questions, also focuses on how toddlers imitate and recognize the intentions of social robots through ostensive communication. Accordingly, we elaborate on whether toddlers can generalize their human-specific adaptation for pedagogy when learning from humans to non-human social partners that provide similar ostensive cues. Each study contributes to the knowledge of how ostensive cues influence toddlers' early imitation and developmental processes through social learning.

1.1.2 Limitations of Natural Pedagogy Theory

Natural Pedagogy Theory, like other theories, has faced criticism. For example, it has been criticized for overemphasizing explicit teaching and ostensive cues while neglecting facilitative teaching and apprentice learning observed in hunter-gatherer societies (i.e., learning through observation and participation without direct instruction) (Nakao & Andrews, 2014). Additionally, critics argue that it underestimates children's active role in learning and selecting social partners to learn from, regardless of ostension (Nakao & Andrews, 2014). Furthermore, Beisert et al. (2012) criticized the theory for overestimating toddlers' cognitive abilities when the theory suggests that toddlers imitate selectively because they evaluate the rationality of the experimenter's actions. Heyes (2016) also argues that young children's sensitivity to ostension is not just pedagogical but also plays an essential role in affiliation and social bonding. Finally, other researchers suggest that young children are sensitive to ostension because these cues are more attention-grabbing and arousing than non-ostensive cues (Gredebäck et al., 2018; Szufnarowska et al., 2014).

1.1.3 Cognitive versus social motivations to imitate

In Study 1, we also present Uzgiris's (1981) theory, which posits that imitation serves both social and cognitive functions. This theory is relevant for Study 1 because it describes how developmental changes in young children's motivations might influence their imitation and thus explains why older toddlers might imitate more faithfully than younger toddlers. Specifically, younger toddlers may imitate primarily for cognitive reasons, such as acquiring new knowledge, like learning about object functions (Uzgiris, 1981). In comparison, older toddlers may be motivated by social goals, like affiliating with others (Uzgiris, 1981). Relatedly, Over and Carpenter (2012) suggest that when cognitive motivations are predominant, the child is likely only to imitate actions they believe are essential to achieve a goal. Conversely, if social motivations predominate, they may faithfully imitate all modeled actions regardless of their necessity for achieving the goal (Over & Carpenter, 2012).

1.2 Imitation

Imitation naturally occurs when interacting with others and involves reproducing an action after observing it performed by another person (Nielsen, 2009). Relatedly, researchers widely agree that imitation involves reproducing both the observed goal (i.e., copying the outcome) and the means used to achieve it (e.g., Huang & Charman, 2005; Lyons et al., 2011; Nielsen & Tomaselli, 2010). There is something uniquely human about imitation, as human children, under specific circumstances, also imitate causally irrelevant means to attain goals (Horner & Whiten, 2005; Lyons et al., 2007). In contrast, non-enculturated great apes have been found to emulate rather than imitate, which involves learning the results of actions using their own familiar means (Horner & Whiten, 2005). Relatedly, Horner and Whiten (2005) demonstrated that while human children would imitate a human experimenter's unnecessary use of a tool to retrieve a reward from a puzzle box, chimpanzees did not. Instead, chimpanzees *emulated*, using their own efficient means to retrieve the reward when the tool-use was visibly irrelevant and only using the tool when its purpose was unclear and potentially causally relevant. Imitation has cultural roots, and information has been transmitted across generations through imitation (Over & Carpenter, 2013). We consciously or unconsciously imitate simple bodily gestures to affiliate with others and to fit in with social groups (Chartrand & Bargh, 1999; Lakin & Chartrand, 2003; Lakin et al., 2003). However, for children, imitation is an especially important socio-cognitive skill that helps them to acquire new skills and to affiliate with others socially (Uzgiris, 1981). Researchers investigate children's imitation to learn about the nature of imitation itself, as well as the various forms of knowledge that the child possesses (Jones, 2009). Understanding child imitation is a complex process, with significant variations in what children imitate, from whom, why, and under what circumstances they imitate (Over & Carpenter, 2013). To assess child imitation, the researchers typically compare the production of specific target behaviors between children who have observed the demonstrated behaviors and those who have not (i.e., control condition or a baseline phase) (e.g., Barr et al., 1996). An imitation effect is established when toddlers who have seen a demonstration produce significantly more target behaviors than when toddlers have not seen any demonstration (e.g., Barr et al., 1996). Although the current thesis focuses on imitation in child development, the importance of imitation extends beyond this field. Our understanding of human imitation benefits several other research fields, such as research on animal cognition and developmental robotics (e.g., Bates & Byrne, 2010; Breazeal & Scassellati, 2002; Lungarella et al., 2003).

1.2.1 Developmental changes in imitation from infancy to toddlerhood

Children begin to imitate others early in life. During the first six months of life, they show imitative responses such as facial gestures and expressions, vocalizations, and eye, finger, and head movements (Fontaine, 1984; Kugiumutzakis, 1999). There has been a long-standing controversy and ongoing debate within developmental psychology regarding *when* imitation emerges in infants and whether it is innate or learned (e.g., for a review Davis et al., 2021; Slaughter, 2021). On the one hand, seminal studies by Meltzoff and Moore (1977; 1983) and many other studies provide evidence supporting the existence of neonatal imitation (e.g., Field et al., 1982; Heimann & Tjus, 2019; Meltzoff & Keith Moore, 1992; Nagy et al., 2007; Reissland, 1988; Soussignan et al., 2011), such as imitation of tongue protrusion and mouth opening. On the other hand, many studies have shown that newborns do not necessarily imitate (e.g., Anisfeld et al., 2001; Hayes & Watson, 1981; McKenzie & Over, 1983; Oostenbroek et al., 2016), and some researchers have argued that what has been thought of as imitative responses might instead be expressions of increased arousal to interesting stimuli (e.g., Jones, 2006).

From the age of six months, infants not only imitate bodily behaviors (e.g., facial gestures and expressions) but also start imitating behaviors involving objects due to their improved manual skills, enabling them to manipulate objects intentionally (Barr et al., 1996; Fagard & Lockman, 2010). For instance, Barr et al. (1996) demonstrated that 6-month-old infants imitated a target action sequence with a puppet when tested immediately after the demonstration, which included removing a mitten from the puppet's hand, shaking the mitten to produce sound, and then putting it back. Moreover, Fagard and Lockman (2010) demonstrated increased manual action imitation on objects when comparing the performances of 10- and 12-month-olds, such as rubbing two sponge cubes together or scribbling a line on paper. However, because neonatal and infant imitation below 12 months is not the focus of this thesis, it will not be discussed further.

The thesis focuses on toddlerhood, defining toddler age as 1 to 3. Toddlerhood is a period characterized by significant cognitive, social-emotional, perceptual, physical, and motor development (Carpenter, Nagell, et al., 1998; Kail & Cavanaugh, 2016). Additionally, toddlers' imitation abilities undergo significant changes throughout toddlerhood. For example, Barr and Hayne (2003) found age-related differences in toddlers' ability to imitate action sequences in a sample of 12-, 15-, and 18-month-olds, showing that older toddlers were likelier to imitate multi-step action sequences, whereas younger toddlers typically imitate single actions. Furthermore, research has demonstrated age-dependent changes in children's immediate and deferred imitation measures. Immediate imitation is assessing imitation immediately after demonstrating a target behavior and only requires working memory. On the other hand, deferred imitation is assessed after a delay and is a measure of declarative memory, which thus involves encoding, retaining, and conscious retrieval of the memory (Barr et al., 1996). Previous research has demonstrated that immediate (Devouche, 2004; Elsner & Aschersleben, 2003; McCabe & Uzgiris, 1983) and deferred imitation improves in the first two years of life (Barr et al., 1996; Hayne et al., 2000; Herbert et al., 2006). For example, as infants grow older, they require fewer demonstrations to remember actions for longer delays than immediately after demonstration (Barr et al., 1996). Moreover, several studies have demonstrated flexibility in toddlers' deferred imitation (i.e., memory flexibility), enabling them to generalize target actions they learned with objects in one imitative situation to another despite changes in objects used or the social context (Barnat et al., 1996; Hanna & Meltzoff, 1993; Hayne et al., 2000). For instance, Hayne et al. (2000) found that this flexibility increased when comparing 6-month-olds with toddlers aged 12 to 18 months. Another developmental change in imitation relates to children's imitation pattern (i.e., selective vs. faithful imitation), i.e., what type of actions toddlers choose to imitate in the specific imitative situation, which will be discussed in section 1.2.2.

1.2.2 Selective versus faithful imitation

In the second year of life, toddlers do not imitate everything they observe in an imitation setting mindlessly. Instead, they sometimes imitate selectively and, at other times, faithfully, potentially based on an understanding of others' intentions and goals. Selective imitation involves imitating some aspects of a modeled behavior, for instance, such as attaining a goal, and ignoring the rest of the modeled events. For example, in the study by Brugger et al. (2007), 14- to 16-month-olds observed a model opening wooden boxes using several action steps, of which the first action step was either necessary or unnecessary to open the boxes. The results showed that toddlers tended to selectively imitate the first action step when it was either physically necessary or ostensively cued (Brugger et al., 2007). However, sometimes toddlers imitate faithfully everything, including the goal and the means to achieve it (for a review, see Hoehl et al., 2019). Notably, depending on research tradition, faithful imitation is sometimes referred to as exact imitation or used by the subordinate term over-imitation. In this thesis, the term “faithful imitation” will be used for simplicity, although Study 1’s manuscript uses the term “exact imitation.” Compared with other species, human children sometimes faithfully imitate not just the observed goal but also the specific means by which a goal is achieved (Clay & Tennie, 2018; Horner & Whiten, 2005). For example, in the seminal study by Horner and Whiten (2005), preschoolers and chimpanzees observed a model demonstrate a sequence of relevant and irrelevant actions to retrieve a hidden reward from a puzzle box. The box was either transparent or opaque, making the actions’ purpose clear or unclear. Results showed that children and chimpanzees imitated the irrelevant steps with the opaque box when the reason for performing them was unclear. However, with the transparent box, when the action steps served no purpose, the chimpanzees retrieved the reward more efficiently by omitting irrelevant steps (i.e., emulation), whereas children still imitated the irrelevant steps. Horner and Whiten (2005) suggest several explanations of why children choose this in-efficient strategy to retrieve the reward, one of these being that children interpret these actions of the demonstrator as intentional. It is hypothesized that this faithful imitation has been vital for advancing cumulative cultural evolution (e.g., Tennie et al., 2009).

The pattern of selective versus faithful imitation in toddlers has been demonstrated using different types of imitation tests, such as the Novel Means Test (Gergely et al., 2002) (Herold & Akhtar, 2008), the Necessary versus Unnecessary Test (Brugger et al., 2007; Hilbrink et al., 2013), and the Functional versus Arbitrary Test (e.g., Óturai et al., 2012). A common element in these tasks is that toddlers observe a model performing actions that are rational or functionally justified in some way (e.g., necessary to attain a goal or functionally related to the object’s properties) alongside actions that are either unnecessary or arbitrary. Subsequently, the children are given the opportunity to manipulate the same object themselves.

Some studies suggest that children's selection of what to imitate varies depending upon ostensively marked relevance (Brugger et al., 2007; Southgate et al., 2009), while others focus on what is perceived as goals (Carpenter et al., 2005) or the situational constraints of the social partner demonstrating the behaviors compared to their own situation (Gergely et al., 2002). Moreover, this selection process also depends upon children's developmental stage. While infants around 12 months of age tend to imitate selectively (Hilbrink et al., 2013; Kolling et al., 2014; Óturai et al., 2018; Óturai et al., 2012; Schwier et al., 2006), research indicates that from 18 months of age, toddlers begin to imitate more faithfully in some circumstances. This means they will faithfully imitate everything modeled, including arbitrary and unnecessary actions (Nielsen, 2006; Óturai et al., 2013; Óturai et al., 2012; Tennie et al., 2006). As toddlers reach two years of age, they primarily use faithful imitation strategies (Bauer & Mandler, 1989; Call et al., 2005; Nagell et al., 1993; Nielsen, 2006; Tennie et al., 2006). This increased faithful imitation in the second year of life may be due to a more substantial influence of social context and social motivations at this age, compared to earlier stages where cognitive motivations, such as learning about the functional use of objects, appear more crucial (Nielsen & Blank, 2011; Over, 2020; Over & Carpenter, 2013; Taniguchi & Sanefuji, 2017; Uzgiris, 1981). As children grow older, their tendency to faithfully imitate others gradually increases (McGuigan et al., 2011; McGuigan & Whiten, 2009; Nielsen & Tomaselli, 2010; Yu & Kushnir, 2014). For example, McGuigan and Whiten (2009) demonstrated that 30-month-olds were likelier to imitate irrelevant actions to retrieve rewards from puzzle boxes than 23-month-olds. Furthermore, this increase in faithful imitation may persist into adulthood (McGuigan et al., 2011).

1.2.3 Understanding others' intentions

This section describes the nuanced ways in which young children develop an understanding of others' intentions. In contrast with the Natural Pedagogy Theory (Gergely & Csibra, 2005), some researchers argue that imitation requires children to understand the underlying intentions of others' actions (Tomasello et al., 1993). Understanding intentions is important to the Theory of Mind development (ToM), i.e., the ability to understand that others have agency, such as having mental states such as beliefs, desires, and intentions (Rakoczy, 2022a). Notably, while ToM is not fully developed in children before the age of four, early signs of ToM can be observed in 9-month-old infants who track others' perceptions, attribute goals to their behavior, and expect animate agents to act rationally when pursuing goals (Brooks & Meltzoff, 2002; Gergely & Csibra, 2003; Rakoczy, 2022a; Woodward, 1998). Basic ToM abilities are refined throughout toddlerhood (Rakoczy, 2022a). For instance, intentional understanding advances from recognizing the intentions behind straightforward actions, such as reaching for objects (Woodward, 1998), to understanding that someone's intentions may correspond with their current actions or situation (e.g., Meltzoff, 1995).

Researchers have used various methods to examine young children's understanding of others as intentional agents, such as investigating toddlers' attention following (e.g., following of gaze or pointing) (Behne et al., 2005; Johnson et al., 1998; Phillips et al., 2002; Tomasello et al., 2005; Woodward, 1998) and imitation behavior (Carpenter, Akhtar, et al., 1998; Gergely et al., 2002). Using imitation paradigms, researchers have investigated advanced forms of intentional understanding by examining whether children distinguish between intentional actions and failed or accidental attempts (Bellagamba & Tomasello, 1999; Carpenter, Akhtar, et al., 1998; Meltzoff, 1995). In the failed-attempt paradigm, the experimenters try but fail to perform specific actions on objects (e.g., Meltzoff, 1995). For example, a seminal study by Meltzoff (1995) investigated understanding of intentions using various test objects, such as whether 18-month-old toddlers understood an experimenter's intention to place beads into a cylinder after several failed attempts. The study found that toddlers who only observed the experimenter who was trying but failing to attain a goal, showed just as high reproduction of the intended act as those who observed a successful demonstration, indicating that they understood the experimenter's underlying intentions (Meltzoff, 1995). Several studies have replicated this finding, suggesting that children between 15 and 41 months of age understand the intentions of others' intended but unconsummated actions (Bellagamba & Tomasello, 1999; Huang et al., 2002, 2006; Johnson et al., 2001), but not 1-year-olds (Bellagamba & Tomasello, 1999). Using the accidental-attempt paradigm, Carpenter, Akhtar, et al. (1998) investigated 14- and 18-month-old toddlers' intentional understanding of an experimenter's actions with objects that were verbally marked either as accidental with "Wopps" or as intentional with "There!". The results demonstrated that toddlers in both age groups imitated intentional actions more than accidental ones, indicating an ability to discern the experimenter's intention. Some researchers argue that children's re-enactments of intended actions after observing failed attempts may not necessarily indicate intentional understanding but rather a form of stimulus enhancement or emulation learning (Huang et al., 2002). In studies on gaze following, researchers typically present children with a social partner who directs their head and eyes or points toward one of two potential targets (for a review, see Del Bianco et al., 2019). Gaze following occurs when the child, more frequently than expected by chance, shifts their gaze from the social partner's face to the target the social partner is looking or pointing at (Del Bianco et al., 2019). In this context, gaze and point following are interpreted as the child's attribution of mental states to the gazer and understanding of these behaviors as referential signals or as communicative acts (Csibra, 2003; Del Bianco et al., 2019). However, the literature notably discusses whether gaze following is merely reflexive orienting, not an expression of understanding other people's intentions (Del Bianco et al., 2019).

Ostensive communication is suggested to be essential for children to recognize others' communicative intentions, helping them establish a common ground and understand the social partner's intention to communicate something relevant (Csibra & Gergely, 2006; Gergely & Csibra, 2005; Király et al., 2013). Relatedly, Király et al. (2013) propose that when a social partner demonstrates actions in an ostensive communicative manner, children may be more likely to infer that these actions are meaningful and relevant for them to learn, even if the actions may not be the most efficient or rational way to attain a goal. Moreover, ostensive cues also facilitate children's understanding of referential intentions underlying other's gazing and pointing behaviors (Behne et al., 2005; Tomasello et al., 2007). According to Tomasello et al. (2007), ostensive cues help establish a common ground for the interaction between the child and the social partner, which is necessary for both interactional partners to focus on the relevant part of the stimulus and thus identify the target of the referential behaviors. Relatedly, several studies show that infants and toddlers find it easier to understand gaze and pointing as referential acts when the social partner communicates ostensively with either eye contact, gaze, infant-directed speech, contingent responsivity, or addresses the child by name (Behne et al., 2005; Daum et al., 2013; Gliga & Csibra, 2009; Hernik & Broesch, 2019; Johnson et al., 1998; Senju & Csibra, 2008; Tomasello et al., 2007). For instance, Daum et al. (2013) found that 12-month-old toddlers quickly directed their gaze toward the target that matched the direction of a pointing gesture when the pointing was accompanied by ostensive communicative speech, suggesting that they understood the intended referent of the pointing.

An important area of investigation is whether the attribution of intentions to an agent depends on this agent being human or having human-like features, such as having a social appearance with a face, and whether toddlers can attribute intentions to inanimate objects. On the one hand, it is argued that the ability to attribute intentions to others is human-dependent because it develops through human interactions and, therefore, only gradually can generalize to other agents (e.g., Meltzoff, 1995; Meltzoff, 2002; Tomasello, 2023). Conversely, others propose that we possess an innate inferential mechanism sensitive to specific cues, such as contingent responsivity and self-propulsion, which activates an understanding of others' intentions (e.g., Gergely & Csibra, 2003; Gergely et al., 1995; Johnson, 2000). Yet another suggestion is that infants may apply an interpretational system called the "teleological stance" which is based on the principle of rational action, which allows them to understand the actions of inanimate objects as goal-directed even without agency cues such as self-propulsion (Csibra et al., 1999). Moreover, Johnson et al. (1998) showed that 12-month-olds follow the gaze of a non-human agent as long as it either had a face or behaved contingently. Research has demonstrated that by the end of the first year, infants may attribute intentions to moving inanimate objects with and without social appearance (Csibra et al., 2003; Csibra et al., 1999; Johnson et al., 1998; Johnson et al., 2001; Kuhlmeier et al., 2003). For example, Gergely et al. (1995) demonstrated that 12-month-olds not only ascribed goals to the movements of basic geometrical shapes but also assessed the rationality of the movements in achieving the goal, suggesting that they attributed intentions to these agents. Moreover, Csibra et al. (1999) demonstrated that 9- and 12-month-olds attributed goals to inanimate objects even without any human-like agency cues. Nevertheless, social appearance can influence how likely agents are to be perceived as intentional in some situations (Johnson et al., 2001; Meltzoff, 1995). For example, Meltzoff (1995) demonstrated that 18-month-old toddlers re-enacted a human experimenter's intended but failed attempt to pull apart a dumbbell. However, they did not re-enact this when mechanical pincers mimicked the same movements, suggesting that the social appearance of the agent was relevant in the attribution of intentions. On the contrary, Johnson et al. (2001) demonstrated that 15-month-olds would re-enact an orangutan puppet's (agent with a face) intended but failed attempt to put beads inside a cup, indicating that the toddlers attributed goals to the puppet which had a social appearance. Relatedly, it is proposed that human-like appearance and behavior increase the likelihood of anthropomorphizing non-human agents, i.e., attributing mental states to them, such as intentions, beliefs, and desires (Duffy, 2003). Therefore, young children might find it easier to perceive non-human agents with social features, such as a face, as intentional, compared to simpler non-human agents without these features, like a box. Additionally, according to a review paper by Goldman and Poulin-Dubois (2024), although children's tendency to attribute lifelike qualities to non-living objects (i.e., animacy attribution) generally decreases with age, their attribution of animacy to social robots may differ from this developmental trend.

1.3 The social context and imitation

What toddlers imitate in a specific imitative situation depends on many factors, some related to the social context. In this section, I will give a general overview of several aspects of the social context that impact imitation. Firstly, I will present some aspects related to the imitation setting and then give a general review of studies on how model characteristics affect imitation behavior differently. Then, I will delve into a more detailed description of the types of social partners central to the thesis: socially available adults, distracted adults, and social robots.

1.3.1 The imitation setting

Imitation studies can be conducted in different locations or settings, such as in the child’s home, on the playground, in a kindergarten, or controlled environments such as laboratories (Mukherji & Albon, 2022). Furthermore, the children might meet the experimenters within the same physical space (e.g., in a lab or a kindergarten) or via a computer monitor. Previous studies on toddlers’ selective versus faithful imitation patterns have been conducted in laboratories (e.g., Hilbrink et al., 2013) and via video (e.g., Chudek et al., 2016; Nielsen et al., 2008; Yu & Kushnir, 2014). These demonstration formats can affect imitation behavior differently. For example, studies have found that toddlers between 1 and 3 years of age show video deficit (Anderson & Pempek, 2005) when meeting televised social partners, i.e., that their imitation learning is poorer when watching demonstrations of actions from televised social partners as compared to live in-person demonstrations (Barr & Hayne, 1999; Hayne et al., 2003; McCall et al., 1977). This poorer learning performance from videos compared to real-life settings in toddlerhood has been explained from several accounts. For example, Jing and Kirkorian (2020) suggest that videos, compared to real-life events, have fewer ostensive cues to make the learning content socially relevant, poorer visual and auditory information, and that encoding video content is more cognitively demanding for toddlers as it requires more representational competence. However, today’s toddlers, who are increasingly exposed to digital screen media, may exhibit a reduced video deficit compared to findings in earlier research. Relatedly, Sommer et al. (2023) found that 2-year-old toddlers imitated both a physically present and a televised experimenter with equal proficiency, suggesting a shift in how young children process digital interactions.

The three studies in the thesis involve different imitation settings that may affect toddlers’ imitation or understanding of the social partners’ ostensive communication (see

Table 1). More specifically, toddlers in the experimental studies (Studies 1 and 2) participated in controlled settings either in a laboratory (Study 1) or in an online setting with participation from home using a computer (Study 2). Study 3 consisted of publications that conducted studies in controlled settings or laboratory, naturalistic, or ecological settings.

1.3.2 Type of social partners and communicative intentions

Children typically communicate with different social partners, such as their caregivers, siblings, other relatives, kindergarten staff, and family pets. Numerous studies have shown that toddlers' imitation behavior is affected by characteristics related to *whom* they imitate. For instance, it is demonstrated that imitation is affected by the model's age, such as toddlers imitating adults versus peers differently (Seehagen et al., 2017; for a review see Zmyj & Seehagen, 2013). Whom a toddler chooses to imitate also depends on their motivations, such as whether they are mainly motivated to learn (i.e., cognitive motivation) or to affiliate with others (i.e., social motivation). Regarding the chosen imitation strategy (i.e., selective vs. faithful), children tend to imitate observed actions faithfully when socially motivated (Nielsen & Blank, 2011; Over & Carpenter, 2012; Slaughter et al., 2008). Moreover, research has shown that 14-month-old toddlers are likelier to imitate older, more competent individuals rather than less competent peers when the action being demonstrated is new, as opposed to familiar with nothing new to learn (Zmyj, Aschersleben, et al., 2012; Zmyj, Daum, et al., 2012). This suggests that they prefer to learn from more competent individuals when encountering new experiences (Zmyj, Aschersleben, et al., 2012; Zmyj, Daum, et al., 2012; Zmyj & Seehagen, 2013). Furthermore, the ostension or social behavior the social model provides also affects imitation. For instance, studies have shown that toddlers' imitation is facilitated when the model behaves socially (e.g., warm and friendly) before or during the imitation test compared to behaving non-socially (e.g., aloof or noncontingent) (Brugger et al., 2007; Kim et al., 2018; Nielsen, 2006; Nielsen et al., 2008). Furthermore, Southgate et al.'s study (2009) found that 18-month-old toddlers are more likely to imitate actions that are indicated as important by ostensive cues, as opposed to actions that are simply cognitively relevant to learn (i.e., all actions are new and relevant for the child to learn). Next, toddlers sometimes imitate social partners differently based on familiarity (Learmonth et al., 2005; Shimpi et al., 2013). For example, Learmonth et al. (2005) showed that toddlers aged 12-, 15, and 18 months did not imitate when the experimenter in the test phase was someone different from the demonstration phase. However, in some contexts, toddlers imitate unfamiliar and familiar social partners equally well (Devouche, 2004; McCabe & Uzgiris, 1983; Shimpi et al., 2013). Moreover, toddlers' imitation can also be affected by the social partner's reliability (Poulin-Dubois et al., 2011; Stenberg, 2019; Zmyj et al., 2010) and in- versus outgroup membership (Buttelmann et al., 2013; Howard et al., 2015).

This thesis focuses on three types of social partners potentially affecting toddlers' imitation and their interpretation of the model's communicative intent in the imitative or social learning situation. First, familiar versus unfamiliar social partners who socially engage with toddlers in an ostensive-communicative fashion (Study 1). Second, social partners who disrupt ostensive communication with toddlers in favor of smartphones (Study 2). Third, robotic social partners developed for human-robot interactions that are programmed to provide ostensive cues comparable to humans (Study 3).

1.3.2.1 Ostensive social partners and toddlers' imitation

Illustrator: Siri Jachlin

Ostensive social partners in child-adult interactions actively communicate using ostensive cues, such as eye contact, contingent responsivity, infant-directed speech, and the child's name. Relatedly, as suggested by Natural Pedagogy Theory, children have an innate predisposition and receptiveness toward ostensive cues of others, which signal that the social partner intends to teach them something new and relevant (Csibra & Gergely, 2011; Gergely & Csibra, 2005). In an imitation setting, this sensitivity to ostensive cues enables children to focus on what is essential to learn and guide their selection of which actions to imitate (Gergely, 2003). Research indicates that such ostensive interactions facilitate children's imitation (Brugger et al., 2007; Király et al., 2013; Matheson et al., 2013; Nielsen, 2006; Sage & Baldwin, 2011; Shneidman et al., 2014). For example, Brugger et al. (2007) found that 14- to 16-month-old toddlers were likelier to imitate an action with a wooden box when the experimenter socially cued it by directing eye gaze, speech, and posture towards the child before demonstrating the action. Moreover, toddlers aged 15 to 18 months are more inclined to faithfully imitate the actions of a social partner who uses these ostensive cues compared to observing a social partner demonstrating the actions without the ostensive communication (Király et al., 2013; Matheson et al., 2013; Nielsen, 2006; Sage & Baldwin, 2011; Shneidman et al., 2014). Furthermore, research indicates that toddlers' fidelity to faithful imitation is age-dependent and increases during the second year of life (Hilbrink et al., 2013; Óturai et al., 2018). At least two factors may explain the increased faithful imitation in the second year of life. First, older toddlers may be more adapted to recognizing ostensively communicated actions as intentional or purposeful (Gergely, 2003). Second, they may be more interested in affiliating with their social partners than when they were younger (Hilbrink et al., 2013; Uzgiris, 1981). The exact timing when children shift from selectively imitating object functions to faithfully imitating novel actions is still unclear. Study 1 of the thesis investigates whether this developmental transition occurs in 18-month-old toddlers in an ostensive social context, aiming to clarify whether this shift is stable and consistent in this age group.

1.3.2.2 Distracted social partners and ambiguous communicative intent

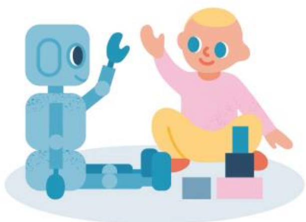
Illustrator: Siri Jachlin

The caregiver's responsiveness and social availability are crucial for children to form attachments and use their caregivers as a secure base for exploring and regulating emotions (Bowlby, 1988). However, building communicative competence also involves recognizing that social interactions are imperfect and that social partners can sometimes be distracted and temporarily unavailable. In the classical still-face experiments, Tronick et al. (1978) studied how infants respond to brief disruptions in caregiver-infant interactions. Notably, most infants quickly recovered when caregivers resumed normal responsive behaviors after a brief period of unresponsiveness. This may suggest that "social damages" can be repaired when the caregiver re-engages after unresponsive episodes, helping children learn to feel secure even after communication disruptions.

In today's social interactions, a common disruption is smartphone use during face-to-face interactions across all age groups, including in adult-child interactions within families (Abeele et al., 2019; Al-Saggaf & MacCulloch, 2018; Bury et al., 2020; Chotpitayasunondh & Douglas, 2016; Hiniker et al., 2015; Lemish et al., 2019; Mangan et al., 2018; Radesky et al., 2014; Saltzman et al., 2019; Vanden Abeele et al., 2020; Wolfers et al., 2020). This disruption is referred to as phubbing and is defined as "the act of snubbing someone in a social setting by concentrating on one's phone instead of talking to the person directly" (Chotpitayasunondh & Douglas, 2016, p. 9). Phubbing introduces new challenges for young children, including discerning whether a phone-using social partner intends to communicate with them or someone on the phone. Although the phone-user may not intend to end communication with the child, their inconsistent delivery of ostensive behaviors during smartphone use, such as disrupted eye contact and less contingent responses, can violate children's expectations for ostensive communication (Chotpitayasunondh & Douglas, 2018; Mantere, 2022; McDaniel & Wesselmann, 2021). Relatedly, research shows that caregivers' communication is less contingent, sensitive, and responsive to children's communicative bids when using smartphones (Elias et al., 2020; Kelly & Ocular, 2020; Vanden Abeele et al., 2020; Wolfers et al., 2020). Moreover, research shows that children respond to caregivers' phubbing with increased negative affect (Elias et al., 2020; Radesky et al., 2014). Given that phubbing behavior disrupts ostensive communication and children are sensitive to such disruptions (Hains & Muir, 1996; Papoušek, 2007; Yamamoto et al., 2019), they may infer smartphone use as incompatible with ostension and infer that this behavior signals a lack of intent to communicate.

Despite the prevalence of phubbing in child-caregiver interactions (Hiniker et al., 2015; Lemish et al., 2019; Mangan et al., 2018; Radesky et al., 2014; Vanden Abeele et al., 2020), it is still poorly understood whether toddlers recognize smartphone use in face-to-face interactions as incompatible with ostensive communication. Previous research has used non-contingent, aloof, or distracted social partners to study its impact on toddler learning, revealing that social responsiveness influences imitation behavior (Konrad et al., 2021; Nielsen, 2006; Nielsen et al., 2008; Reed et al., 2017). Toddlers aged 1.5 and 2 years old are less likely to faithfully imitate actions from less responsive social partners, suggesting their imitation might be socially motivated (Nielsen, 2006; Nielsen et al., 2008). However, the communicative attributions of toddlers to social partners who disrupt ostensive face-to-face communication with smartphones have not yet been examined. Study 2 of the thesis addresses this knowledge gap, using imitation methods to investigate toddlers' early inferences about communicative intention in face-to-face communication disrupted by a social partner's smartphone use.

1.3.2.3 Non-human agents and social robots



Illustrator: Siri Jachlin

It is suggested that children are innately adapted to communication with humans through their sensitivity to ostensive cues (e.g., Csibra, 2010). However, not all social partners that children encounter are humans. Young children also interact with pets and engage in imagery play with toys, such as stuffed animals and dolls. They also encounter various non-human agents in imitation research, including puppets and mechanical pincers (Slaughter & Corbett, 2007; Vaporova & Zmyj, 2020). Previous research has shown that toddlers imitate these non-human agents, although the extent of imitation may be influenced by the humanness of the agents' appearances (Slaughter & Corbett, 2007; Slaughter et al., 2008). For example, while 1.5- and 2-year-olds imitated actions of mechanical pincers, their imitation was less frequent than that of humans and disembodied human hands (Slaughter & Corbett, 2007; Slaughter et al., 2008). Additionally, 1-year-olds who imitated both human and disembodied human hands equally did not imitate mechanical pincers performing the same actions (Slaughter & Corbett, 2007). This suggests that toddlers may find it more challenging to learn from agents that lack a human-like appearance.

Some newer forms of non-human agents increasingly present in children's everyday lives are technology-based, such as conversational artificial intelligence agents (e.g., ChatGPT, Google Assistant, and Alexa) (Xu, 2023) and social robots, which are robots specifically developed to interact with humans (e.g., Bartneck & Forlizzi, 2004; Breazeal, 2004). Given that Study 3 of the thesis is about social robots, I will discuss this topic in more detail. Due to the growing presence of social robots, researchers are interested in exploring several aspects of their influence on children. For example, they investigate whether children of various ages, including toddlers, perceive them as social partners (Federico Manzi et al., 2020; Peca et al., 2016), their potential in learning environments (for a review, see Belpaeme et al., 2018; or, see, van den Berghe et al., 2019), and their ability to support children's health (e.g., Kabacinska et al., 2021; Lewis et al., 2021).

There is no uniform definition of social robots (Sarrica et al., 2020). However, a proposed definition is: “A social robot is an autonomous or semi-autonomous robot that interacts and communicates with humans by following the behavioral norms expected by the people with whom the robot is intended to interact” (Bartneck & Forlizzi, 2004, p. 592). A social robot’s design varies depending on the specific robot, with its autonomy, appearance, social behaviors, and purpose or application area (Baraka et al., 2020; Fong et al., 2003). The robot’s autonomy can range from fully autonomous, where they act independently based on their programming, to partially controlled by a person in real-time (Baraka et al., 2020; Bartneck & Forlizzi, 2004). Many social robots have a social appearance that is either human- or animal-like (i.e., biologically inspired), with a body and a head with facial features such as eyes, nose, and mouth (Baraka et al., 2020; Fong et al., 2003). Notably, robots that lack a social appearance (e.g., functional robots) can still be considered social due to their social behaviors (Baraka et al., 2020; Fong et al., 2003). However, this thesis focuses on robots with a social appearance, which are better suited for human communication and likely to elicit similar communicative expectations as interactions between humans (Adams et al., 2000; Baraka et al., 2020; Breazeal, 2004; Fong et al., 2003). Although robots are not conscious, they can be programmed to exhibit various social behaviors, like how humans communicate and signal communicative intentions to one another (Adams et al., 2000; Breazeal, 2003; Fong et al., 2003). For example, they can communicate verbally or non-verbally through gestures such as pointing, shifting gaze, making eye contact, or responding contingently in interactions (Baraka et al., 2020; Breazeal & Scassellati, 1999; Fong et al., 2003; Onyeulo & Gandhi, 2020). Because social robots with human-centered designs look and behave in familiar ways, adults and older children tend to anthropomorphize them (Barco et al., 2020; Krach et al., 2008; F. Manzi, Giulia Peretti, et al., 2020), attributing to them human qualities and actions such as intentions, beliefs, feelings, and desires (Breazeal, 2003;

Duffy, 2003; Fong et al., 2003). Since toddlers are naturally predisposed to recognize ostensive communicative signals and infer intentions from human communication (Csibra, 2010), they may extend this ability to robots that mimic such human-like ostensive communication. Moreover, young infants prefer face-like stimuli over other stimuli (Batki et al., 2000; Farroni et al., 2002; Farroni et al., 2005; Frank et al., 2009; Goren et al., 1975; Johnson et al., 1991). Consequently, the human-like appearance of social robots may make them more familiar and attractive to young children.

Social robots might be used as tools in developmental research if young children can perceive them as social partners and understand their ostensive communication. As Sommer, Redshaw, et al. (2021) suggest, social robots may be more effective as experimenters in imitation studies than simple non-human agents such as puppets and mechanical pincers due to their high degree of human likeness. However, our understanding of toddlers' imitation, intentional attributions to, and perceptions of these robots remains limited. Relatedly, developmental researchers have addressed a need to examine whether social robots can facilitate learning in young children (e.g., Sommer, Redshaw, et al., 2021). In Study 3 of the thesis, we address this knowledge gap by reviewing the existing literature on how toddlers imitate, learn from, and understand the communicative intentions of social robots in research settings.

1.4 Social-emotional development

Early developmental research has often separately measured specific social and cognitive abilities. However, this does not imply that different abilities are not interconnected. One understudied association is between children's imitation and their social-emotional development. The Social-Emotional Foundations for Early Learning (2010) defines social-emotional competence in young children as their ability to form secure relationships, appropriately handle their emotions, and engage in learning and exploring within their social and cultural surroundings. As children develop their social and emotional understanding, they better interpret the social behavior and underlying intentions of people around them. Some studies indicate that there might be an association between children's imitation or social learning and their social-emotional development (Heimann, 2022; Hilbrink, 2011; Kolling & Knopf, 2015; Rawlings et al., 2017). For instance, some studies have found associations between children's social learning and traits such as extraversion and temperament (Heimann, 2022; Hilbrink, 2011; Hilbrink et al., 2013; Rawlings et al., 2017). For example, Hilbrink et al. (2013) found that 12 and 15-month-old toddlers with higher surgency levels – a temperament trait involving high levels of social engagement and considered a precursor of extraversion – were more likely to faithfully imitate than those with lower levels. Furthermore, others have found an association between toddlers' imitation and social development, social autonomy, and peer interactions (Kolling & Knopf, 2015).

2 Research aims and hypotheses

The overarching aim of the present thesis was to increase knowledge about how toddlers imitate different social partners and comprehend communicative intentions when ostensive cues are present or lacking (e.g., disrupted). The main research question is: *"How do the social partner type and various forms of ostension affect imitation and understanding of communicative intentions in toddlers?"*.

In Study 1, we examined toddlers' imitation patterns of selective vs. faithful imitation in a traditional ostensive communicative interaction, where the experimenter communicated in an ostensive manner throughout the imitation test. Although we did not systematically manipulate ostension in this study, we were interested in whether the toddlers had reached a developmental stage in which their imitation patterns are more influenced by ostensive communication. In Study 2, we specifically manipulated the social interaction by exposing the toddlers to an experimenter who first communicated ostensively and then disrupted this communication either by non-ostensive smartphone use or wristwatch fiddling to assess its impact on toddlers' attribution of communicative intent. Lastly, in Study 3, we reviewed the literature on toddlers' imitation of and responses to various ostensive cues displayed by social robots. The main research question implies investigations and descriptions of how toddlers learn and interpret ostensive and non-ostensive cues with different social partners. We combined experimental research and a scoping literature review study to gain a more comprehensive understanding. Specifically, our objectives and hypotheses were:

1. To investigate whether there is a developmental shift from selective towards faithful imitation in the second year of life when assessed in a traditional social context with ostensive-communicative teaching. Such a developmental shift involves toddlers not

only considering instrumental aspects of an imitative situation but also the social partners' communicative intentions to teach them something new and relevant. To better understand this developmental shift, we tested three main hypotheses. We hypothesized that 1.5-year-old toddlers' selective versus faithful imitation would be consistent across different imitation tests (H1), stable across a short-term design (H2), and related to toddlers' social-emotional development (H3). Additionally, we tested an explorative hypothesis about whether short-term familiarity with the experimenter impacted this imitation pattern (H4).

2. To examine toddlers' representation of communicative intention when a social partner disrupts ostensive communication with smartphone use. Toddlers' expectations of ostensive communication (i.e., ostension, reference, and relevance) may be violated when social partners use smartphones during face-to-face interactions due to: a) lack of or inconsistent delivery of ostensive cues, such as breaks in eye contact and slower responses; b) ambiguity regarding whom the social partner is communicating with; and c) delays in the turn-taking. We hypothesized that 1.5-year-old toddlers recognize smartphone use in face-to-face interactions as incompatible with ostension. Consequently, we expected them to be less likely to attribute communicative intention to a social partner who disrupts ostensive communication with smartphone use compared to a matched control where the ostensive communication was disrupted by wristwatch fiddling. Toddlers are suggested to imitate sub-efficient means faithfully when demonstrated ostensively due to their sensitivity to ostension, which marks these means as new and relevant to learn (Csibra & Gergely, 2006; Gergely & Csibra, 2005; Király et al., 2013; Southgate et al., 2009). Following this, we predicted that toddlers would imitate novel sub-efficient means less faithfully when the social

partner disrupted ostensive communication with a smartphone, compared to toddlers in the matched control condition.

3. To evaluate social robots' potential in developmental research (e.g., imitation studies). When using social robots as research tools, the premise is that toddlers identify them as social partners and understand their ostensive communication. Therefore, we aimed to review the empirical research on toddlers' social learning and imitation of social robots, as well as their understanding of social robots' ostensive communication. More specifically, we also aimed to identify which features in robots, either in appearance or behavior, which are necessary to be present for toddlers to recognize them as social partners and to understand their communicative intentions. Notably, the scoping review itself followed a broader approach targeting all studies on how social robots have been used to study social and cognitive concepts in infants and toddlers. Accordingly, the scoping review itself was guided by three broader research questions: 1) to summarize and disseminate the current state of knowledge in using social robots as a research tool to study social and cognitive development in infants and toddlers; 2) to identify what the primary research focuses and findings are in this research literature; 3) to identify what the authors report as challenges and gaps of knowledge when using social robots in research. By asking these broad questions, the aim was to provide a broad foundational overview to inform the thesis's more targeted questions related to toddlers' imitation and understanding of social robots' ostensive communication.

3 Methods

We chose a multimethod approach to investigate how social partner type and the role of ostension influence toddlers' social learning, including imitation, and their understanding of communicative intentions. This included two experimental studies (Studies 1 and 2) and a scoping review study (Study 3).

3.1 Participants

An overview of the samples in the three studies is presented in Table 2. This thesis focuses on toddlerhood, i.e., children between 12 and 35 months, just shy of three years. In the two experimental studies, the participants were approximately 1.5 years old, specifically 18 months ± 2 weeks in Study 1, and between 17 months to 19 months in Study 2. We chose the 1.5-year-old period for our experimental studies because previous research (e.g., Nielsen, 2006; Southgate et al., 2009) indicates that toddlers' imitation is increasingly affected by the social context at this age. Additionally, this limited age range was chosen to control for potential age effects that could interfere with experimental manipulations. For Study 3, we decided on a broader age range to provide a fuller understanding of social learning and the role of ostensive cues with different types of non-human social partners in toddlerhood and not just restricted to the 1.5-year period. The participants in Study 3 were between 2 to 35 months of age. The neonatal period (0 to 2 months) was not included due to distinct developmental differences compared to infants and toddlers. Although the scope of the present thesis is the toddlerhood period, we included infants aged 2 to 12 months in Study 3 to better understand the developmental trajectory of young children's understanding of robots.

All toddlers in the two experimental studies were typically developing, born after ≥ 37 weeks of gestation without complications, and had a minimum birth weight of 2500 grams. In Study 3, we included only publications that focused on typically developing children. All participating parents and toddlers in the two experimental studies (Study 1 and 2) lived in Norway. The participants in Study 1 participated in our university laboratory in Tromsø, a Norwegian university town. Whereas the participants in Study 2 were from all over Norway and participated digitally on Zoom. Because the experimental studies were conducted in Norwegian, the children were required to understand Norwegian. For Study 3, we included empirical publications published in English regardless of geographical location. The geographical locations of these publications are detailed in section 4.3.

3.2 Recruitment and data collection for Studies 1 and 2

We distributed information flyers and posters to recruit participants for our two experimental studies. We advertised through social media channels (e.g., Facebook and Instagram), kindergartens, health stations, and libraries. Additionally, we advertised through media coverage on local television news, magazines, newspapers, and radio interviews both locally and nationally. For Study 1, we advertised about the study primarily in our local community, while for Study 2, all over Norway. We translated our information material into English, enabling parents who did not speak Norwegian to participate with their children. However, all children of non-Norwegian-speaking parents were required to understand the Norwegian language and to be regularly exposed to it, such as in kindergarten or elsewhere. Toddlers in both experimental studies received a small gift and a certificate. Parents in Study 1 were also compensated with a gift card worth 150 NOK to cover their travel expenses.

3.2.1 Data collection for Study 1

For Study 1, we piloted *N* = 22 participants and conducted two experiments. In Experiment 1 (E1), the total sample size was *N* = 52 toddlers. Three participants were excluded because of fussiness (*n* = 2) and lack of rapport with the experimenter (*n* = 1). The final sample size of E1 was *N* = 49.

In Experiment 2 (E2), the total sample size was *N* = 69. Three participants were excluded from all analyses (e.g., from both test days) due to experimenter error (*n* = 1), lack of rapport with the experimenter (*n* = 1), and not meeting the birthweight criteria (1). Of the remaining 66 toddlers, *N* = 57 had valid data for both appointments. Some toddlers had only valid data for one appointment but not both. Nine participants were excluded from one of the two test appointments because of experimenter error (*n* = 2), invalid data (*n* = 6), and illness (*n* = 1). Ultimately, in E2, the final sample size was *N* = 63 toddlers at the first lab appointment, and *N* = 60 had valid data at the second.

3.2.2 Data collection for Study 2

Prior to the main data collection, Study 2 involved a pilot with *N* = 27 participants. Both the piloting and the main data collection of Study 2 were commenced during the COVID-19 lockdown. Study 2 comprised two experiments. In E1, a total of *N* = 64 toddlers participated. Of these, 16 toddlers were excluded for the following reasons: not manipulating the objects (*n* = 8), major procedural disruptions such as prolonged crying (*n* = 3), or parents interfering with the procedure (*n* = 5). The final sample size was *N* = 48 in E1.

In E2, a total of *N* = 27 toddlers participated. In the baseline condition of E2, three participants were excluded due to parental interference (*n* = 1), incorrect test objects (*n* = 1), and failure to complete the baseline phase along with no object manipulation (*n* = 1). In the no-disruption condition, five participants were excluded due to technical error (*n* = 1), parental interference (n = 1), or not completing the test phase (n = 3). The final sample sizes in E2 were N = 24 in the baseline condition and N = 22 in the no-disruption condition. N = 21 toddlers had valid data in both conditions of E2.

Table 2

Overview of the samples in Studies 1-3

Study	Age	*N*	Location	Social context	Time of data collection
Experimental studies					
Study 1	18 months ± 2 weeks		Tromsø	Human social partner, ostensive	01-16-2018 to 09-21-2019
Pilot		22			08-27-2017 to 12-15-2017
Experiment 1		49			01-16-2018 to 09-15-2019
Experiment 2				Familiar or unfamiliar	07-31-2018 to 09-21-2019
1st test day		63			
2nd test day		60			
Study 2	17-19 months		Norway	Human social partner, Disrupted vs. non-disrupted ostensive communication	04-07-2021 to 11-05.2022
Pilot		27			08-10-2020 to 08-02-2021
Experiment 1		48		Disrupted ostension	04-07-2021 to 11-09-2021
Experiment 2					08-23-2022 to 11-05-2022
Baseline		24			
No-disruption		21		Non-disrupted ostension	
Scoping review study					
Study 3	2-35 months	29 studies	Australia, Canada, Italy, Japan, Romania, Taiwan [a], United Kingdom & United States	Various social robots, ostensive & non-ostensive	Databases were searched on May 29, 2023. The included studies were published between 1991-2023
Relevant to thesis	12-35 months	20 studies			

Note. *N* = Number of participants included in the final analyses. [a] Taiwan was not represented in the *n* = 20 studies relevant to the thesis

3.3 Measures for Studies 1 and 2

In Study 1 and 2, we collected data on toddlers' imitation behavior using different imitation tests and demographic information. We collected the imitation data in our university laboratory for Study 1 and through the online communication platform Zoom for Study 2. Parents self-reported all demographic information during an informational meeting held prior to the imitation tests. Additionally, in Study 1, we collected parental reports of toddlers' socio-emotional development.

3.3.1 Demographic information

Inclusion criteria: We collected demographic information by interviewing the parents to ensure that toddlers fulfilled the inclusion criteria to participate in Studies 1 and 2, i.e., that they were typically developing, understood Norwegian, and were within the target age of the study. Firstly, to be regarded as typically developing, the toddlers must have been born at least 37 weeks into gestation, weigh a minimum of 2500 grams at birth, and not have or be diagnosed with any motor, sensory, neurological, or developmental impairments that the parents know about. Thus, we collected information about the number of gestational weeks and birth weight and asked about developmental impairments. Secondly, we asked the parents about their children's Norwegian understanding (e.g., regularly exposed to Norwegian home and/or in kindergarten) and whether they would understand the experimenter(s) who spoke Norwegian. To ensure that the toddlers were within the target age, we collected information about birth dates and scheduled appointments within the period the child was at the correct age to participate. Additionally, we calculated some central tendency measures such as the mean, standard deviation, and range of the sample's age in both studies. Furthermore, we collected information about the toddlers' gender, which was used to describe our sample. See Table 3 for descriptive information about the samples in the two experimental studies.

Table 3

Descriptive information about the samples in Studies 1-2

Study	*N*	Gender (girls)	Age (in days)		
			M	*SD*	range
Study 1					
E1	49	26	548.22	8.28	532-562
E2					
T1	63	27	543.13	7.49	531-561
T2	60	28	551.48	7.53	535-563
Study 2					
E1	48	23	546.98	18.58	519-578
E2					
Baseline	24	14	548.21	19.18	518-577
No-disruption	22	12	547.91	18.72	518-577

Note. E1 = Experiment 1; E2 = Experiment 2; T1 = First test appointment; T2: Second test appointment

3.3.2 Social-emotional development for Study 1

The Social-Emotional Scale is a subtest of the Bayley Scales of Infant and Toddlers Development 3ed (Bayley, 2006) that measures emotional milestones in children from birth to 42 months. In Study 1, we assessed toddlers' socio-emotional development by having parents to complete stages 1 to 5b (28 items) of the Social-Emotional Scale. We used the validated English version of the scale (Bayley, 2006; Breinbauer et al., 2010). Parents were encouraged to inquire about any unfamiliar English terms with the experimenter. Although the toddlers in Study 1 were 18-month-old, the parents answered items from stages 5a and 5b about skills in using symbols to convey intentions or feelings (stage 5a) and to express more than basic needs (stage 5b). Stages 5a and 5b are relevant for toddlers aged between 19 to 30 months (about two and a half years) of age. Our purpose with this was to capture potential individual differences in social-emotional development. The parents were asked to answer how frequently the child displayed a specific behavior on a scale from 0 to 5: 0 = can' tell; 1 = none of the time; 2 = some of the time; 3 = half of the time; 4 = most of the time; and 5 = all of the time.

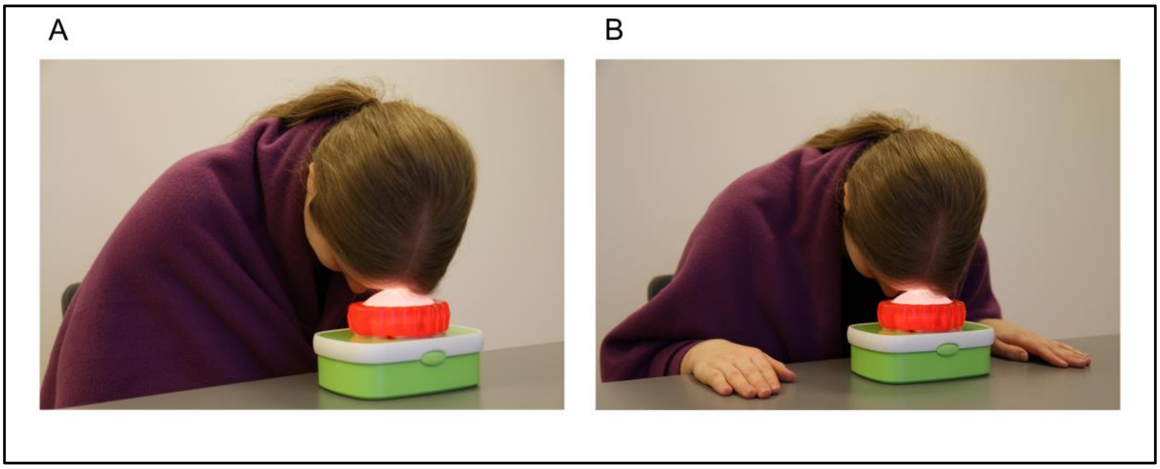
3.3.3 Imitation behavior

In both experimental studies, we measured toddlers' imitation of target actions with objects. In Study 1, we evaluated toddlers' imitation pattern, specifically whether they chose to imitate selectively or faithfully in three different imitation tests: a Novel Means Test, a Necessary versus Unnecessary Test, and a Functional versus Arbitrary Test. Additionally, we collected data on toddlers' overall imitation, i.e., imitation of all sorts of target actions. In Study 2, we assessed toddlers' faithful imitation of sub-efficient novel means actions and imitation of a goal-outcome in the Sock Ball Task.

Novel Means Test (NM-test) in Study 1: We used two versions of the NM-test: Version A with a push lamp (adapted from Meltzoff, 1988) and Version B with a desk bell (adapted from Herold & Akhtar, 2008). In the NM-test, the model demonstrates a novel action to attain a goal. In Version A, the model performed the novel action of using her forehead to illuminate the push lamp (see Figure 1), whereas in Version B, she rang the bell with her elbow. The model varied her hand positions, either free or occupied holding a blanket, while performing the novel actions (adapted from Gergely et al., 2002; see Figure 2 for an illustration).

Figure 1

Modeling of the novel action with the push lamp in the Novel Means Task



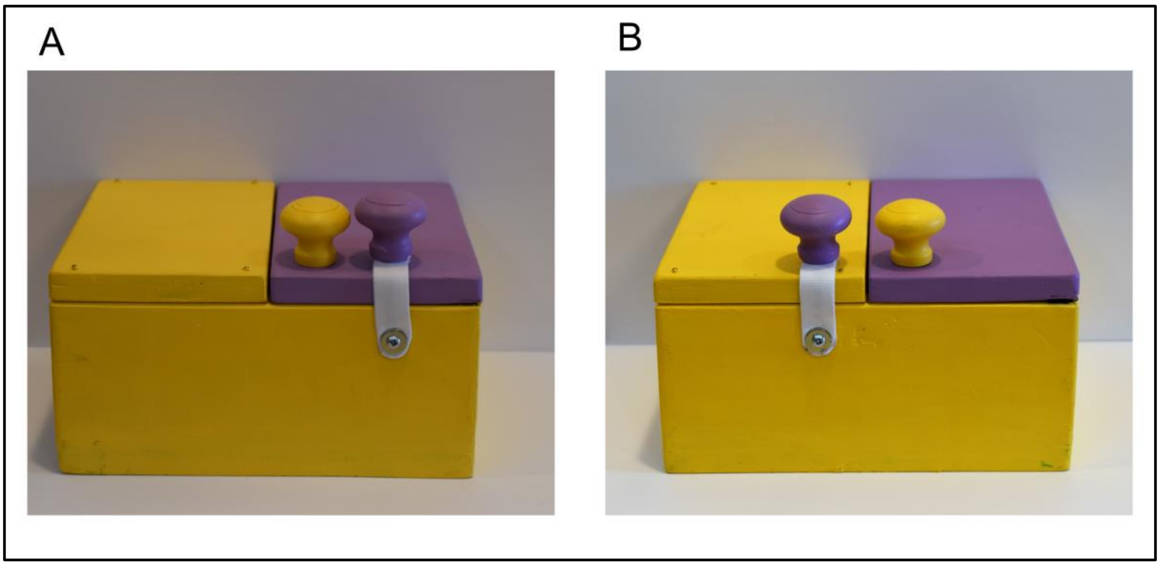
Note. (A) The model performs the novel action with hands occupied. (B) The model performs the novel action with hands free.

When the model performs the novel action when her hands are free instead of just using her hands, it might induce toddlers to think that the novel action must have a hidden advantage over the more familiar method of using their hands. We measured whether children selectively only imitated the goal in the NM test, i.e., ringing the bell or illuminating the lamp with their hands. Alternatively, whether they imitated faithfully also the modeled novel means to attain the goals.

Necessary versus Unnecessary Test (N/UN-test) in Study 1: We utilized two versions of the N/UN-test (adapted from Brugger et al., 2007; Yu & Kushnir, 2014). In Version A, the test objects were wooden boxes, and in Version B, they were wooden birdhouses. In each test version, children observed a four-step sequence to open the box or the birdhouse to retrieve a toy. We varied whether the first step (i.e., to open a latch) was necessary or unnecessary to attain the goal (i.e., opening the container) (adapted from Hilbrink et al., 1013). For an illustration of the necessary and unnecessary test objects in Version A of the N/UN-test, see Figure 2.

Figure 2

Illustration of the test objects of the Necessary vs. Unnecessary Test (Version A with boxes)



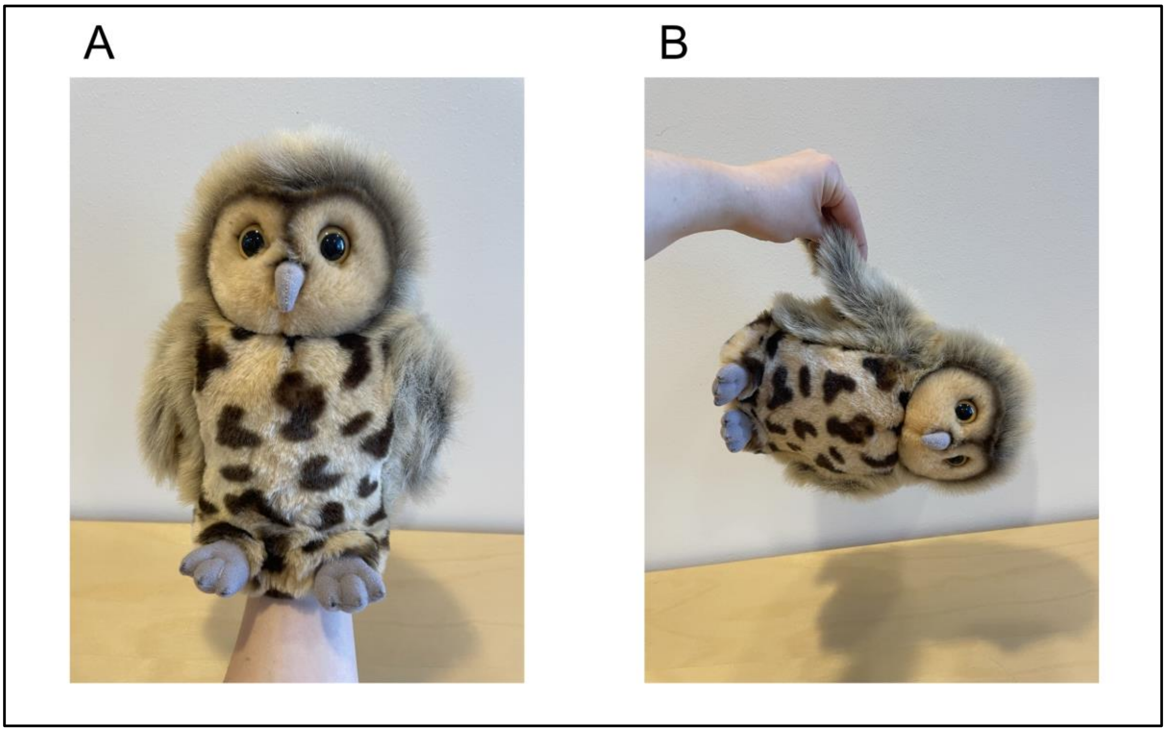
Note. (A) Opening the latch to open the box is necessary. (B) Opening the latch to open the box is unnecessary.

The selective imitation measure in this test was the imitation of only necessary actions to attain the goal, i.e., opening the latch when necessary (necessary condition) but omitting to open the latch when it is unnecessary (unnecessary condition). We also included an alternative measure of selective imitation (adapted from Brugger et al., 2007), where the child was required to imitate the first two action steps in the demonstrated order in the necessary condition but not in the unnecessary condition. When toddlers do not imitate the unnecessary step, this behavior is regarded as toddlers' recognition of the relationship between an object's physical properties and functional use. Faithful imitation involved imitating all the actions, regardless of their necessity.

Functional versus Arbitrary Test in Study 1: We developed an F/A-test for Study 1, which consisted of two versions, each with six test objects. The model performed both a functional and an arbitrary action with each test object (adapted from Kolling et al., 2014; Óturai et al., 2013; Óturai et al., 2012). A functional action is more closely tied to the object's properties. For instance, using a hand puppet involves placing your hand inside it to use it as a hand puppet (see Figure 3). On the contrary, arbitrarily swinging the hand puppet can be done with other objects (see Figure 3). In the F/A Test, selective imitation involved imitating only functional actions, while faithful imitation involved imitating both functional and arbitrary actions.

Figure 3

Illustration of a functional and an arbitrary action with a hand puppet in the Functional vs. Arbitrary Test



Note. (A) The functional action of using it as a hand puppet. (B) The arbitrary action of swinging the puppet by its wing.

The Sock Ball Task for Study 2: The Sock Ball Task is an online imitation test we developed for Study 2, which measures faithful imitation of sub-efficient novel means to attain a goal. The test objects consist of two A5 sheets of wrinkled paper and a sock ball. The sub-efficient means actions are to cover the sock ball with one of the papers, grasp the sock ball through the paper, move the paper-wrapped sock ball, and then drop the sock ball above the other paper. The goal-outcome of this target action sequence is that the sock ball lies on the other paper. Please see Figure 4, a picture of the test objects, and Figure 5, for a simplified graphical representation of the target action sequence and the goal-outcome.

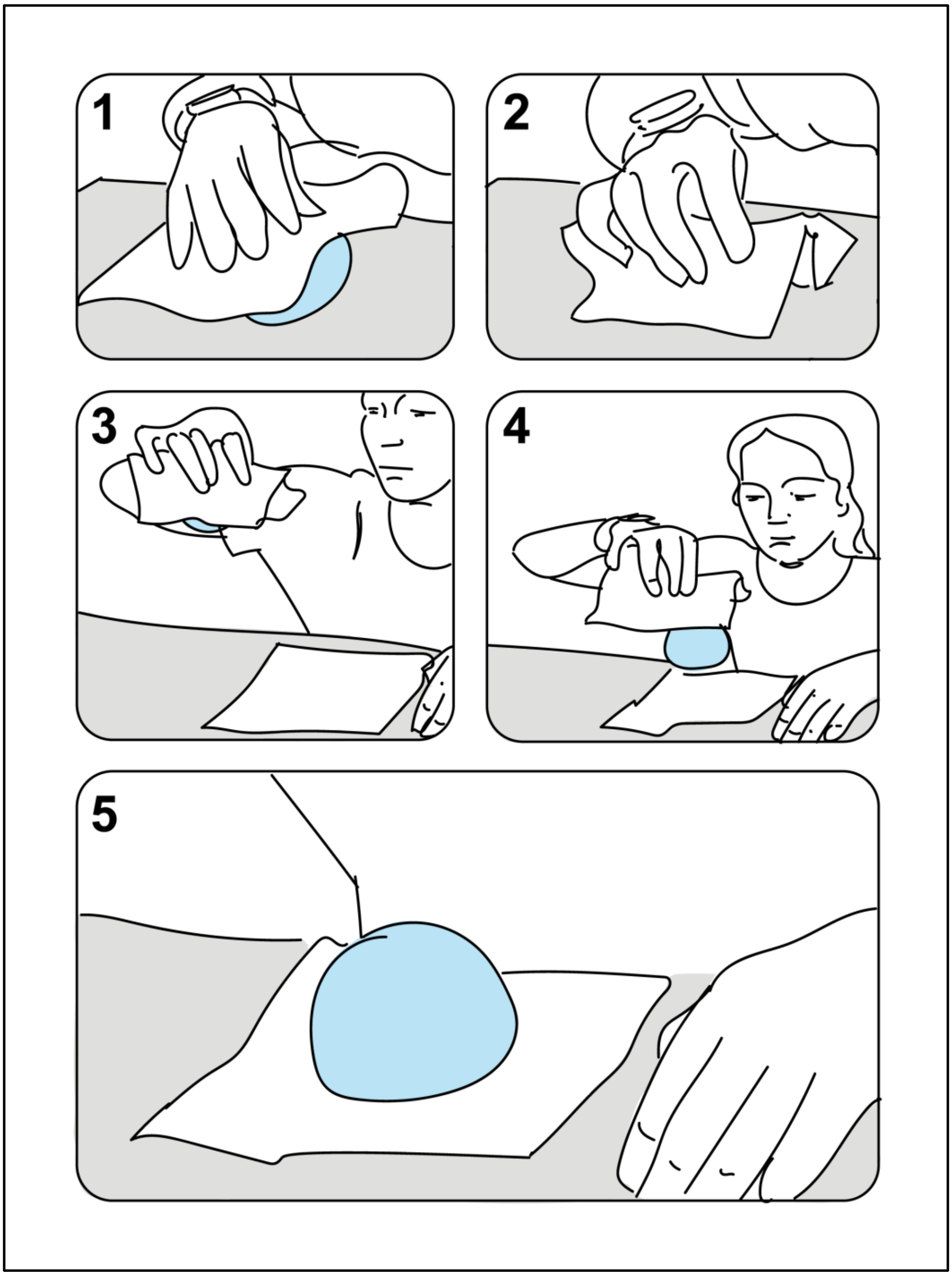
Figure 4

Illustration of the test objects in the Sock Ball Task

Note. Two A5 sheets of wrinkled white paper and a green ball made of a pair of socks.

Figure 5

A representation of the target action sequence in the Sock Ball Task for Study 2



Note. Images 1 to 4 display the four sub-efficient novel means actions: 1) cover, 2) grasp, 3) move, and 4) drop. Image 5 shows the goal-outcome ball on paper. This figure is a schematic illustration of the target actions in the Sock Ball Task. Images of the actual stimuli are presented in Study 2.

3.3.4 Immediate and deferred imitation

In Study 1, we used both immediate and deferred imitation measures. We measured toddlers' immediate imitation in the NM-test and the N/UN-test, whereas deferred imitation was measured after a 30-minute delay in the F/A-test. In Study 2, all imitation measures were collected using an immediate procedure.

3.4 Experimental designs and procedures for Studies 1 and 2

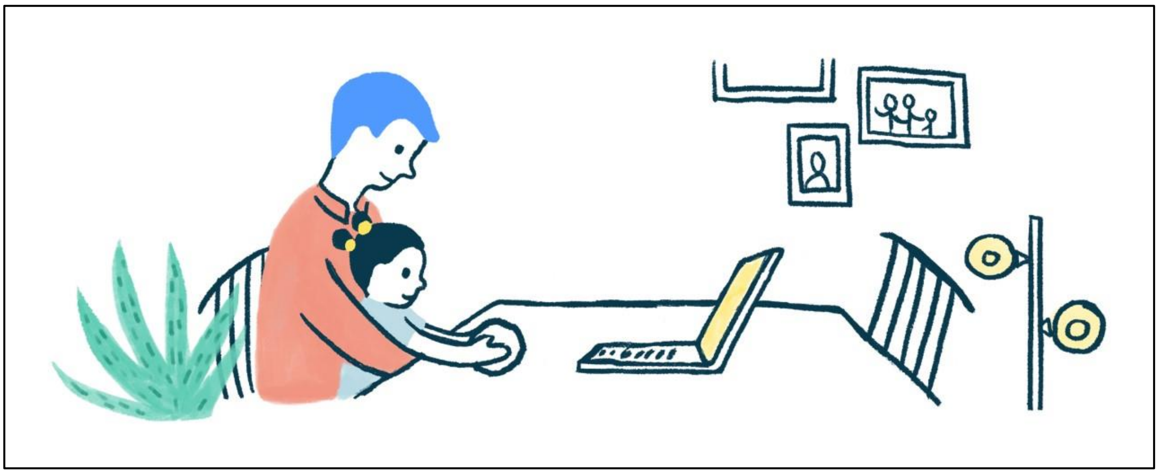
3.4.1 General procedure and design

Data collection for Study 1 was conducted at our university lab at the Department of Psychology, UiT - The Arctic University of Norway. The families participating in the experimental groups in E1 spent 1.5 hours in the procedure, which included both a demonstration and a test phase. In contrast, the control group spent only 1 hour, as they did not observe any target action demonstrations and only manipulated the test objects for us to assess their spontaneous production of target actions. Families in E2 also attended two appointments, each lasting 1.5 hours.

Data for Study 2 was collected online using the Zoom platform, with families participating from their homes using a computer with a web camera and microphone (see Figure 6). The procedure lasted approximately 40 minutes. This included a 30-minute information meeting the parent attended alone, followed by a a 10-minute imitation test with the parent and the child.

Figure 6

The experimental set-up from families' point of view for the online imitation procedure in Study 2



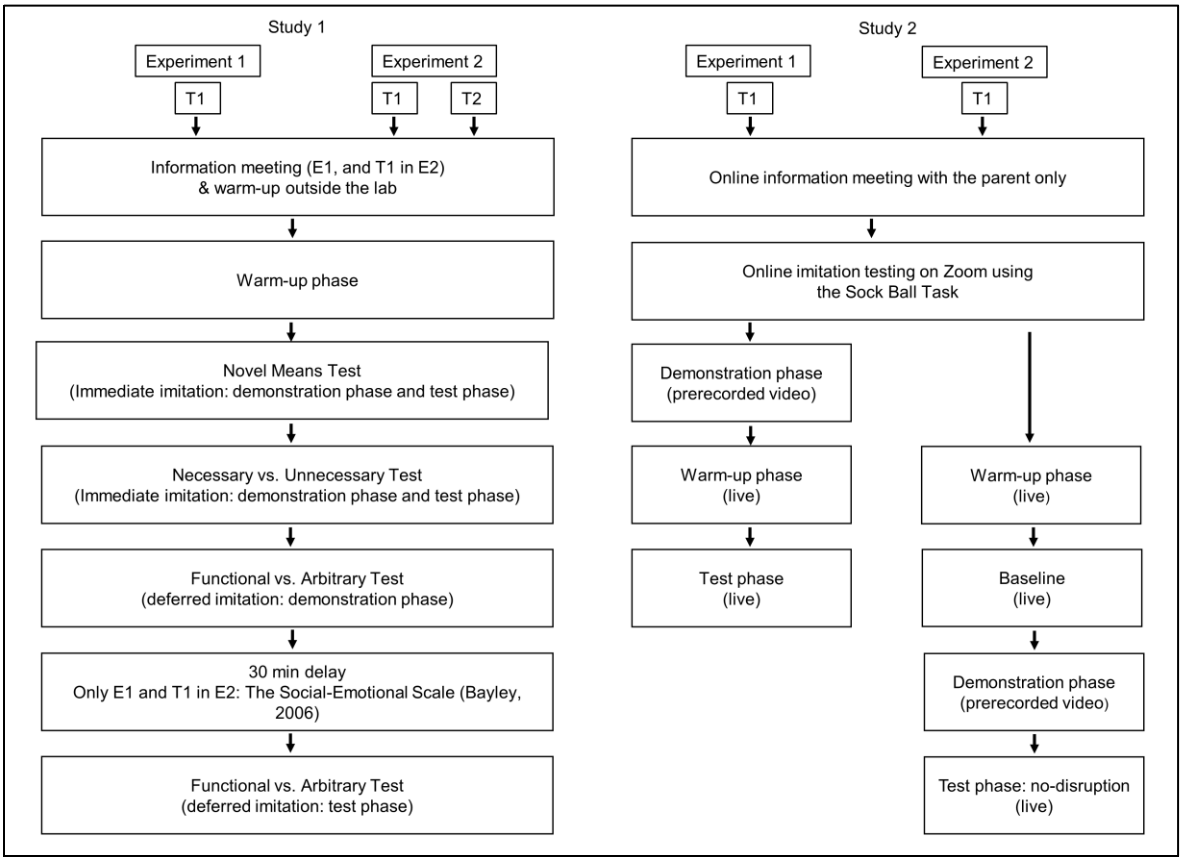
Note. Toddlers participated from home via a computer with a web camera and a microphone. The experimenter was visible on their computer monitor. Illustrator: Siri Jachlin.

For an overview of the general procedure of both studies, please see Figure 7. In both studies, the procedure began with an information session where the experimenter briefed the parents about the study, and the parents provided their informed consent on behalf of their children. In Study 1, we obtained written informed consent from the parents. In Study 2, we obtained verbal informed consent via a video meeting on Zoom, and the consent was recorded in the video. Following the information meeting in both studies, the children participated in imitation testing, either in the lab for Study 1 or online via Zoom for Study 2. In Study 1, the imitation test was conducted on the same day as the information meeting in E1 and E2 when the families attended their first lab appointment. In Study 2, only parents attended the information meeting, which was not always conducted on the same day as the imitation test. To ensure that parents remembered the information about the online procedure of the imitation test, we scheduled the information meeting near the upcoming imitation test.

We made sure that the child did not meet the experimenter before the imitation test, as any social interaction with the experimenter could influence the social manipulation of the study.

Figure 7

Overview of the procedure in Studies 1 and 2



Note. T1 = First test day; T2 = second test day. In Study 1, the information meeting with the parent and completing the Social-Emotional Scale (Bayley, 2006) always took place on the first test day for E2. In Study 2, the information meeting occurred sometime before the imitation test.

In Study 1, the toddlers participated in three different imitation tests: the NM-, N/UN-, and the F/A-test. Additionally, the parents completed the Social-Emotional Scale of the Bayley Scales of Infant and Toddlers Development, third edition (Bayley, 2006). We counterbalanced the order of the test versions. In E2 of Study 1, toddlers were presented with different versions of each imitation test (i.e., different test objects) across the two scheduled appointments to avoid practice effects. In E2, the toddlers either met the same experimenter (same model condition) or a different experimenter (different model condition) at their second lab appointment. In the different model condition, we counterbalanced which experimenter the toddlers met. In Study 2, toddlers participated in the online imitation test, The Sock Ball Task.

3.4.1.1 The social behavior of the experimenter(s)

In Study 1, the experimenter(s) were instructed to engage with the toddlers in a social and friendly manner. During the lab session, they used ostensive communication to address the toddlers and draw their attention to the test objects and target action demonstration. For instance, the experimenter would address the toddler by their name and make eye contact while "[Toddler's name], Look at this!" using infant-directed speech before demonstrating the target actions. Moreover, the experimenter would respond contingently to the toddler's communicative bids during the imitation test's demonstration and test phases. For example, during the test phase, if the toddler returned any objects to the experimenter, they would respond to the toddler by smiling and saying, "[name of child], it is your turn".

In Study 2, toddlers in the experimental conditions viewed a pre-recorded video of the experimenter, who appeared to ostensively greet them by making direct eye contact, smiling, and waving while saying "Hi". The phrasing "appeared to greet ostensively" is used to clarify that this was not an actual live interaction but a prerecorded video. Depending on the condition, this ostensive communication was either disrupted by smartphone use (smartphone condition) or wristwatch-fiddling (wristwatch condition) or not disrupted at all (no-disruption condition). Thereafter, toddlers met the experimenter in a live test phase, where the experimenter socially interacted with the toddlers following a verbal script. For instance, if a toddler showed an object, the experimenter would consistently respond with a smile and say “Oh, how nice!”. Toddlers in the baseline condition attended a test phase without a prior demonstration video. During the warm-up phase, the experimenter interacted with the parent to avoid influencing the social manipulation while the toddler observed.

3.4.2 Study design

In E1 of Study 1, toddlers were randomly assigned to either the experimental or the control group. All toddlers in E2 participated in the experimental group and had two scheduled appointments. For details about versions of the imitation tests used in the different conditions and test days, please see Study 1. In both studies, we performed between-subjects comparisons between the experimental groups and the baseline control group to establish imitation effects, i.e., toddlers’ production of the target actions was higher in the experimental group than at baseline. In E2 of Study 2, we also performed a within-subjects comparison to establish imitation effects by comparing the same toddlers’ production of target actions at baseline and in the no-disruption condition. Furthermore, in Study 2, we conducted three between-subjects comparisons between all experimental conditions to detect group differences in imitation behavior.

3.5 Sample size and power calculations

We used different approaches to calculate sample sizes in the two studies. For Study 1, we conducted a priori power analyses using G*Power (Faul et al., 2007) for both experiments. The power analysis indicated a target sample size of N = 42 participants for E1 and a sample size of *N* = 54 for E2. We expected a large effect size *d* = 0.80 in E1 (power = 0.8, α-level = 0.05) based on previous imitation studies with the same age group that have reported big imitation effects (Óturai et al., 2013; Óturai et al., 2012). For E2, we expected a medium effect size *f* = 0.39 (power = 0.8, α-level = 0.05) in E2 based on a previous study that found a moderate correlation between deferred imitation assessed at two measurement points (Kolling et al., 2010).

For Study 2, there were no completely comparable studies as we tested a novel hypothesis. We based the target sample size on typical sample sizes used in previous research that examined communicative cues related to imitation or learning and papers on imitation from video (Barr & Hayne, 1999; Barr et al., 2007; Konrad et al., 2021; Matheson et al., 2013; Nielsen, 2006; Reed et al., 2017; Repacholi et al., 2008). We estimated a sample size of *N* = 48 (*n* = 24 in each condition) for E1 and *N* = 24 for the baseline condition in E2. The estimation was based on an α-level of .05. We based our expected effect size on the study by Király et al. (2013), which reported imitation data from two slightly comparable conditions to our study (i.e., their communicative and incidental observation groups in the hands-free condition were comparable to our fiddling and smartphone conditions). We ran a Fisher's Exact test on their data to test for group differences in faithful imitation. The comparison was non-significant (*p*-value = .08), but the effect size was big (*OR* = 4.4). In our study, we therefore used a potentially more sensitive measure of faithful imitation than just a binary score, and we tested the comparison in an older age group than in the study by Király et al. (2013).

3.6 Analytical strategy

We used IBM SPSS (Statistical Package for Social Sciences) for Windows, version 28.0, for all statistical analyses. For both Studies 1 and 2, we assessed normality through visual inspection of QQ-plots, boxplots, histograms of frequency distributions, and the Kolmogorov-Smirnov test for normality. The data were not normally distributed for any outcome measures in the two studies, so non-parametric tests were conducted for the analyses. We considered the results as statistically significant if the *p*-value was less than .05. It is rare to report effect sizes with non-parametric tests, and we, therefore, did not report the effect sizes.

3.6.1 Study 1

To test for imitation effects of the target actions, we conducted between-subjects comparisons (experimental group vs. baseline control group) using Fisher's Exact test for dichotomous categorical variables and the Mann-Whitney test for continuous variables. To test whether the study replicated former findings on imitation patterns within the age group, we conducted Fisher's Exact tests (categorical variables), McNemar's Test (dichotomous variables), and the Wilcoxon-signed rank tests (continuous variables). The dependent measure for the four main hypotheses was the exact imitation score. We used two versions of the exact imitation score, one that was binary and one non-binary. For the four main hypotheses, we checked Cronbach's alpha value for our consistency hypothesis, and we conducted Spearman's rho tests for the remaining hypotheses (i.e., the stability hypothesis, the model stability hypothesis, and the social-emotional correlation hypothesis).

3.6.2 Study 2

We used the same statistical tests as for Study 1 to test for imitation effects. Additionally, we performed within-subject comparisons between the same toddlers' production of target actions at baseline and in the no-disruption condition to test for imitation effects, using a Wilcoxon-signed rank for production of sub-efficient means (continuous variable) and a McNemar test for production of the goal-outcome (dichotomous variable). For our main hypotheses, the dependent variable was the Faithful imitation score, a continuous variable. For our main hypothesis in E1, we conducted a Mann-Whitney test to determine whether there were any significant differences between the conditions in faithful imitation. Moreover, we used a Generalized Estimating Equations (i.e., a general logistic model and an exchangeable covariance matrix structure) for the binary variables with a Wald Chi-Square to analyze the proportion of imitators producing the means over the goal-outcome (means vs. goal) across the two conditions (condition: smartphone vs. fiddling). Lastly, in E2, we tested whether the null finding in E1 was due to the procedure by comparing group differences in imitation production in the no-demonstration baseline to the no-disruption condition. Specifically, we used Mann-Whitney tests to compare the production of sub-efficient means (continuous variable) and the Fisher's Exact test to compare the production of goal-outcome (categorical variable).

3.7 Ethical considerations for Studies 1 and 2

3.7.1 Ethical approval

The Norwegian Social Science Data Service (NSD, now named Sikt – Norwegian Agency for Shared Services in Education and Research) granted approval for both experimental studies (ref: Study 1:54084; Study 2: 973260) before the researcher began recruiting study participants and collecting data. The local ethics committee at the Department of Psychology, UiT The Arctic University of Norway, also approved both studies (Study 1, Ephorte no. 2016/9228; Study 2, ref. no.: 2017/2012).

3.7.2 Informed consent

The experimental studies involved children, so we obtained informed consent from the parents on behalf of the participating children. Parents received information about the studies both orally and in written form, and were informed about voluntary participation, anonymity, and the opportunity to withdraw. We provided both Norwegian and English versions of the information letters to ensure that non-Norwegian parents could receive the information in English, both orally and in writing. In Study 1, parents signed the informed consent forms. In Study 2, parents gave verbal consent in a digital meeting on Zoom that was video recorded. The English versions of the information letters for both studies are included in the Appendix. There are four information letters in total because each of the two studies comprised two experiments, each with its own information letter.

3.7.3 Data management

The names of the research participants in the experimental studies (Studies 1 and 2) were anonymized and replaced with number codes. A list of names and number codes was securely stored on password-protected hard drives. The raw data consisted of video recordings of children's looking at the video demonstration (i.e., attention) and their object manipulation during the experiments. This raw data is considered sensitive data because the videos contain personal information, as both the parents and the children are visible and recognizable in the videos. Therefore, we adhered to the university's recommendations for managing sensitive data. The raw data for both studies were stored on encrypted and password-protected hard drives.

In Study 1, the hard drives were securely stored in a locked cabinet in our university lab, accessible only to project members. In Study 2, the researcher conducted the experiment from her apartment and collected data via Zoom (during the COVID-19 pandemic) on a laptop owned by UiT. We used a university Zoom subscription provided by Uninett AS, which adheres to the General Data Protection (GDPRS) and Norwegian privacy laws and regulations. To ensure security and to prevent uninvited guests from joining the Zoom meetings, each family received a unique Zoom link and passwords for each meeting. The video recordings from the Zoom meetings were stored securely on an encrypted and password-protected hard drive kept securely in a cabinet in the researcher's apartment throughout the data collection period. Once data collection was completed, we stored the primary hard drive and two backup hard drives in the university lab.

All coding of data was conducted on a lab computer without an internet connection. In accordance with the FAIR principles (i.e., Findability, Accessibility, Interoperability, and Reuse of digital assets) (Wilkinson et al., 2016) and UiT's principles and guidelines for good data management (UiT The Arctic University of Norway, 2021), we developed a data management plan for Study 2 before we started the data collection. Notably, UiT's principles and guidelines were not yet published during the planning of Study 1, but a data management plan was described in the NSD application.

3.7.4 Research on children

Children are considered a vulnerable group in research (Council for International Organizations of Medical Sciences & World Health Organization, 2002; World Medical Association, 2013). This is because of the imbalance in power between children and adults, and because children cannot consent to research participation by themselves (Kipnis, 2003). Although the parents have the formal competence to consent on behalf of their children, it is also important to consider child assent and dissent in research (Brown et al., 2017; Syse, 2000). Researchers are required to obtain assent from children who are developmentally capable of providing it (Brown et al., 2017). Because the toddlers in Studies 1 and 2 were too young to provide assent, we only obtained consent from their parents. Nevertheless, it is important that the researcher continuously consider whether the child's welfare and best interest are protected throughout their participation. A part of this evaluation is to evaluate the toddlers' signs of discomfort and rely on the parents' judgments of whether these signs are typical for their everyday behavior (Brown et al., 2017). Although imitation studies are usually enjoyable for young children and only involve playing with toys, children may become upset. Consequently, we sometimes paused the research to allow the parent to comfort their child, or in some cases, we would stop the research process completely if the toddler was crying extensively and it was not in their best interest to continue.

3.8 Study 3: Scoping review study

A scoping review aims to map, identify, and characterize the current state of knowledge in a research field of interest (Arksey & O'Malley, 2005; Levac et al., 2010; Peters et al., 2020). Although scoping reviews share similarities with systematic reviews in their transparent methodologies for identifying, charting, and analyzing relevant studies, they differ in their approach to formulating research questions (Arksey & O'Malley, 2005; Munn et al., 2018). Unlike systematic reviews, which ask specific research questions, scoping reviews pose broader questions, allowing for the inclusion of a wider array of studies and thereby providing a more comprehensive overview of the research field (Arksey & O'Malley, 2005; Munn et al., 2018).

3.8.1 Study protocol

Before conducting the study, we developed a study protocol in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015 statement (Shamseer et al., 2015), and the checklist PRISMA extension for Scoping

Reviews (ScR) (Tricco et al., 2018). Additionally, our protocol was inspired by the theoretical framework of Arksey and O'Malley (2005) and the advancements of this method (Levac et al., 2010). We adhered to the Joanna Briggs Institute's guidelines for scoping reviews and refined our protocol accordingly (Peters et al., 2020; Peters et al., 2015). The protocol included the purpose of the scoping review, the research questions, the inclusion criteria to inform the search, the search strategy for each database, descriptions of the screening and the data charting processes, and the plan for analysis and presentation of results.

3.8.2 Identifying relevant studies

We developed inclusion criteria based on publication type, target child population, robot type, and research focus. Furthermore, we developed search queries in collaboration with a senior academic librarian to identify relevant studies. We conducted the literature searches on the databases PsychInfo, ERIC, Web of Science, and the preprint repository PsyArXiv. We exported all search results to the web-based software Covidence (*Covidence systematic review software*), which was used for screening the studies and to chart data from the included studies.

My research collaborators, Lars Ailo Bongo (LB) and Vi Tran (VT), and I performed the initial screening of titles and abstracts and assessed the full-text studies for eligibility using a predeveloped screening questionnaire (doi.org/10.17605/OSF.IO/4BGX6). After that, I charted data related to the research questions from the included studies. LB and VT checked the charted data for accuracy. Data related to the research questions was charted from the publications using a data charting template (doi.org/10.17605/OSF.IO/B32R6).

3.8.3 Methods of analysis

In Study 3, we summarized, reported, and discussed the reviewed studies following the fifth stage of Arksey and O'Malley's (2005) scoping review framework. We summarized general characteristics, developmental concepts studied, research methods, characteristics of children and robots, types of interactions, outcome measures and instruments, key research focuses and findings, and reported gaps and challenges. We also calculated simple frequencies for several of these characteristics.

3.8.4 Reporting the results

To maintain transparency, we reported the study following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-analysis extension for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018). The checklist is provided in the supporting information of Study 3 which can be found in the online version, at https://doi.org/10.1371/journal.pone.0303704.s001.

3.8.5 Ethics

The scoping review itself does not involve any data collection of humans or animals that requires ethical considerations. However, it is relevant to describe the ethical considerations related to the research covered in the literature review and how the authors of the included studies have addressed these. For instance, were there any risks in the studies when exposing robots to young children? It is important that children's rights are protected and that researchers act in the child's best interest when using robots with children. For instance, some robot types are inappropriate for children to use because they are not designed to be safe for children (e.g., contain small parts). We found no alarming issues regarding the ethics in the reviewed studies. Most of the reviewed studies did not involve physical contact between the child and the robot, and in studies that involved physical contact, the robots were supervised by the researchers. From a broader developmental perspective outside the research setting, we can also discuss ethical concerns, such as whether young children need interactions with robots and if these interactions can reduce human communication. Real social interactions with humans are fundamental for children's development, and while robots can complement these interactions, they should never replace them.

3.9 Preregistration

All studies in the present thesis are registered on Open Science Framework (OSF), and the dates and links to the registrations are included in each paper. Specifically, E1 of Study 1, Study 2, and the study protocol for Study 3 were preregistered on OSF before data analyses. E2 of Study 1 was post-registered on OSF. However, a project site was registered for both experiments in Study 1 before data collection (before I started my Ph.D. position). This project site included the same project description and the analysis plan as in the formal post-registration.

3.10 Data availability

Data from Study 2 and 3 are openly available for other researchers at Open Science Framework (OSF), Study 2: DOI 10.17605/OSF.IO/SJF4D; Study 3: DOI 10.17605/OSF.IO/WF48R. Notably, the data from Study 2 are anonymized numeric data, whereas data from the literature review study (Study 3) consists of the charted data from the studies included in the review. All data are presented in Excel files that can be downloaded and easily exported to other software (e.g., analytical software).

4 Summary of the papers

4.1 Summary of Study 1

Title: Flatebø, S., Johansen, L., & Óturai, G. 18-month-olds show neither stability nor consistency in selective vs. exact imitation.

Aims and hypotheses: In Study 1, we first aimed to investigate the consistency of toddlers' selective versus faithful imitation patterns across three imitation tests. Secondly, we aimed to examine whether toddlers' faithful imitation is stable when measured twice within the same month. Third, we aimed to explore the impact of toddlers' short-term familiarity with a social partner on the stability of their faithful imitation. Lastly, we aimed to examine if faithful imitation is related to a more general measure of socio-emotional development. We hypothesized that toddlers would demonstrate a consistent pattern of imitation (selective vs. faithful) across various tests and that this pattern would remain stable over a short period. Moreover, we expected faithful imitation to correlate with socio-emotional development scores. The effect of familiarity with the social partner on imitation pattern was exploratory, without a specific directional hypothesis.

Methods: The study consisted of two experiments with a total sample of 112 typically developing 18-month-old toddlers. In E1, 49 toddlers participated in a single lab session. In E2, 63 toddlers attended two sessions, encountering either the same or a different model at their second visit. We measured their imitation pattern using three imitation tests: a Novel Means Test, a Necessary versus Unnecessary Test, and a Functional versus Arbitrary Test. To assess toddlers' socio-emotional development, parents completed the Social-Emotional Scale of The Bayley Scales of Infant and Toddler Development (Bayley, 2006).

Results and discussion: Contrary to our expectations, our results indicated that toddlers' selective vs. faithful imitation patterns were neither consistent across different tests nor stable over the short-term period. Interestingly, post hoc analyses revealed that overall imitation in the deferred Functional versus Arbitrary Test was stable, suggesting a potential area for future research. Additionally, there was no significant association between faithful imitation and socio-emotional development scores. Familiarity with the model did not influence the stability of faithful imitation, suggesting that toddlers' accumulated rapport with the model did not influence the stability of their faithful imitation performance across this short-term design.

4.2 Summary of Study 2

Title: Flatebø, S., Óturai, G., & Hernik, M. No evidence for adult smartphone use affecting attribution of communicative intention in toddlers: online imitation study using the Sock Ball Task.

Aims and hypotheses: The study's main hypothesis, which was tested in E1, was that toddlers represent a social partner's smartphone use as incompatible with ostension and rely on this representation when inferring the social partner's communicative intent. We hypothesized that if toddlers represent smartphone use as incompatible with ostensive communication this would be evident in less faithful imitation of sub-efficient means when exposed to a social partner disrupting the ostensive communication using a smartphone compared to someone fiddling with a wristwatch (matched control). In E2, we aimed to establish that our online imitation test measured imitation behavior. Furthermore, since we found no support for our main hypothesis in E1, we investigated in E2 whether procedural factors, such as lack of extended warm-up, might have dampened toddlers' imitation in E1.

We hypothesized that if procedural factors influenced toddlers' imitation in E1, then faithful imitation should not be different between toddlers who were exposed to a social partner either not disrupting or disrupting the ostensive communication with smartphone use or fiddling.

Methods: The study consisted of two experiments with a sample size of 72 typically developing toddlers aged 17-19 months. All toddlers participated in an online imitation test, where they observed a social partner who ostensively greeted them and non-ostensively performed sub-efficient actions with test objects to achieve a goal in a demonstration phase. This was followed by a test phase where the toddlers were allowed to play with the test objects. In E1, 48 toddlers were randomly assigned to either a condition where they observed a social partner who ostensively greeted them, then disrupted this ostensive communication with smartphone use (n = 24) or a matched control condition where the social partner fiddled with a wristwatch (n = 24). In E2, we assessed the validity of our imitation test by first evaluating the toddlers' spontaneous production of the key actions in a baseline condition without a demonstration phase (n = 24) compared to the imitation performance of the three experimental conditions exposed to a demonstration of the key actions (no-disruption, smartphone, and wristwatch conditions). Then, the same toddlers participated in a no-disruption condition, and we assessed their imitation behavior after observing the social partner ostensively greeting them, followed by an uninterrupted demonstration (n = 22).

Results and discussion: In E1, toddlers who watched a social partner disrupting the ostensive communication by smartphone use did not imitate less faithfully than toddlers who watched a matched control disruption. Thus, we did not find support for our hypothesis that toddlers represent smartphone use in social interactions as incompatible with ostension. In E2, we established imitation effects for modeled sub-efficient novel means. This was evident by toddlers' imitating the sub-efficient means significantly less at baseline compared to all the experimental conditions (i.e., the no-disruption, smartphone, and fiddling conditions). The results related to the imitation effect of the goal-outcome were unclear and only significant for the within-subjects comparison between the baseline and the no-disruption condition. Lastly, toddlers' imitation of the modeled sub-efficient novel means and the goal-outcome did not significantly differ between the no-disruption condition and the smartphone condition, nor between the no-disruption condition and the wristwatch condition. This suggests that our null finding in E1 is less likely to be due to procedural matters. This study contributes a new online imitation paradigm.

4.3 Summary of Study 3

Title: Flatebø, S., Tran, V. N., Wang, C. E. A., & Bongo, L. A. Social robots in research on social and cognitive development in infants and toddlers: A Scoping review.

Aims: The main objective of Study 3 was to review empirical research on toddlers' imitation and understanding of ostensive cues from social robots. Study 3 addresses this by providing a broad overview and summary of all the existing research on how social robots have been applied in early childhood developmental research to investigate social and cognitive concepts in infants and toddlers. Moreover, the review aimed to identify the key research focuses and findings in this field and the reported research gaps and challenges reported by the authors.

Methods: We chose to conduct a scoping review to encompass the potential diversity in methods and developmental concepts in the research field. Like systematic reviews, scoping reviews follow a transparent method of locating, charting, and analyzing data. We developed a search strategy based on predefined inclusion criteria and searched for literature in PsychINFO, ERIC, Web of Science, and PsyArXiv. We included empirical studies published between 1990 to May 29, 2023, that tested social and/or cognitive development in typical developing children between 2-35 months using social robots. All studies were screened by two reviewers using the Covidence software, firstly by screening titles and abstracts and then by screening full texts. Lastly, the first author charted data from each included study, and a second reviewer checked the charted data. The data from the included studies were summarized, reported, and discussed in alignment with the research aims.

Results and discussion: We included 29 studies in the review published between 1991 to 2023. The research was conducted in various countries, including Australia, Canada, Italy, Japan, Romania, Taiwan, the United Kingdom, and the United States. Most studies were quantitative, conducted in laboratories, and focused on toddlers. We identified 16 social robots, mostly humanoid and pre-programmed to do specific behaviors in the studies. Most commonly, the children interacted with the robot in a one-to-one situation in the same physical space as the robot. Still, often, it did not involve any physical contact with the robot. In some studies, the robot was presented in a video. We identified the following four key developmental research focuses: 1) Animacy understanding, 2) action understanding, 3) imitation, and 4) early conversational skills. However, an overarching focus in most of the studies was whether young children represent social robots as social partners or intentional agents. The studies show that children have diverse perceptions of social robots as social partners, and their understanding of robot behavior varies. However, these studies indicate that children sometimes, even from an early age, are attentive to robots, learn from them, and recognize their ostensive cues. Various research gaps and challenges related to using social robots in early developmental research were reported by the authors, many concerning the children's lack of familiarity with and challenges with robotic designs. The review contributes to the discussion on whether young children represent more ambiguous objects, such as social robots as social partners or intentional agents. Furthermore, the findings emphasize that robot behaviors such as interactivity and contingency are especially important for young children to perceive social robots as social partners. Hopefully, this review will guide robot designers in making appropriate social robots for young children.

Results relevant for the thesis: Because the scoping review adopts a broad approach, only 20 of the 29 reviewed studies are relevant to the thesis, and these are summarized here and categorized by their research focus (see Table 4 for an overview). The remaining nine studies were irrelevant because children were younger than the target age of the thesis (n = 5) (Arita et al., 2005; Deng et al., 2023; Fitter et al., 2019; Funke et al., 2018; Kamewari et al., 2005) or because of irrelevant research focus, i.e., that the publication was neither about imitation, ostension, nor perceptions of robots as social partners (n = 4) (Boccanfuso et al., 2015; Critten et al., 2022; Ferrier et al., 2000; Hsiao et al., 2015). All the same, countries except the study from Taiwan (Hsiao et al., 2015) were represented in this smaller subset of studies. The research focuses included imitation of or with robots, intentional understanding of robots, animacy perceptions, and sensitivity to the robot's contingent versus non-contingent verbal responses. The imitation studies found that 1 to 3-year-old toddlers imitate both live and on-screen humanoid robots' goal-directed actions with objects, that imitation increases with age (Sommer, Redshaw, et al., 2021; Sommer, Slaughter, et al., 2021), and that toddlers are more likely to imitate robots they previously interacted with or that they had seen another interact with (Meltzoff et al., 2010; Sommer, Slaughter, et al., 2021). However, some results demonstrated a robot deficit effect, i.e., toddlers imitate humans more than robots (Sommer, Redshaw, et al., 2021; Sommer, Slaughter, et al., 2021). The studies on animacy were mixed, with findings sometimes indicating toddlers perceive robots as alive (Alac et al., 2014; Matsuda et al., 2015; Peca et al., 2016) and other times not

(Barber et al., 2023; Kahn et al., 2006; Poulin-Doubois et al., 1996). The studies on toddlers' understanding of the robot's ostensive communication and the attribution of intentions to robots yielded different findings. While some findings suggested that toddlers attribute intentions and goals to robots (Manzi et al., 2022; Okumura et al., 2013b, 2013c; Sommer et al., 2023; Wang et al., 2020), other studies did not support this (F. Manzi, M. Ishikawa, et al., 2020; O'Connell et al., 2009; Okumura et al., 2013b, 2013c; Sommer et al., 2023; Wang et al., 2020).

Table 4

The studies from Study 3 that are relevant to the thesis including research focuses and robots used

Research focus	*N*	Robots used	Representative studies
Imitation	3	RUBI-6; Opie	Sommer, Redshaw, et al. (2021); Sommer et al. (2023); Sommer, Slaughter, et al. (2021)
Intentional understanding			
Goal attribution	3	Robovie; Robovie2	Itakura et al. (2008); Manzi et al. (2022); Wang et al. (2020)
Referential understanding	6	Robovie2; HOAP-2; Dr. Robot Inc.	F. Manzi, M. Ishikawa, et al. (2020); Meltzoff et al. (2010); O'Connell et al. (2009); Okumura et al. (2013a, 2013b, 2013c)
Intentional agency	1	MyKeepon	Peca et al. (2016)
Animacy perceptions	5	RUBI; MiRoE; AIBO; ReplieeQ2; Robie Sr.	Alac et al. (2014); Barber et al. (2023); Kahn et al. (2006); Matsuda et al. (2015); Poulin-Doubois et al. (1996)
Contingency in verbal responses	2	Robie Sr.	Dunham and Dunham (1996); Dunham et al. (1991)

Note. The study by Itakura et al. (2008) is sorted under the category of intentional understanding, which was the main research focus, although the study used imitation methods. Itakura et al. (2008) measured the re-enactment of an unforeseen intended act, which is usually not considered imitation.

5 Discussion

In the following sections, the findings from the three studies will be discussed in alignment with the overarching aim of the thesis: to increase knowledge about how toddlers imitate different social partners and understand communicative intentions in social contexts with varying levels of ostensive communication. Initially, the discussion will focus on the findings' contributions to understanding how toddlers imitate different social partners, including humans and non-human social robots. Subsequently, the discussion will address how toddlers interpret the communicative intent of social partners when ostensive cues are provided, are absent, or are disrupted. Thereafter, the studies' limitations, methodological considerations, and potential implications will be discussed. Lastly, future directions will be suggested, and a conclusion will be presented.

5.1 Adaptable imitation of different social partners

The three studies show that toddlers imitate different social partners with various levels of ostension, which may suggest adaptability in whom they imitate. These include ostensively communicative adults, adults whose ostensive communication is disrupted by smartphone use, and non-human social robots that communicate ostensively. In Study 1, the results show that the toddlers imitated unfamiliar and "short-term" familiar experimenters who engaged in an ostensively communicative fashion during three imitation tests (i.e., the NM-, N/UN, and the F/A-test) in a laboratory setting. However, the toddlers generally demonstrated a low degree of faithful imitation within these imitation tests, which will be discussed further in section 5.2. Study 2 showed that the toddlers faithfully imitated sub-efficient actions demonstrated by an unfamiliar on-screen adult regardless of whether this person disrupted ostensive communication with smartphone use or wristwatch fiddling. This indicates that the toddlers may perceive an experimenter as worthy of imitation regardless of minor communicative disruptions caused by smartphone use. Additionally, Studies 1 and 2 successfully established imitation effects for all imitation tests (Study 1: the NM-, N/UN-, and the F/A-test; Study 2: the Sock Ball Task), i.e., the toddlers showed higher performance of target actions in experimental groups who saw a demonstration of target actions than control groups that did not see any demonstrations. However, although we established imitation effects for the sub-efficient means actions in the Sock Ball Task in Study 2, we found mixed results for the imitation effect of the goal-outcome.

Study 3 included publications demonstrating that toddlers aged 1 to 3 years imitated goal-directed actions with objects demonstrated by a social robot, such as assembling and shaking a rattle (Sommer, Redshaw, et al., 2021; Sommer, Slaughter, et al., 2021). Furthermore, toddlers imitated both the robot when it was physically present in the lab and on-screen, and their imitation of robots increased with age (Sommer, Redshaw, et al., 2021; Sommer, Slaughter, et al., 2021). However, the toddlers demonstrated the robot deficit effect, meaning they imitated the human experimenter more than the robot (Sommer, Redshaw, et al., 2021; Sommer, Slaughter, et al., 2021). Sommer, Slaughter, et al. (2021) propose that toddlers may have more difficulty adopting a pedagogical stance when interacting with robots compared to humans. Relatedly, it is discussed that toddlers' developmental increase in imitation of social robots may suggest that they first need to learn *how to learn* from humans. As they grow older, they can generalize this knowledge to social robots (Sommer, Slaughter, et al., 2021). Alternatively, robots may be perceived as part of an outgroup and, as a result, may be less likely to be imitated (Sommer, Slaughter, et al., 2021). However, these findings (Sommer, Redshaw, et al., 2021; Sommer, Slaughter, et al., 2021) are based on interactions with just one type of robot, the RUBI-6. Therefore, it is still unclear whether toddlers would imitate other kinds of social robots or if their imitation performance varies depending on the robot. Moreover, since these studies did not include non-human controls, it is unclear if toddlers, for instance, imitate social robots more efficiently than other types of non-human agents without social appearance and behavior, such as geometrical shapes or mechanical pincers. Notably, Study 3 also identified that social robots can be implemented in other ways within imitation methods, for example, to test toddlers' intentional understanding in a failed-attempt paradigm (Itakura et al., 2008) and to investigate whether a social robot's social behavior can enhance the imitation of another demonstrator (Sommer et al., 2023).

Together, the three studies show that toddlers adaptably imitate different types of social partners, both human and non-human, and with various levels of ostension. However, Study 3 demonstrated that imitation fidelity and preferences can vary based on whether the social partner is a human or a robot, which may suggest that humans trigger the pedagogical stance more effectively than robots. Additionally, the toddlers' selection of what to imitate in specific tests and conditions did not always align with our predictions for the experimental studies (Studies 1-2), namely, that toddlers imitate more faithfully in ostensive contexts. This will be discussed in more detail in the next section 5.2.

5.2 The role of ostension in imitation and in understanding others' communicative intentions

The three studies presented in the thesis investigate the role of varying levels of ostension from human or non-human social partners in toddlers' social learning, imitation included, and inferences about others' communicative intent. The studies are based on Natural Pedagogy Theory, which suggests that children are sensitive to social partners' ostensive communication (Csibra, 2010; Csibra & Gergely, 2006; Gergely & Csibra, 2005). This type of communication indicates to children that the information being shared is specifically meant for them and is important for their learning (Csibra, 2010; Csibra & Gergely, 2006; Gergely & Csibra, 2005). Consequently, toddlers may faithfully imitate social partners who communicate ostensively, guided by the principle of relevance (Csibra, 2010; Csibra & Gergely, 2006; Gergely & Csibra, 2005). Studies 1 and 2 focused on assessing toddlers' imitation patterns, providing a deeper understanding of faithful imitation during the 1.5-year-old period and toddlers' ability to make inferences about communicative intentions in varying contexts with human social partners. Study 3 includes several publications assessing toddlers' imitation, looking behavior, and verbal responses to contribute more knowledge on whether toddlers recognize social robots as social partners with agency and their intentional understanding of robots' actions when ostensive cues are provided. The following sections will discuss the findings from each of the three studies in more detail. Studies 1 and 2, which assessed selective and faithful imitation patterns, will be discussed more collectively, whereas Study 3 will be discussed separately. Finally, a summary encompassing all three studies will be presented.

Studies 1 and 2 show that 1.5-year-old toddlers' faithful imitation was not influenced by the social partners' type of ostensive communication as we had hypothesized. In Study 1, we hypothesized that 1.5-year-old toddlers would show a developmental shift in their imitation where they are more influenced by the social partner's ostensive cues, involving them not only in imitating actions based on their functionality but also in faithfully imitating actions that were made relevant by the ostensive cues from their social partner. Thus, we predicted that toddlers' faithful imitation would be consistent and stable across different imitation tests and measure points in the 1.5-year-old period. Contrary to our expectations, despite all actions in all tests being demonstrated ostensively by the experimenter, toddlers showed inconsistent and unstable patterns of faithful imitation. Moreover, we tested an explorative hypothesis and found that familiarity with the experimenter did not affect the stability of faithful imitation. This aligns with previous research that found no difference in toddlers' imitation of unfamiliar versus familiar social partners (Devouche, 2004; McCabe & Uzgiris, 1983; Shimpi et al., 2013). Notably, toddlers also exhibited a low degree of faithful imitation in two of the three imitation tests (the NM- and the F/A-test), which may have accounted for the lack of support for our hypotheses regarding consistent and stable imitation. The low degree of imitation of arbitrary actions in the F/A-test may also be due to the lengthy procedure requiring toddlers to participate in two imitation tests before the F/A-test.

In Study 2, we measured group differences in toddlers' imitation patterns of goals versus sub-efficient means to learn more about toddlers' inferences about communicative intent when a social partner disrupts ostensive communication with either smartphone use or wristwatch fiddling (matched control). The target actions were demonstrated non-ostensively after ostensive communication was disrupted by smartphone use or fiddling. We hypothesized that if toddlers represented adults' smartphone use as incompatible with their expectations for ostensive communication, they would infer that the phone-using social partner in the imitation test was not intending to communicate with them, and therefore, influencing them to imitate less faithfully than toddlers exposed to the matched control disruption. Surprisingly, we did not find evidence for this hypothesis, as toddlers were just as likely to faithfully imitate sub-efficient novel means regardless of whether the ostensive communication was disrupted by smartphone use or wristwatch fiddling. Thus, we find no support for our hypothesis that toddlers represent smartphone use as incompatible with ostension and use this representation to make rich inferences about the model's communicative intentions.

The results from Studies 1 and 2 align with the mixed findings found in previous research regarding the role of ostension in children's faithful imitation. While some studies have found that toddlers' faithful imitation of particular means or irrelevant actions to attain goals are facilitated by ostension (Király et al., 2013; Kupán et al., 2017; Nielsen, 2006; Nielsen et al., 2008), others suggest that both toddlers and older children may faithfully imitate irrelevant actions regardless of whether they are ostensively demonstrated (Hoehl et al., 2014; Tecwyn et al., 2020).

There are many potential explanations for why toddlers did not imitate as we predicted in Studies 1 and 2. For example, individual differences in children's social versus cognitive goals (Yu & Kushnir, 2020) or their personality traits (e.g., temperament) (Hilbrink et al., 2013; Yu & Kushnir, 2020) may have affected toddlers' imitation patterns. Furthermore, although research on the relationship between sleep measures and imitation in toddlers is still limited and poorly understood (Konrad et al., 2019; Konrad et al., 2016), it is plausible to consider that day-to-day variances in sleep may play a role in their imitation performance given that general sleep patterns tend to vary between individual toddlers (Galland et al., 2012). Although toddlers' faithful imitation was inconsistent and unstable in Study 1, this does not mean that 1.5-year-olds do not shift from selective toward more faithful imitation. Instead, it suggests that faithful imitation may not yet be sufficiently developed at this age to manifest consistently across various tests and remain stable throughout this period. Additionally, it is plausible that while the tests used in Study 1 (i.e., the NM-, N/UN-, and the F/A-test) are theoretically designed to measure the same concepts, variations in task characteristics could be responsible for the differing outcomes observed in toddlers' imitation patterns. Regarding the stability across the two measurement points in Study 1, we cannot rule out that the variability in toddlers' daily behavior could have significantly influenced their imitation patterns and that we used too few measurement points. While we did not find evidence for toddlers representing smartphone disruption as lack of communicative intent in Study 2, this does not imply that this effect does not exist, and future replications are needed to clarify this. However, an alternative explanation could be that toddlers might have habituated to this behavior and adjusted their expectations about face-to-face interactions. For instance, in Study 2, toddlers may have learned from past experiences that the norm is that smartphone disruptions are usually temporary and that the social partner will re-engage with them. This understanding could lead them to faithfully imitate an adult despite such disruptions, expecting the communication to resume eventually. This behavior aligns with findings from Tronick et al. (1978) in the classical still-face study, where infants learned to expect their unresponsive caregivers to re-engage and repair the interaction eventually. Moreover, research has demonstrated that infants' protest responses to a mother's still-face decrease as they grow older (Melinder et al., 2010), which may indicate that older infants adapt better to communicative disruptions. Additionally, research suggests toddlers are more likely to faithfully imitate behaviors from in-group members, possibly to conform to social norms (e.g., Buttelmann et al., 2013).

Study 3 demonstrated mixed findings on toddlers' perception of social robots as communicative social partners and the role of the robot's ostension on toddlers' intentional understanding and social learning. Some studies demonstrated that toddlers considered the social robots as animate (Alac et al., 2014; Matsuda et al., 2015; Peca et al., 2016), but not always (Barber et al., 2023; Kahn et al., 2006; Poulin-Doubois et al., 1996). Naturally, living beings are more likely to be perceived as potential social partners and attributed mental states, such as intentions and agency, than inanimate objects. Several publications showed that ostensive communication, such as eye contact, infant-directed speech, and contingency, facilitated toddlers' understanding of a social robot's communicative intentions and their social learning of the content the robot was communicating about (Manzi et al., 2022; Okumura et al., 2013b, 2013c; Sommer et al., 2023; Wang et al., 2020). For example, when a robot made direct eye contact with another social partner, 2 to 3-year-olds were likelier to re-enact this robot's intended but failed act (Itakura et al., 2008). Furthermore, Okumura et al. (2013a) found that infant-directed verbal signals enhanced 1-year-old toddlers' understanding of the robot's referential intentions. Additionally, contingent verbal responses from robots enhanced toddlers' conversation engagement and their likelihood of following the robots' gaze (Dunham & Dunham, 1996; Dunham et al., 1991). Moreover, toddlers between 1 and 3 years of age were more likely to learn from and imitate robots with whom they had a prior contingent interaction or observed an adult interacting contingently (Meltzoff et al., 2010; Sommer, Slaughter, et al., 2021). However, other studies suggest that ostensive communication from robots had no significant impact on toddlers' learning or understanding of the robots' referential intentions (F. Manzi, M. Ishikawa, et al., 2020; O'Connell et al., 2009; Okumura et al., 2013b, 2013c; Sommer et al., 2023; Wang et al., 2020). For instance, direct eye contact from a robot was insufficient for toddlers aged 1 and 1.5 years to understand its referential intentions (F. Manzi, M. Ishikawa, et al., 2020; Okumura et al., 2013b, 2013c). Moreover, observing a robot engage in contingent interactions did not help 1.5-year-olds use the robot's gaze to learn new words (O'Connell et al., 2009). Furthermore, 13-month-olds did not attribute cooperative intentions to robots that communicated ostensively with adults (Wang et al., 2020). Moreover, Sommer et al. (2023) demonstrated that a 1.5-year-old's imitation of a televised human experimenter was not facilitated by having a robot ostensively communicate with the child to draw attention to the demonstration. Although ostensive cues sometimes facilitated toddlers' understanding of the robot's referential intentions and enhanced learning from the robot, human ostension was more robust than the robot's (F. Manzi, M. Ishikawa, et al., 2020; O'Connell et al., 2009; Okumura et al., 2013b, 2013c; Sommer, Redshaw, et al., 2021; Sommer, Slaughter, et al., 2021), but not always (Manzi et al., 2022). For example, 1-year-olds followed the direction of both human and robot gaze, but they could only use human gaze as a referential signal when learning about objects (Okumura et al., 2013b, 2013c). The studies suggest several reasons why toddlers did not understand the robots' referential intentions. For example, toddlers may not consider the robot's gaze shift as a communicative act intended to transmit information, and therefore, they do not have referential expectations for its gaze (Okumura et al., 2013b, 2013c). Furthermore, toddlers might respond better to human ostension due to their natural adaptation to human communication and limited familiarity with robots (F. Manzi, M. Ishikawa, et al., 2020; Okumura et al., 2013a, 2013b). Accordingly, toddlers might need multiple ostensive cues and not just a single cue to understand robots' actions as intentional and to learn from them (Okumura et al., 2013a). Nevertheless, toddlers were sensitive to the robot's eye contact and they followed its gaze direction, which may suggest that they considered the robots as social partners (F. Manzi, M. Ishikawa, et al., 2020; O'Connell et al., 2009; Okumura et al., 2013b, 2013c). Relatedly, Okumura et al. (2013c) demonstrated that toddlers only follow the turning direction of a robot if it has eyes, which suggests that eyes play an important role in toddlers' recognition of agents and that they do not just look toward the robot's motion direction.

Together, the three studies suggest mixed findings on the role of ostension in toddlers' social learning, including imitation, and their understanding of their social partners' communicative intentions to teach. In Studies 1 and 2, although toddlers in the 1.5-year-old period are thought to increasingly consider the social partners' ostensive cues and thus be more socially motivated to imitate in ostensive contexts compared to younger infants faithfully, the results showed that their faithful imitation was not necessarily dependent on the social partner's level of ostension. More specifically, in Study 1, toddlers' faithful imitation was inconsistent and unstable across tests and over time. In contrast, in Study 2, toddlers' faithful imitation was the same regardless of whether the ostensive communication was disrupted by smartphone use or wristwatch fiddling or not disrupted at all. The findings from Study 1 and Study 2 highlight the complex relationship between ostensive communication and faithful imitation in 1.5-year-old toddlers. Lastly, Study 3 yielded mixed findings on the role of robots' ostension on toddlers' inferences about communicative intent and social learning. In some ostensive contexts, but not all, toddlers showed signs of recognizing the robots' communicative intentions to teach, and they were able to learn from these robots as assessed by imitation or gaze following.

5.3 Limitations and methodological considerations

The present work had some limitations. First, the broad scope of this thesis can be considered a limitation because not all topics are discussed in detail. However, each of the three studies includes a presentation of the current knowledge and relevant literature. The experimental studies (Studies 1 and 2) addressed specific research questions about a narrow age group of children (1.5-year-olds). In contrast, Study 3 posed broader research questions and encompassed a wide range of developmental concepts across a wider age range (toddlerhood period). Nevertheless, the use of a multimethod approach and the inclusion of a broader age group can also be considered strengths, as it provides a more holistic presentation of the overarching aim of the thesis, which was to increase knowledge about toddlers' imitation of different social partners and their understanding of communicative intentions when ostensive cues are present or lacking (e.g., disrupted ostensive communication).

Secondly, Studies 1 and 2 have limitations related to generalizability to other populations. The samples in the experimental studies consisted of families living in Norway. Norway's population is primarily White and highly educated (SSB, 2021, 2023) Consequently, the findings may not apply to the global population but may be relevant to WEIRD populations (Western Educated Industrialized Rich and Democratic samples) (Henrich et al., 2010; Singh et al., 2023). Moreover, since we did not gather any demographic information regarding the parents of the children involved in the study, such as their income and educational background, their socio-economic status is unknown. This information would have helped us understand the broader applicability of our findings. However, our experimental studies relied on volunteer participants. Some studies suggest that more advantaged families are usually more likely to participate in research, as shown in the study by Høifødt et al. (2020).

Third, there are some considerations related to the ecological validity and the chosen locations for testing in the experimental studies, i.e., participation in the laboratory (Study 1) or from home via a computer (Study 2). The research setting of Study 2 can be considered a hybrid between a highly controlled and a naturalistic setting. The home environment is more natural than a laboratory, yet the control exerted does not make it entirely naturalistic. Results from a specific research setting do not necessarily generalize to another type of setting. For instance, the laboratory setting involves a highly controlled and somewhat artificial reality, which provides high internal validity (Alnajjar et al., 2021). However, laboratory settings differ greatly from everyday naturalistic settings, and we must interpret findings from experiments in the lab with caution when applying them to other settings (Alnajjar et al., 2021). In contrast, there is less internal validity when conducting experiments in people's homes, as we did for Study 2. Although we tried to control the setting as much as possible and informed the parents how to prepare their homes for the experiment (e.g., how to limit sources of distraction during the experiment), we cannot rule out that there will always be differences across the children's homes that we cannot control. Moreover, in our online imitation test, toddlers were exposed to both a pre-recorded video of the experimenter and a live video meeting with the same experimenter. Relatedly, research indicates that toddlers are likelier to imitate actions when the person they see on screen is live and interactive rather than pre-recorded (Jing & Kirkorian, 2020). It is important to consider that imitation behavior might have differed if the demonstration format was entirely live or all pre-recorded. Additionally, previous research has found that learning from screens, in general, is difficult for toddlers compared to real-life settings (Jing & Kirkorian, 2020). Thus, it is uncertain whether our expected results would be better captured in other settings, such as conducting the study in a face-to-face lab interaction.

Fourth, societal circumstances can influence research results. Data collection for Study 2 was conducted during the COVID-19 pandemic, introducing societal changes that could have impacted toddlers' social development. For example, toddlers in Norway may have reduced opportunities for face-to-face interactions outside their households due to closed kindergartens (Hall et al., 2022; Utdanningsdirektoratet, 2021) and the decreased social interactions in the population because of social distancing recommendations (Ursin et al., 2020; Veneti et al., 2024). Moreover, some researchers discuss that the widespread use of face masks may have affected young children's socio-communicative development (Carnevali et al., 2022; Kim et al., 2024). The pandemic also potentially increased parental stress due to economic pressures, balancing home office and parenting, and social isolation, potentially affecting the parent-child relationship and children's socio-emotional development (e.g., Bjørknes et al., 2022; Imboden et al., 2022; Kuehn et al., 2024). However, research on parental stress in Norway during this period is sparse (Bjørknes et al., 2022; Johnson et al., 2021), with one study noting increased parental stress among younger parents (aged 18-29 years) but not among older parents (older than 29 years). Furthermore, it is plausible that toddlers in this period were more accustomed to others' smartphone use in face-to-face interactions, given that research from countries worldwide showed increased screen use during the pandemic (for a review see, Trott et al., 2022) and parents are found to use smartphones while parenting (Elias et al., 2020; Hiniker et al., 2015; Lemish et al., 2019; Mangan et al., 2018; Radesky et al., 2014; Saltzman et al., 2019; Vanden Abeele et al., 2020; Wolfers et al., 2020). However, a limitation of Study 2 is that we did not measure parents' smartphone behavior, which could have provided insights into toddlers' experiences with smartphone-disrupted interactions.

Fifth, there are methodological considerations related to the standardization of the social context in experiments. In Studies 1 and 2, we aimed to standardize the procedures for each child. Nevertheless, natural variations in human interactions, such as differing levels of eye contact, smiling, or speech variations, could cause variability in the experimenter's social behavior across test sessions and influence toddlers' imitation. This may be a more plausible concern for Study 1, as we did not systematically control the social behavior of the experimenters. Although the experimenters were instructed to be warm and friendly in a similar manner with each participant, this approach may nevertheless lead to variability in how different experimenters conducted the test. Conversely, it is less likely that toddlers' imitation in Study 2 was influenced by such variability in the experimenter's social behavior, as we systematically controlled the social context. More specifically, we used a pre-recorded demonstration phase with a video of the experimenter so that each participating child was exposed to the same social stimuli. Furthermore, in the live test phase, the experimenter used a pre-defined script when responding to various child behaviors. For instance, when a toddler lifted an object to the screen as if showing it to the experimenter, the experimenter would always say “how nice”. Yet, by engaging in live interactions, the experimenter was able to adjust the procedure for each child to some extent, such as responding to the child’s communicative attempts to maintain their focus on the task. Another challenge was familiarizing the toddlers with the experimental setup, which is important to create a friendly and secure atmosphere that encourages the toddlers to play with the test objects. In Study 1, toddlers were made comfortable with the environment and the experimenter by playing with toys with the experimenter in a friendly waiting area and a warm-up phase in the laboratory while the parent was present. However, in Study 2, we needed to maintain a neutral social setting to avoid influencing social manipulation. This meant we could not have a familiarization involving direct interactions between the toddler and the experimenter. Participating in an experiment and meeting an unfamiliar experimenter in a video call can be an unfamiliar situation for many children. During pilot tests, we observed that many toddlers were hesitant to interact with the test objects and they displayed signs of discomfort, such as trying to leave the parent’s lap or avoiding looking at the experimenter. To address this challenge, the parent and the experimenter interacted socially while the toddlers observed, which allowed them to familiarize themselves with the experimental setup indirectly without compromising the social manipulation in the experiment.

Sixth, there are several measurements we could have considered including in both experiments, which could have provided a broader understanding of our results (Studies 1 and 2). In both studies, we relied on toddlers' imitation performance. Study 1 also measured toddlers' social-emotional development using a parental questionnaire to assess social-emotional development, i.e., the Social-Emotional Scale of the Bayley Scales of Infant and Toddlers Development 3ed (Bayley, 2006). Because there is no Norwegian version of this scale, we used the available English version of the scale, which is validated in the U.S. population (Bayley, 2006; Breinbauer et al., 2010). Naturally, it would be easier for parents to answer questions in Norwegian; however, the experimenter helped translate and answer questions when the parents filled out the questionnaire. For Study 1, we could have included a more proximal measure of social-emotional development to evaluate socio-emotional skills because there is uncertainty involved in parental questionnaires due to social desirability (Brenner, 2020), and parents might be biased when evaluating their children's skills. Brito et al. (2019) present various measures to assess social-emotional development, including laboratory tasks and other parental questionnaires, which we could have considered. Relatedly, we could have considered measuring and controlling for toddlers' temperament for both experimental studies, as it is considered a precursor to personality development and potentially impacts imitation behavior (Hilbrink et al., 2013; Shiner & DeYoung, 2013). The limitation of not assessing social-emotional development in Study 2 is that we could have explored its role in toddlers' representation of non-communicative intent during smartphone disruptions.

Seventh, we must consider the possibility that the null findings in our experimental studies might be due to the small sample size. We used different approaches when determining the sample size for Studies 1 and 2. In Study 1, we calculated the sample size using the software G*Power (Faul et al., 2007), whereas in Study 2, we based our sample size on previous imitation studies that investigated similar phenomena. Both approaches have their advantages and limitations. Using software to determine the sample size allows for precise calculations based on parameters set by the researcher, such as effect size, alpha level, and statistical tests (Faul et al., 2007). However, misestimating these parameters can result in underpowered studies, which lack sufficient power to detect real effects, or overpowered studies, which may detect non-meaningful effects (Gelman & Carlin, 2014). On the other hand, basing sample size on previous studies ensures that the calculations are grounded in a similar context, which might include similar populations, settings, and variables. Notably, previous studies can also have misestimated their sample size, and relying solely on isolated studies for sample size determination is not advisable (Gelman & Carlin, 2014).

Lastly, I want to point out some limitations and methodological considerations related to the scoping review (Study 3). First, the use of social robots as research tools in early child development is an evolving field, and it is suggested that scoping reviews are a suitable review type to choose when faced with such developing research areas (Levac et al., 2010; Ringnes et al., 2024). Furthermore, the scoping review method was a preferred choice of review type due to its established and systematic method, which helps reduce biases (Ringnes et al., 2024). For instance, instead of the researcher making independent choices about which papers to include in the review, which can be subjective, the scoping review follows criteria for which publications to include (Ringnes et al., 2024). Second, the scoping review (Study 3) consists of a limited dataset of only 20 publications relevant to the thesis, four studies about toddlers' imitation and robots or using imitation as a part of the method, and 16 studies that did not use imitation methods but focused on toddlers' recognition of robots as social partners and the impact of ostension in understanding of the robots' communicative intentions. Thus, considering the limited dataset, these findings should be considered as preliminary findings in the field and be interpreted cautiously. Given that the field of using robots in developmental research is rapidly evolving, the current state of knowledge could quickly change as new technologies and insights become available in future publications. Third, unlike systematic reviews and meta-analyses, scoping reviews do not assess the methodological quality of the included publications, and we cannot, therefore, draw firm conclusions from our results (Arksey & O'Malley, 2005; Levac et al., 2010; Peters et al., 2020). Fourth, the findings of the imitation studies do not necessarily generalize to the global population, as the data collection of the studies was limited to three geographical locations (i.e., Australia, the United States, and Japan) (Itakura et al., 2008; Sommer, Redshaw, et al., 2021; Sommer et al., 2023; Sommer, Slaughter, et al., 2021).

5.4 Future research

As mentioned in the respective papers, the results from the three studies presented in this thesis offer several opportunities for replication and refinement. Overall, more future work is needed to understand toddlers' early inferences about social partners' communicative intent within imitative contexts. For example, the imitation tests we developed for the experimental studies in the thesis (Studies 1 and 2) should be refined and replicated in future studies. In Study 1, we found variability in task difficulty between the two versions of the F/A-test (i.e., the target actions in Version B seemed more difficult for the toddlers than in Version A), which should be evened out. Furthermore, we did not find evidence for a developmental shift from selective towards faithful imitation in 18-month-olds. Thus, future studies should address whether this null finding is due to the age group by replicating the study using a wider age range to establish at what stage this transition in imitation patterns occurs. In Study

2, we found mixed results regarding the imitation effect for the goal-outcome (i.e., ball on paper). We found an imitation effect for the within-subject comparison between the no-disruption and the baseline conditions, but no imitation effects were found for the between-subject comparisons. Future studies should replicate this experiment with more participants to determine whether the absence of an imitation effect for the goal may be due to the small sample size. Moreover, since the test objects (i.e., the papers and the sock ball) were placed closely together on the table, toddlers may have achieved the goal-outcome due to their proximity. Future studies should explore whether toddlers still imitate the goal when the objects are spaced further apart on the table. Additionally, future studies should replicate our studies outside of Norway to generalize the results to the broader population.

Also, most of the reviewed studies in Study 3 focused on whether toddlers are sensitive to robots' ostensive communication and whether they imitate robots. However, none of these studies investigated whether toddlers imitate robots for social reasons. So far, it has been demonstrated that preschoolers faithfully imitate social robots to satisfy social motivations (Sommer et al., 2020). Future studies should investigate whether toddlers also can be socially motivated to imitate causally irrelevant actions of robots. Furthermore, none of the included studies examined how effective ostension is when provided by social robots compared to non-human objects. Future work should examine the effectiveness of ostensive communication provided by robots compared to other non-human social partners. Relatedly, several researchers have criticized the use of puppets as research tools in developmental research because puppets might not be recognized as animate, which is connected to perceiving agents as social partners (Packer & Moreno-Dulcey, 2022; Rakoczy, 2022b). Thus, social robots might be more suitable as controls for human experimenters as they are more likely to be perceived as animate than puppets. Finally, one purpose of conducting scoping reviews is to determine whether it is worthwhile to conduct a full systematic review (Arksey & O'Malley, 2005). We did not find any systematic literature reviews on how social robots have been used as a research tool to study social and cognitive development in infants and toddlers. However, since our review provides a preliminary mapping of a field that is still small and emerging, we do not think it is necessary to conduct a systematic review yet.

5.5 Implications

The thesis's main implication is that it provides more knowledge about toddlers' imitation of and intentional understanding of human and non-human social partners. A contribution is the new knowledge gained about toddlers' reactions to more modern forms of social interactions, i.e., face-to-face interactions interrupted by someone else's smartphone use and how they communicate with and respond to social robots. Furthermore, this thesis adds to our knowledge about toddlers' imitation patterns, suggesting that faithful imitation is still inconsistent and unstable in the 18-month period. The three studies in the current thesis also have individual contributions, which will be presented in the selections 5.5.1 and 5.5.2.

5.5.1 New imitation tests for testing in the lab and online

The two experimental studies contribute new imitation tests. In Study 1, we developed a new test battery of three different imitation tests that enables the evaluation of toddlers' imitation patterns of selective versus faithful imitation across multiple tests. This approach provides a more comprehensive understanding of toddlers' imitation patterns than relying on results from just one type of imitation test. However, as discussed in section 5.4, the test battery has limitations and requires further improvement. Furthermore, given that post hoc analyses revealed stable overall imitation performance in the deferred F/A-test, this could suggest that deferred imitation could effectively serve as a measure for assessing individual differences or for diagnostic purposes. In support of this, Brito et al. (2019) highlight that deferred imitation measures might serve as a promising diagnostic tool for identifying individual differences and developmental delays in infants and toddlers.

Furthermore, Study 2 contributes to the research field – the online imitation test developed for this study, the Sock Ball Task. As evidenced by the results of Study 2, the Sock Ball Task successfully measures toddlers' faithful imitation of novel sub-efficient means actions. Hopefully, this has implications for future studies that plan to conduct imitation testing online. The test objects used in the Sock Ball Task are inexpensive, easy for families to prepare on their own, and do not require any shipping. The test objects are made from a pair of socks and a piece of paper, which most people have in their homes. Online testing using video-chat platforms might be advantageous for more effective recruitment (e.g., ensuring recruitment of enough participants and sooner completion of data collection) and more diverse recruitment of participants (Sheskin et al., 2020). Since online testing does not require a physical presence in a laboratory, it allows recruiting participants regardless of their geographic location and enables conducting the same study across different countries (Lo et al., 2024). It makes participation easier because it involves less planning for the parents, such as no need to commute to the university. Since child developmental research often suffers from small and non-diverse samples (Nielsen et al., 2017; Singh et al., 2023), online testing can potentially enhance the sample's representativeness more effectively than in-person procedures (Gosling et al., 2004; Sheskin et al., 2020). Notably, online testing requires access to digital devices and the internet, which may exclude lower-income families and limit the sample's representativeness (Lourenco & Tasimi, 2020).

5.5.2 New technologies changing communication and research

Studies 2 and 3 provide valuable knowledge about how new technologies impact early childhood communication. More specifically, Study 2 contributes to the existing body of research by demonstrating that, within the specific experimental design of our study, there is no evidence to suggest that toddlers recognize smartphone use during face-to-face interactions as incompatible with their expectations for ostensive communication. Therefore, while our results did not support the initial hypothesis, the possibility of an effect under different conditions cannot be discounted. At the same time, we cannot rule out that the opposite may be true – toddlers' expectations of ostensive communication are not violated when face-to-face interactions are disrupted by others' smartphone use. If so, our findings might be interpreted as toddlers habituating to smartphone behavior and adjusting their communicative expectations. Nevertheless, this does not suggest that smartphone disruptions do not impair communication and relationships. Given that research suggests that smartphone disruptions in face-to-face interactions negatively impact communication between caregivers and their children (Elias et al., 2020; Kelly & Ocular, 2020; Vanden Abeele et al., 2020; Wolfers et al., 2020), it may be advisable to consider such implications of smartphone use while caring for children. Moreover, it may also be essential to repair communication with the child after disruptions with unresponsiveness (Tronick et al., 1978).

Study 3 extends the research by systematically reviewing empirical studies on using social robots to test infants' and toddlers' social and cognitive development, which, to our knowledge, has not been reviewed before. The thesis' objective with Study 3 was to evaluate the potential of using social robots within developmental research, including imitation studies. A premise for using social robots within developmental research is that toddlers can learn from them and recognize their communicative intentions. Study 3 demonstrated that toddlers are capable of this in some situations but not always. Moreover, several robot behaviors that improve toddlers' understanding and communication with robots were identified, including interactivity, contingency, and the use of multiple ostensive cues. Additionally, as the reviewed studies showed that toddlers imitate functional goal-directed actions modeled by social robots, these robots may be relevant for testing instrumental imitation learning. Based on the findings from Study 3, social robots may have the potential to be social partners in developmental research, such as in imitation studies. However, these potential contributions must be interpreted cautiously as Study 3 is based on a limited number of publications, and more future research is needed to clarify.

6 Conclusion

The findings of the three studies in the current thesis suggest that toddlers exhibit an adaptable approach to imitation and imitate different forms of social partners with varying levels of ostensive communication. However, toddlers' faithful imitation in the experimental studies did not align with our hypotheses. In Study 1, 18-month-olds demonstrated inconsistent and unstable patterns of faithful imitation, even though all target actions were demonstrated ostensively. Study 2 showed that toddlers were equally likely to faithfully imitate an adult regardless of whether ostensive communication was disrupted by smartphone use or wristwatch fiddling. Thus, we did not find support for the hypothesis that toddlers recognize smartphone use as incompatible with ostension and rely on this representation when making inferences about communicative intentions. Although previous research has indicated that ostensive contexts generally facilitate faithful imitation, the fidelity of such imitation can also be influenced by other factors, including the developmental stage of the child, differences in task characteristics, individual child differences in social versus cognitive goals or in personality, or daily well-being (e.g., sleep). Study 3 showed that in some situations, but not all, toddlers could learn and understand communicative intentions from social robots. Toddlers' social learning and intentional understanding of robots were often facilitated in contexts where the robot provided multiple ostensive cues and when the robot behaved contingently and interactively. However, toddlers respond more effectively to human ostension. Since toddlers can learn from robots and understand their intentions in some situations, they may be a potential tool for future early developmental research, including imitation studies. Together, these findings highlight the complexity of toddlers' social learning and imitation behaviors, demonstrating variability in how ostension influences their understanding of others’ communication in various social contexts.

7 References

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Appendices

- Appendix A: Study 1
- Appendix B: Study 2
- Appendix C: Study 3
- Appendix D: Study 1, information letter for Experiment 1
- Appendix E: Study 1, information letter for Experiment 2
- Appendix F: Study 2, information letter for Experiment 1
- Appendix G: Study 2, information letter for Experiment 2

Appendix A: Study 1

Flatebø, S., Johansen, L., & Óturai, G.

18-month-olds show neither stability nor consistency in selective vs. exact imitation

(Manuscript submitted)

18-Month-Olds Show Neither Stability nor Consistency in Selective vs. Exact Imitation

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Abstract

A developmental shift from selective towards exact imitation in the second year of life has been demonstrated using different imitation tests, such as the Novel Means Test (NM-test), the Necessary vs. Unnecessary Test (N/UN-test), and the Functional vs. Arbitrary Test (F/A-test). This shift has been explained by developmental changes in psychological mechanisms underlying imitation behavior, such as the emergence of mentalizing action interpretation schemes or social motivations. Considering this, we predicted that 18-month-old toddlers' selective vs. exact imitation would be consistent across test types, remain stable throughout a short-term design, and be related to their social-emotional development. In two experiments, we tested toddlers' imitation patterns in a NM- and a N/UN-test assessing immediate imitation, and a F/A-test assessing deferred imitation. Toddlers visited the lab once in Experiment 1 ($N = 49$) and twice in Experiment 2 ($N = 63$). Our results did not support our main hypotheses but instead indicated that toddlers' imitation is influenced by the task at hand and the current situation. Interestingly, post hoc analyses showed that overall imitation in the deferred F/A-test was stable. Together these findings imply that overall deferred imitation performance could be suitable for diagnostic purposes and assessing individual differences, while patterns of selective vs. exact imitation may not be.

Introduction

Imitation serves both cognitive and social functions in early childhood (Uzgiris, 1981), such as discovering how objects work, affiliating with others, or conforming to social norms (Nielsen, 2009; Over, 2020; Over & Carpenter, 2012; Uzgiris, 1981). In some cases, children imitate only the parts of the modeled actions relevant to the functional use of the target object (*selective imitation*). In other cases, they imitate the modeled actions exactly (*exact imitation*). Imitation patterns are also influenced by the social context, with research indicating that children's imitation becomes increasingly exact when the context is more social (for a review, see Hoehl et al., 2019; cf. also Over & Carpenter, 2012). Thus, when children imitate exactly, they also imitate actions made relevant by the social context - evoked by social motivations (Nielsen & Blank, 2011; Over & Carpenter, 2012; Slaughter et al., 2008; Uzgiris, 1981) or by the experimenter's social-communicative cues (Brugger et al., 2007; Nielsen, 2006).

Children's selective and exact imitation have been operationalized in different tests, such as the Novel Means Test (NM-test), the Necessary vs. Unnecessary Test (N/UN-test), and the Functional vs. Arbitrary Test (F/A-test). In the NM-test, a model performs a novel action to attain a goal, e.g., she uses her forehead to illuminate a lamp (Gergely et al., 2002) or her elbow to ring a bell (Herold & Akhtar, 2008), while her hands are either free or occupied holding a blanket. The objects' affordances change for the model depending on whether her hands are occupied or not, but they remain the same for the child. Therefore, the model's choice of the unusual action in the *hands free condition* prompts toddlers to interpret that this action must have a hidden advantage over the more familiar alternative (Gergely, 2003; Gergely et al., 2002). Thus, selective rational imitation is regarded as imitating the novel means action in the *hands-free condition* and using the familiar hand action in the *hands-occupied condition*, reflecting children's evaluation of the efficiency of the unusual action depending on the models' situational constraints (Gergely et al., 2002). Imitating the novel means action in both conditions is regarded as exact imitation. In the N/UN-test, the first step of the modeled goal-directed action (e.g., opening a latch) is necessary to attain the goal (e.g., opening a container) in one condition but unnecessary in the other (Hilbrink et al., 2013). Here, selective imitation is interpreted as imitating the first action step (alternatively, by imitating the first two action steps in the demonstrated order, see Brugger et al. 2007) in the *necessary condition* but not in the *unnecessary condition*. Omitting the unnecessary first action step shows toddlers' sensitivity to the relation between the physical properties of objects and their functional use. Exact imitation is indicated by imitating the first action step (or by imitating the first two action steps in the demonstrated order) in both conditions (Brugger et al., 2007; Hilbrink et al., 2013). Finally, in the F/A-test, the model performs a functional and an arbitrary action on each of several target objects (e.g., Óturai et al., 2012), whereby the functional actions are more strongly related to the objects' physical properties than the arbitrary ones. An object's physical properties are both determined by and indicative of its intended function (Kelemen & Carey, 2007): For example, a finger puppet must be open at the bottom to function as intended, and the opening at the puppet's bottom informs users that it is a finger puppet (Kelemen & Carey, 2007). In the F/A-test, selective imitation is regarded as imitating only functional target actions, while the imitation of both functional and arbitrary target actions indicates exact imitation (Óturai et al., 2012).

Findings stemming from the NM-, N/UN, and the F/A-test converge on an essential developmental change in the degree of selective vs. exact imitation in the second year of life. Toddlers are found to shift from imitating a novel means action only if it seems to be rational towards imitating it regardless of its rationality in the NM-test (Gergely, 2003; Király et al., 2013; Matheson et al., 2013), from only imitating the necessary action steps to reach a goal towards imitating action steps regardless of necessity in the N/UN-test (Hilbrink et al., 2013), and from imitating only functional actions towards imitating both functional and arbitrary actions in the F/A-test (Óturai et al., 2012). Overall, infants around their first birthday imitate predominantly selectively (Hilbrink et al., 2013; Kolling et al., 2014; Óturai et al., 2018; Óturai et al., 2012; Schwier et al., 2006), while two-year-old children imitate predominantly exactly (Bauer & Mandler, 1989; Call et al., 2005; Nagell et al., 1993; Nielsen, 2006; Tennie et al., 2006). During the second year of life, the degree of exact imitation increases (Hilbrink et al., 2013; Óturai et al., 2018), and 18-month-olds' imitation is between the two extremes of the selective-to-exact imitation scale (Nielsen, 2006; Óturai et al., 2013; Óturai et al., 2012; Tennie et al., 2006). The rate of exact imitation continues to increase after the age of two years, as discussed in the literature on overimitation, i.e., "imitation of perceivably causally unnecessary actions in relation to the goal of an action sequence performed by a model" (Hoehl et al., 2019, p. 91). However, there seems to be a gap between studies on the developmental trend towards exact imitation in the second year of life and those on overimitation in older children: According to the review by Hoehl and colleagues (2019), 23-month-olds usually do not imitate any irrelevant actions in the puzzle-box task frequently used in studies on overimitation. This contrasts with the increasing rate of imitating the irrelevant action step in the N/UN-test in the second year of life (Hilbrink et al., 2013). Here, we will focus on the issue of selective vs. exact imitation in the second year of life.

The existence of a developmental shift from selective towards exact imitation implies that situational factors cannot sufficiently explain why toddlers imitate selectively or exactly in a given study. In fact, findings show that situational factors and the imitators' age interact in that the social context only starts to impact toddlers' imitation from around the age of 18 months on when they begin to imitate more exactly in more social contexts (Király, 2009; Nielsen, 2006; Nielsen et al., 2008). These findings are compatible with the view that while younger toddlers imitate predominantly to fulfill cognitive goals, older toddlers also imitate to achieve social goals, such as showing affiliation with the model (Nielsen & Blank, 2011; Over, 2020; Over & Carpenter, 2013; Uzgiris, 1981). In a different view, Gergely (2003) explains the developmental shift by a change from teleological to mentalizing action interpretations. According to Gergely's theory (2003), younger infants' teleological action interpretation focuses on the action's goal and situational constraints without considering the model's intentions. Contrary to this, toddlers from 18 months on apply a mentalizing interpretation scheme focusing on the model's communicative signals, interpreting the situation as the model's act to teach them something new and relevant (Gergely, 2003)[1].

In sum, not only situational factors but also toddlers' age affects their selective vs. exact imitation, which points to the existence of a developmental change that systematically influences how toddlers interpret and copy others' actions, over and above specific task characteristics. Therefore, the central predictions of the present study were that the degree of exact imitation at 18 months would be consistent across different types of imitation tests *(consistency hypothesis)*, stable across a short-term design *(stability hypothesis)*, and correlated with theoretically related, more general measures of social-emotional development *(social-emotional correlation hypothesis)*. These hypothesized effects would carry important implications about the suitability of imitation tests to assess individual differences and, thus, their potential as diagnostic tools (cf. Brito et al., 2019).

First, regarding the *consistency hypothesis*, only a few previous studies have combined different types of tests to assess selective vs. exact imitation in toddlers. Yu and Kushnir (2015, 2020) used a set of different N/UN tests and the "mouse and house" test developed by Carpenter et al. (2005) to test 2-year-olds' faithful imitation and goal

[1] Recently, Gergely and his colleagues revised their theory to suggest that 14-month-olds are influenced by the model's pedagogical signals and their selective imitation in the NM-test is impacted by the content they learn in the two conditions. Namely, in the hands-occupied condition, they only learn the sub-goal of "making contact with the lamp", while in the hands-free condition, they learn an additional sub-goal of "using the head to make contact with the lamp" (Király et al., 2013). However, the revised theory does not explain the developmental shift towards exact imitation.

emulation. While they found that both faithful imitation and goal emulation (Yu & Kushnir, 2015), as well as overall imitation performance correlated positively between the two types of tests (Yu & Kushnir, 2020), they also report that imitation of both necessary and unnecessary actions only correlated between two out of three different N/UN tests. In another study, Kim et al. (2018) tested 18-month-olds with a NM-test, a N/UN test, and a F/A test. The results showed a positive correlation between the arbitrary target action performance in the F/A-test and imitation of the unnecessary first actions in the N/UN-test (Z. Kim, personal communication, May 19, 2016), both of which are indicators of exact imitation. However, a variation in the social context affected toddlers' performance in these two tests differently (Kim et al., 2018). Together these findings indicate that more research is needed to clarify the comparability of different test types. We hypothesized that 18-month-olds' exact imitation would be consistent across the NM-test, the N/UN-test, and the F/A-test.

Second, although the stability of deferred imitation is well established (Heimann & Meltzoff, 1996; Kolling et al., 2009; Nielsen & Dissanayake, 2004; Sundqvist et al., 2016), there have been few studies to investigate the stability of selective vs. exact imitation. Wagner et al. (2020) found a weak but significant positive correlation in the imitation of arbitrary actions between 2 and 3 years of age in a sample of more than 600 children. Imitation of functional actions did not show the same correlation. Sakkalou and colleagues (2013) found that infants' goal-directed (selective) imitation correlated positively between 13 and 14 months. Nevertheless, infants participated in two different tests at the two measurement points, thus stability across time was confounded with consistency across tasks. In our study, we tested stability and consistency separately by using parallel versions of three different imitation tests. With the *stability hypothesis,* we expected that toddlers' exact imitation would be stable across a short-term design consisting of two test appointments. Relatedly, we tested an explorative hypothesis on the strength of the stability correlations of exact imitation in a condition where toddlers met the same model at both appointments vs. a condition where toddlers met a new model at each appointment (*model stability hypothesis*). On the one hand, we argued that if the degree of exact imitation in an imitation setting is influenced by the personal affiliation or rapport between the child and the model, above and beyond the general aspects of the social context, then exact imitation will be more stable across appointments for toddlers who meet the same model repeatedly, compared to toddlers who meet a new model at each appointment. On the other hand, if the general aspects of the social context, such as the model being friendly and communicative, are more critical than prior experience with the specific person, then the exact imitation stability correlations will not differ between the same model condition and the different model condition.

Third, it has been suggested that individual differences in the tendency to use social learning to solve novel problems are associated with extraversion and related traits (Rawlings et al., 2017). For example, 7- to 11-year-old children's agreeableness was associated with their choice to use social information, while conscientiousness was associated with attempting(Rawlings et al., 2022)￼. Regarding imitation in the second year of life, it has been shown that 18-month-olds'(Kolling & Knopf, 2015)￼. Logically, this effect might be primarily driven by the imitation of target actions that are only made relevant by the social context (i.e., exact imitation). Studies on individual differences in exact imitation in the second year are scarce. Still, one study found that more extroverted infants imitated more exactly than less extroverted infants (Hilbrink et al., 2013), and another study (Yu & Kushnir, 2020) found a positive correlation between 2-year-olds' faithful imitation and sharing behavior and a negative correlation between faithful imitation and negative emotionality. Both findings point to a relation between how infants behave as social actors and how they imitate other people's actions. Therefore, in the *social-emotional correlation hypothesis* we expected that toddlers' social-emotional development is related to how receptive they are to the social cues of the model in an imitation task. As a result, toddlers' general functional, everyday social-emotional behavior scores (The Social-Emotional Scale of the Bayley Scales of Infant and Toddler Development; Bayley, 2006; Breinbauer et al., 2010) would be positively related to their exact imitation score.

To investigate these hypotheses, we developed a new test battery consisting of two parallel versions of the NM-test, N/UN-test, and F/A test. The NM- and the N/UN-test had an immediate imitation design, and the F/A-test had a deferred imitation design, because the test battery was developed for a larger project that required both designs. Although the NM test was originally developed as a deferred imitation test (Gergely et al., 2002), we argue that for differentiating between selective and exact imitation, the delay is not essential, as selective (or exact) imitation is decided during the encoding of target actions (Beisert et al., 2012; Gergely & Csibra, 2006; Király et al., 2013; Király & Oláh, 2020; Langeloh, 2020; Lyons et al., 2007; Pfeifer & Elsner, 2013; Zmyj & Buttelmann, 2014). For assessing deferred imitation, we chose the F/A test that was originally developed in a deferred imitation design and offers a range of scores that makes it suitable to measure memory performance (Óturai et al., 2012). The parallel versions aimed to provide two independent measures of selective vs. exact imitation across the three test types. Before testing the main hypotheses, we tested whether our test battery replicates earlier findings on imitation effects and imitation patterns of selective vs. exact imitation. These will be presented as preliminary analyses.

Method

Participants

Participants were typically developing 18 months ± 2 weeks old toddlers (born without complications, ≥ 37 weeks of gestation, birth weight 2500-4500 g) living in Tromsø, a university town in Northern Norway that compares well with the rest of the country. The

Norwegian population is predominantly White and highly educated, with one-third of people over 16 years having completed higher education (SSB, 2021). The participants were recruited via advertisements in the local community and social media. Data collection took place between January 2018 and September 2019 in a university laboratory. The project was approved by the Research Ethics Committee at our department and the Norwegian Centre for Research Data (NSD, project nr. 54084), and it followed the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. Parents gave informed consent before the experiment began. After the experiment, toddlers received a small toy and a certificate, and parents were given a gift card worth 150 NOK.

For Experiment 1 (E1), an a priori power analysis indicated a target sample size of $N = 42$ (G*Power, Faul et al., 2007). Three participants were excluded from the final analysis due to fussiness (2) or no rapport with the experimenter (1). To compensate for non-valid data specific to the different imitation tests, we tested ten more toddlers (see details under Valid Data). Thus, the final sample of E1 consisted of $N = 49$ toddlers (23 boys; $M = 548.22$ days, $SD = 8.28$, range: 532-562 days), who were randomly assigned to either the experimental group or the control group.

Based on an a priori power analysis (G*Power, Faul et al., 2007), the target sample size for Experiment 2 (E2) was $N = 54$. Three participants were excluded, due to experimenter error (1), no rapport with the experimenter (1), or not fulfilling the inclusion criterion for birth weight (1). Additionally, nine participants were excluded from one of the two test appointments due to lack of valid data (6, see details under Valid Data), illness (1), or experimenter error (2). To compensate for missing data, we tested 15 more participants. In the final sample, $n = 66$ toddlers had valid data for at least one of the appointments (37 boys; $M_{T1} = 543.06$ days, $SD_{T1} = 7.43$, $\text{range}_{T1} = 531\text{-}561$ days; $M_{T2} = 551.81$ days, $SD_{T2} = 7.51$, $\text{range}_{T2} = 535\text{-}563$ days), $n = 63$ toddlers had valid data for the first appointment (36 boys; M

= 543.13 days, *SD* = 7.49, range: 531-561 days), and *n* = 60 toddlers had valid data for the second appointment (32 boys; *M* = 551.48 days, *SD* = 7.53, range: 535-563 days). Toddlers were randomly assigned to either the same model condition or the different model condition. When testing for imitation effects, baseline data were taken from the control group in E1.

Measures

Imitation Tests

Each imitation test consisted of two parallel versions counterbalanced across participants. The NM-test consisted of a push-lamp (Version A) and a bell (Version B), see Table 1. The novel actions were to turn on the lamp using the forehead (adapted from Gergely et al., 2002) and to use the elbow to ring the bell (adapted from Herold & Akhtar, 2008). Following Gergely et al. (2002), the experimenter demonstrated the target action either with her hands free, visibly on each side of the object on the table, or with her hands occupied, holding a blanket while pretending to be cold. The N/UN-test (adapted from Brugger et al., 2007; Yu & Kushnir, 2014) consisted of wooden boxes (Version A) and wooden birdhouses (Version B), see Table 2. The target actions consisted of four steps, and the first step (i.e., to open a latch) was either necessary or unnecessary to retrieve a toy. The F/A-test (adapted from Kolling et al., 2014; Óturai et al., 2013; Óturai et al., 2012) consisted of six items in each version, with one functional and one arbitrary target action per item, see Table 3.

Social-emotional development questionnaire

Parents completed 28 items (stage 1 to stage 5b) of the Social-Emotional Scale of the Bayley Scales of Infant and Toddler Development, third edition (Bayley, 2006), thus answering items relevant for up to 30 months of age. This aimed to allow for a wider range of scores and avoid a ceiling effect. Items were rated on a scale from 1 = none of the time to 5 = all of the time, with an additional option 0 = can't tell. An example was: "Searches for something he or she wants by looking or getting you to look for it" (item nr. 19). As the scale has not been translated for the Norwegian version of the Bayley Scales, we used the original version which is validated in the U.S. population (Bayley, 2006; Breinbauer et al., 2010).

Table 1

The Novel Means Test: Objects, Target Actions and Operational Definitions

	Version A	Version B
Novel actions	Use the forehead to turn on the lamp.	Use the elbow to ring the bell.
		
Operational definitions	Head touch = the lamp is touched by bringing any part of the head to the lamp. Hand touch = the lamp is pressed with the hand. Actions were coded regardless of press was strong enough to switch on the lamp.	Elbow touch = the upper part of the bell was touched by the elbow or the arm. Hand touch = the upper part of the bell was touched with hand or with one finger. Actions were coded regardless of whether the bell rang.

Note. The experimenter demonstrated the novel actions either with hands free or with hands occupied holding a blanket.

Table 2

The Necessary vs. Unnecessary Test: Objects, Target Actions and Operational Definitions

Action steps and operational definitions	Version A	Version B
Step 1	Open the Velcro latch. *Code as "yes if the child opens or clearly tries to open the Velcro latch, no matter if the movement resembled that of the model.*  	Open the latch. *The child opens the latch.*  
Step 2	Lift the lid to open the chest. *The child opens the chest, no matter the details of the movement.*	Pull the door open. *The child opens the door.*
Step 3	Take out the teddy bear. *The child lifts the teddy bear.*	Take out the bird. *The child takes the bird out of the house.*
Step 4	Shake the teddy bear. *The child shakes the teddy bear, i.e., quickly moves it at least once to the one side and then to the other.*	Make the bird walk on the table. *The child makes at least two steps with the bird on the table.*

Note. Operational definitions are written in italics. Pictures show 1st necessary step (left) and 1st unnecessary step (right) for each version.

Table 3

The Functional vs. Arbitrary Test: Objects, Target Actions and Operational Definitions

Version A: Target objects		Functional action	Arbitrary action
Mouse		Use it as a finger puppet. *The child puts a finger in the mouse or the mouse onto one finger. The mouse does not have to be upright.*	The mouse makes a headstand. *The child turns the mouse upside down.*
Teddy bear and box		Attach the box to the teddy's buttons. *The child attaches or tries to attach the box to the belly of the teddy bear, even if it does not hold.*	The teddy jumps 3×. *The child lifts the teddy bear and quickly places it back on the table consecutively at least 2x.*
Postcard and tiger		Lift the postcard using the tiger as a handle. *The child places the tiger onto the postcard, and then lifts the tiger, even if the postcard is not properly attached.*	Roll the tiger back and forth next to the postcard, keeping it under the hand the whole time. *The child places his/her hand onto the lying tiger and then slides his/her hand forward.*
Teacup and man		Turn the cup around and place the man on the rim. *The child turns the cup around and places, or clearly tries to place the man on the rim.*	Place the man on the top of the cup, lying on his belly. *The child places the man on top of the cap, regardless of whether the man is lying on his belly or his back.*
Belted owl		Remove the belt and open the owl to discover that it is a container with a soft toy inside. *The child opens the owl, regardless of removal of the belt.*	Lay the owl on its back and spin it. *The child makes a spinning motion with his/her wrist or fingers while holding the owl, even if this does not result in spinning, OR the child makes the owl spin by whatever movement. The owl does not have to be lying when spun.*
Whale		Press it to click. *The child presses the whale from above on a horizontal surface (e.g., the table or the child's palm), even if this does not result in a clicking sound. It is OK if the whale is lying upside down.*	Slide it across the table. *The child pushes the whale on the table. The movement does not have to follow a curvy path as in the demonstration.*

Version B: Target objects		Functional action	Arbitrary action
Owl		Use it as a hand puppet. *The child puts a hand in the owl or places the owl onto the hand. It is not important whether the owl is upright.*	Swing it by its wing. *The child grabs the owl by its wing and either actively swings it, or just lets it hang.*
Cubes		Lift one cube using the other one. *The child places one cube onto the other one, and then lifts the first one, even if the second cube is not properly attached.*	Switch the cubes 2× by pushing them on the table. *The child switches the two cubes at least once. It is not important whether both or only one cube is being moved.*
Lion with tail		Attach the tail to the lion. *The child presses the tail against the lion's bottom, even if it does not hold.*	Blow on the tail twice. *The child holds the tail in his/her hand in front or at the side of his/her face and either blows on it or forms his/her lips accordingly, even if no air comes out.*
Duck and octopus		Place the duck onto the octopus. *The child places the duck onto the octopus, even if the duck falls down again.*	Turn the duck 180 degrees and then back. *The child turns the duck at least 90 degrees.*
Lion and squirrel		Place the upper part of the lion over the squirrel, and slide it back and forth on the table to make a rattling sound. *The child covers the squirrel with the lion and then moves the lion on the table back and forth or in different directions.*	The lion is walks around the squirrel. *The child moves the lion around the squirrel at least one quarter of a circle.*
Elephant		Press the head to make a squeaking sound. *The child presses the elephant's head, even if the press is not strong enough to release the squeaking sound.*	Turn it on its back and back to its feet 2× with both hands. *The child turns the elephant on its back and back to its feet within one action (i.e., nothing else happens between these two steps).*

Note. The operational definitions are written in italics.

Design and Procedure

Experiment 1

In E1, parents and toddlers visited the lab once and were randomly assigned to either the experimental or the control group. Lab appointments lasted ca. 1.5 hours for the experimental group and 1 hour for the control group. In the control group, toddlers were presented with both objects of the NM-test and both objects of the N/UN-test, and with all test objects from one version of the F/A-test. In the experimental group, for within-subject assessment of selective vs. exact imitation performance, each participant was presented with both versions of the NM-test and the N/UN-test, one in each condition. However, toddlers participated in only one version of the F/A-test because selective vs. exact imitation in this test is determined by imitating only one or both types of target actions that were varied within each version. The target actions in the F/A-test were demonstrated in one of two orders: In Order 1, the first item started with the functional action, the second item with the arbitrary action, and so on. In Order 2, the first item started with the arbitrary action, the second with the functional action, and so on. The full design is presented in Table 4.

Table 4

Design of Experiment 1

	Control group		Experimental group			
Test			Order 1		Order 2	
NM-test	lamp	bell	lamp O	bell F	lamp O	bell F
N/UN-test	box N	birdhouse UN	box N	birdhouse UN	box N	birdhouse UN
F/A-test	version A		version A – order 1		version A – order 2	
NM-test	lamp	bell	lamp F	bell O	lamp F	bell O
N/UN-test	box UN	birdhouse N	box UN	birdhouse N	box UN	birdhouse N
F/A-test	version B		version B – order 1		version B – order 2	

Note. O = hands-occupied; F = hands-free; N = first action necessary; UN = first action unnecessary. Shading is added for better visibility of procedure variations, consisting of variations in experimental conditions, test versions, and the presentation order of target actions in the F/A test.

The lab appointment started with a warm-up period in a friendly waiting area. The experimenter gave information about the study, obtained the parent's written consent, and gathered background information to ensure that participants fulfilled the inclusion criteria. In addition, she played with the toddler until sufficient rapport was established (i.e., the toddler smiled and was actively engaged with the experimenter). Then, the parent, toddler, and experimenter went to the lab, where the toddler was seated on the parent's lap at a table opposite the experimenter. After a social warm-up play, the imitation tests followed, during which the experimenter continued to act in a social manner (using ostensive cues such as eye contact, infant-directed speech, addressing the child by their name, and responding contingently to the child's communicative bids by smiling). In the experimental condition, the toddler first observed the experimenter perform the target action on one of the versions of the NM-test, and immediately got the opportunity to play with the same object for ca. 30 seconds. The same was then repeated with the other version and with both versions of the N/UN-test. Last, the experimenter demonstrated each target action of the F/A-test three times. The demonstration of target actions on each object was preceded by the experimenter saying to the child: "Look, [child's name]! I'm going to show you something" (before the first demonstration) or "Look! I'm going to show it again." (before the second and the third demonstration). After a delay of 30 minutes, toddlers played with each test item for ca. 30 seconds, in the same order as the items were demonstrated. The experimenter placed each test item in front of the child while saying "Look, [child's name]! Now you can play with this." In the control condition, toddlers did not watch any target action demonstration, but they played with the same objects as the experimental group (ca. 30 seconds each) to test the spontaneous performance of target actions. The experimenter acted in the same social manner as in the experimental group, and she introduced each test item by saying “Look, [child’s name]! Now you can play with this.” We videotaped toddlers’ object manipulation using two cameras: one filmed toddlers and the portion of the table within their reach, while the other filmed the whole table, as well as participants and the experimenter, from above. During the delay (or after testing for the control group), the parent was asked to fill in the Social-Emotional Scale (Bayley, 2006; Breinbauer et al., 2010). While the parent completed the questionnaire, the experimenter played with the child and was available if the parent had any questions or needed any clarification of the items in the questionnaire.

Experiment 2

The design of E2 is presented in Table 5. The same procedure was followed as in E1, with a few differences. Parents and toddlers visited the lab twice. Half of the participants met the same experimenter at both appointments (same model condition), while the other half met a new experimenter at each appointment (different model condition). The models were similar, both being female young adults in their twenties (age difference: 5 years), White, and native speakers of Norwegian. In the different model condition, the order in which they met the experimenters was counterbalanced. Each participant completed only one version of each test per appointment to avoid testing for long-term retention of target actions. The order of test versions was counterbalanced. Parents completed the Social-Emotional Scale questionnaire (Bayley, 2006; Breinbauer et al., 2010) at the first appointment.

Table 5

Design of Experiment 2

Condition	Test	Presentation variations			
Same model					
T1	NM-test	lamp O	lamp F	bell O	bell F

	N/UN-test	box N	box UN	birdhouse N	birdhouse UN
	F/A-test	version A	version B	version A	version B
T2	NM-test	bell F	bell O	lamp F	lamp O
	N/UN-test	birdhouse UN	birdhouse N	box UN	box N
	F/A-test	version B	version A	version B	version A
Different model					
T1	NM-test	lamp O	lamp F	bell O	bell F
	N/UN-test	box N	box UN	birdhouse N	birdhouse UN
	F/A-test	version A	version B	version A	version B
T2	NM-test	bell F	bell O	lamp F	lamp O
	N/UN-test	birdhouse UN	birdhouse N	box UN	box N
	F/A-test	version B	version A	version B	version A

Note. O = hands-occupied; F = hands-free; N = first action necessary; UN = first action unnecessary. Shading is added for better visibility of procedure variations, i.e., variations in experimental conditions and test versions.

Coding

From the two experiments, a total of 188 videotaped sessions were coded according to the operational definitions shown in Tables 1- 3. The first 134 sessions were coded by two naïve coders: 75 sessions by the first coder and 59 by both (44% of the videos, 1137 decisions). The two coders reached a strong agreement (McHugh, 2012), Cohen's kappa: .83, $p < .001$. The final 54 sessions were coded by the last author, who had trained the two naïve coders earlier.

Valid Data

To provide valid data for each test, toddlers had to manipulate (i.e., at least touch) the objects and their object manipulation had to be visible and free from parental interference. See

Appendix B for the number of valid cases within each test and separately for each test version and the two experiments.

Exact Imitation

We defined two different measures for exact imitation. First, for analyses of the consistency of exact imitation across test types, we computed a binary exact imitation score for each test. In the NM-test, exact imitation was coded if the toddler imitated the novel action in both the *hands-free* and the *hands-occupied condition*. In the N/UN-test, exact imitation was coded if the toddler imitated the first target action step in both the *necessary* and the *unnecessary condition*. In the F/A-test, exact imitation was coded if the toddler performed at least one functional and at least one arbitrary action.

Second, for all other analyses including exact imitation, we computed an exact imitation score summing all target actions from all three tests that would not be imitated by selective imitators (the novel action in the *hands-occupied condition* and/or the first action step in the *unnecessary condition*, and the six *arbitrary actions*). In E1, the maximum score was 8, and in E2, it was 7.

Results

Results from both experiments are presented combined, according to the four hypotheses. To test the stability hypothesis and the model stability hypothesis, only data from E2 were used. The analyses for Study 1 were preregistered at OSF (https://osf.io/ygt7k/?view_only=03a0df24221b4947b118c1286f91c3c6).

Preliminary Analyses

We analyzed imitation effects in each task and each version within the task by comparing toddlers' performance of target actions between the experimental and the control groups. An imitation effect was indicated by a significantly higher performance score of target actions in the experimental groups than in the control group. First, we established imitation effects for the NM-test in E1 when examining the two versions combined ($U[N_{cont.} = 24, N_{exp.} = 21] =$ 154.00, $z = -3.09$, $p = .002$, $r = -.46$, M[SD]$_{cont.}$ = 0.04[0.20], M[SD]$_{exp.}$ = 0.48 [0.60]). When tested separately, the imitation effect was only significant for the bell in E1 and the lamp in E2 at both test appointments (see Table 6). The goal attainment on both objects, i.e., pressing the lamp and the bell by any means, was more frequent in the experimental groups than in the control group (Lamp: E1: $\chi^2 = 10.26$, $p = .002$; E2$_{T1}$: $\chi^2 = 11.41$, $p = .001$; E2$_{T2}$: $\chi^2 = 12.70$, $p < .001$; Bell: E1: $\chi^2 = 17.73$, $p < .001$; E2$_{T1}$: $\chi^2 = 8.59$, $p = .007$; E2$_{T2}$: $\chi^2 = 11.35$, $p = .001$). Second, we established imitation effects for the N/UN-test in E1 when examining the two versions combined (N/UN-test: $U[N_{cont.} = 23, N_{exp.} = 23] = 104.00$, $z = -3.57$, $p < .001$, $r = -.53$, M[SD]$_{cont.}$ = 3.43 [1.73], M[SD]$_{exp.}$ = 5.70 [.87]). Moreover, the imitation effects were significant for both versions in both experiments. Third, we established imitation effects for the F/A-test in both experiments when examining the two versions combined (F/A-test: E1: $U[N_{cont.} = 26, N_{exp.} = 22] = 22.00$, $z = -5.59$, $p < .001$, $r = -.81$, M[SD]$_{cont.}$ = 0.77[1.18], M[SD]$_{exp.}$ = 4.55 [1.54]; E2: (T1: $U[N_{cont.} = 26, N_{exp.} = 63] = 65.50$, $z = -6.88$, $p < .001$, $r = -.73$, M[SD]$_{exp.}$ = 4.30 [1.42], T2: $U[N_{cont.} = 26, N_{exp.} = 60] = 41.50$, $z = -7.03$, $p < .001$, $r = -.76$, M[SD]$_{exp.}$ = 4.85 [1.60]). Furthermore, the imitation effects were significant for both versions in both experiments (Table 6). The presentation order of target actions did not have an effect on toddlers' performance, see Appendix A.

Table 6

Imitation Effects in the Three Imitation Tests in Both Experiments

	Baseline		**E1**				**E2: T1**				**E2: T2**			
NM-test	***N***	**%**	***N***	**%**	χ^2	***p***	***N***	**%**	χ^2	***p***	***N***	**%**	χ^2	***p***
Lamp	24	4.17	22	22.73	3.49	.090	33	33.33	7.11	.009	28	57.14	16.48	.001
Bell	26	0.00	22	22.73	6.60	.015	30	13.33	3.73	.115	32	6.25	1.68	.497
N/UN-test	***N***	***M (SD)***	***N***	***M (SD)***	***U***	***p***	***N***	***M (SD)***	***U***	***p***	***N***	***M (SD)***	***U***	***p***
Box	26	1.88 (1.37)	23	3.22 (.85)	135.00	.001	33	3.15 (1.09)	205.50	.001	28	2.39 (1.41)	218.50	.009
Birdhouse	23	1.48 (1.16)	22	2.48 (1.38)	149.50	.008	30	2.57 (0.97)	171.50	.001	31	2.00 (1.37)	220.00	.014
F/A-test	***N***	***M (SD)***	***N***	***M (SD)***	***U***	***p***	***N***	***M (SD)***	***U***	***p***	***N***	***M (SD)***	***U***	***p***
Version A	12	1.25 (1.14)	11	5.64 (0.81)	0.00	.001	33	4.64 (1.39)	15.00	.001	29	4.93 (1.83)	14.00	.001
Version B	14	0.36 (1.08)	11	3.45 (1.29)	7.50	.001	30	3.93 (1.39)	17.50	.001	31	4.77 (1.36)	9.50	.001

Note. NM-test = Novel Means Test; N/UN-test = Necessary vs. Unnecessary Test; F/A-test = Functional vs. Arbitrary Test. Fisher's Exact tests were conducted for the analyses for the NM-test, and Mann-Whitney U tests for the U/UN- and the F/A-test. P-values indicate significant differences compared to baseline performance (two-tailed tests).

Second, we investigated whether toddlers' selective vs. exact imitation patterns matched previous findings. Wilcoxon signed-rank tests confirmed that toddlers' performance was consistent with former findings on 18-month-old toddlers' selective vs. exact imitation in the F/A-test, i.e., toddlers imitated significantly more functional than arbitrary actions in both experiments (E1: $z = -4.14$, $p < .001$, $r = -.88$; E2$_{T1}$: $z = -6.77$, $p < .001$, $r = -.85$; E2$_{T2}$: $z = -6.70$, $p < .001$, $r = -.86$). However, two-sided McNemar's tests indicated that the patterns of selective vs. exact imitation were not in line with former findings in the NM-test in either of the experiments, i.e., toddlers did not imitate the novel means actions in the *hands-free condition* more often than in the *hands-occupied condition*. In E1, 33.3% (7/21) imitated the novel action in the *hands-free condition,* and 14.3 % (3/21) imitated the novel action in the *hands-occupied condition* ($p = .289$). In E2, 28.1 % (16/57) imitated the novel action in the *hands-free condition,* and 24.6 % (14/57) imitated the novel action in the *hands-occupied condition* ($p = .832$). Moreover, imitation patterns were not consistent with former findings in the N/UN-test in either of the experiments, i.e., toddlers did not imitate the first action step in the *necessary condition* more often than in the *unnecessary condition*. In E1, every participant in the necessary (12) and the unnecessary (11) condition performed the first target action step with the boxes. With the birdhouses, 10/12 (83.3%) toddlers performed the first target action step in the *unnecessary condition* and 7/11 (63.6%) toddlers in the *necessary condition*, $\chi^2(1) = 1.16$, $p = .371$. Because of the high imitation performance of the first action step, the performance of the first two action steps in the demonstrated order was examined in post hoc analyses. With the boxes, all toddlers in the *necessary condition* (11) and 5/10 (50%) in the *unnecessary condition* performed the first target action step before the second step ($\chi^2(1) = 7.22$, $p = .012$). With the birdhouses, all toddlers in the *necessary condition* (6) performed the first target action step before the second step, and 6/10 (60%) toddlers in the *unnecessary condition* ($\chi^2(1) = 3.20$, $p = .234$). In E2, the same toddlers participated in both versions of the N/UN-test. Therefore, the performance of the first target action step was analyzed together for both versions. 90.7% (49/54) of participants imitated the first target action step in the *necessary condition*, and 81.5% (44/54) in the *unnecessary condition*. The two-sided McNemar's test indicated that this difference was not significant (p = .267).

Consistency Hypothesis

The consistency of toddlers' selective vs. exact imitation was examined across test types in both experiments. Descriptive statistics are shown in Table 7. In E1, exact imitation had low consistency across the three tests, Cronbach's α = .347. Only one toddler imitated exactly in the NM-test. Removing this test, the consistency between the N/UN-test and the F/A-test was r = .41. In E2, exact imitation had very low consistency across the three tests, Cronbach's α = .034. Only four toddlers imitated exactly in the NM-test. Removing this test, the consistency between the N/UN-test and the F/A-test was r = .08.

Table 7

Descriptive Statistics of Exact Imitation

	Experiment 1 (*n* = 20)			Experiment 2 (*n* = 57)		
Test	Frequency	*M*	*SD*	Frequency	*M*	*SD*
NM-test [a]	1	0.05	0.22	4	0.07	0.26
N/UN-test [b]	15	0.75	0.44	40	0.70	0.46
F/A-test [c]	11	0.55	0.51	27	0.47	0.50

Note. Frequency represents numbers of toddlers who imitated exactly within each test. [a] Imitated the novel action in the hands occupied condition. [b] Imitated the first action step in the unnecessary condition. [c] Imitated some arbitrary actions.

Stability Hypothesis

We investigated the stability of toddlers' exact imitation scores across two test days in E2. Out of a maximum of 7, toddlers (n = 57) had an average exact imitation score of M = 1.32 (SD = .89) on the first test day and M = 1.56 (SD = 1.05) on the second test day. The exact imitation scores did not correlate between the two test days, r_s = -.04, p = .754. However, post hoc analyses showed a significant positive correlation of moderate strength between the overall imitation scores on the two test days (M_{T1} = 7.39, SD_{T1} = 1.78, M_{T2} = 7.88, SD_{T2} = 2.44, r_s = .38, p = .003).

Because the F/A-test was the test with the most variations in imitation performance, in post hoc analyses we examined the stability of exact imitation (i.e., arbitrary action performance) and overall imitation (i.e., imitation of both functional and arbitrary actions) in the F/A-test. The degree of exact imitation in the F/A test did not correlate between the two test days (n = 57, M_{T1} = .88, SD_{T1} = .78, M_{T2} = .96, SD_{T2} = .87, r_s = .18, p = .187). However, the overall imitation score was stable across the short-term design (n = 57, M_{T1} = 4.26, SD_{T1} = 1.42, M_{T2} = 4.89, SD_{T2} = 1.61, r_s = .68, p < .001).

Model Stability Hypothesis

We examined toddlers' stability in exact imitation in the same and different model conditions across the two test days in E2. Exact imitation did not correlate between the first and the second test day either in the same model condition (n = 31, r_s = -.07, p = .713) or in the different model condition (n = 26, r_s = .01, p = .968). These correlations did not differ significantly from each other (z = - 0.285, p = .776). Post hoc analyses showed a moderate significant correlation of overall imitation scores between the two test days in the same model condition (n = 31, r_s = .39, p = .028), and a moderate and non-significant correlation in the different model condition (n = 26, r_s = .36, p = .070). The difference between the two correlations was not significant (z = 0.124, p = .901).

Social-Emotional Correlation Hypothesis

In E1, toddlers (N= 49) had an average Bayley score of M = 116 (SD = 12.01), Mdn = 114, range = 96-140). In E2, for the toddlers with valid data from both appointments (N = 66), the average Bayley score was M = 115.17 points (SD = 12.78), Mdn = 115.50, range = 88-139.

The correlations between social-emotional development scores and exact imitation scores were not significant either in E1(r_s = -.16, p = .488) or in E2 (T1: N = 63, r_s = .17, p = .172; T2: N = 60, r_s = -.002, p = .988).

Discussion

The present study examined toddlers' selective and exact imitation patterns in three imitation tests: the NM-, N/UN-, and the F/A-test. The primary objectives of the study were to investigate whether toddlers' exact imitation is consistent across test types (*consistency hypothesis*), stable across a short-term design (*stability hypothesis*), and related to social-emotional development (*social-emotional correlation hypothesis*). Despite the conceptual similarity of the three test types, toddlers' exact imitation was not consistent across tests. Furthermore, only toddlers' overall imitation performance, but not their degree of exact imitation, was stable across time. Significant correlations between exact imitation and social-emotional development were not found either. Overall, these results do not support the hypothesized underlying developmental change in the action selection processes at this age. Instead, they suggest that toddlers' action selection might vary dynamically across tasks and situations.

Relatedly to the stability hypothesis, we explored whether prior short-term familiarity with the model affected stability correlations of exact imitation (model stability hypothesis). We found that meeting the same model at both appointments did not lead to a stronger stability correlation compared to meeting different models, which suggests that familiarity and accumulated rapport between the child and the model do not affect the stability of exact imitation across a short-term context.

Imitation Effects and Selective vs. Exact Imitation

Our results replicate previous findings on 18-month-olds' overall imitation skills, both in immediate (e.g., Brugger et al., 2007; Kim et al., 2018) and in deferred imitation tests (e.g., Óturai et al., 2013; Óturai et al., 2018; Óturai et al., 2012). Imitation effects were established in all three imitation tests used in the present study, i.e., the experimental groups performed significantly more target actions than the control group. A significant imitation effect was also found in almost all individual test versions (the only exception being the lamp in E1 and the bell in E2 in the NM-test).

Comparing our results to previous findings on selective vs. exact imitation, our adaptations of the N/UN-test and the F/A-test appear more successful than our adaptation of the NM-test. First, in the N/UN-test, most toddlers imitated the first action step regardless of its necessity, but not all did so before performing the second step. Therefore, in post hoc analyses, we compared the imitation of the first two steps in the demonstrated order across conditions, as a stricter measure of exact imitation. Naturally, all participants imitated the first two steps in the demonstrated order in the *necessary condition* (because the opposite order was physically impossible). Still, only half of the participants did so in the *unnecessary condition*. This finding adds to previous research suggesting that 18-month-olds' imitation is neither completely selective nor entirely exact in the N/UN-test (e.g., Brugger et al., 2007; Kim et al., 2018). Second, in the F/A-test, imitation rates of functional and arbitrary actions replicated previous findings showing that 18-month-olds imitate significantly more functional than arbitrary target actions (Óturai et al., 2013; Óturai et al., 2018; Óturai et al., 2012). Yet, contrary to previous studies, the imitation rates of arbitrary target actions did not significantly differ from baseline performance. This could be due to overall task difficulty or the lengthy test procedure with two immediate imitation tests preceding the F/A-test. Third, unexpectedly, the imitation of novel actions in the NM-test did not differ between the *hands-free* and the *hands-occupied* condition. Our study is not the first one that failed to replicate the effect of condition in this test. Both 13- and 16-month-olds in Heimann et al's (2017) study and 18-, 24- and 36-month-olds in Gellén and Buttelmann's (2019) study were equally likely to imitate the novel action in both conditions. However, a numerical difference is apparent in the 18-month-old group of the latter study, approaching statistical significance. Furthermore, although imitation effects were established in the NM-test when analyzing the test versions together, upon analyzing the separate test versions, we discovered that the effects of imitation differed based on the specific items used in each experiment. This pattern of results makes it unlikely that the lack of imitation effect could be explained by inherent characteristics of the test items, such as one of them being less attractive to toddlers than the other.

Consistency of Toddlers' Selective vs. Exact Imitation

Previous research on the consistency of selective vs. exact imitation across different types of imitation tests is sparse, and the available findings do not provide a clear picture. While all of them report correlations between exact imitation on different test types, Kim and colleagues (2018) also found that performance on different tests was impacted by the social context differently. Moreover, Yu and Kushnir (2020) found that imitation was not consistent across all versions of the same task type, and in Sakkalou and colleagues' (2013) study consistency was confounded with stability over a one month period. Our findings show that toddlers' selective vs. exact imitation was not consistent across the NM-, N/UN-, and the F/A-test, which points to the relative importance of task characteristics compared to underlying developmental shifts in action interpretation or motivation. Nevertheless, the lack of consistency might also be merely a consequence of the low variance in exact imitation scores in the NM- and the F/A-test.

Stability of Selective vs. Exact Imitation and Overall Imitation Performance

Contrary to our hypothesis, toddlers' degree of exact imitation was not stable across the two test appointments. In contrast, others have found that infants' selective imitation was stable between 13 and 14 months of age (Sakkalou et al., 2013). These contrasting results might reflect differences in the studied age groups: Infants around the age of 1 year imitate predominantly selectively (Gergely et al., 2002; Kolling et al., 2014; Óturai et al., 2012; Schwier et al., 2006), whereas at 18 months, toddlers' imitation is neither predominantly selective nor exact (Nielsen, 2006; Óturai et al., 2013; Óturai et al., 2012; Tennie et al., 2006). Thus, the lack of stability found in our study could reflect an ongoing developmental shift in the processes underlying 18-month-olds' imitation that are not yet entirely set. Alternatively, similarly to the lack of consistency, this finding could also be due to the low variance in exact imitation scores.

Although the pattern of selective vs. exact imitation was not stable across the short-term design, post hoc analyses found a moderate positive correlation in overall imitation between the two test days. Similar results were obtained when analyzing the F/A-test separately, where we found a strong positive correlation in overall imitation between the two test days. Our findings of stability in overall imitation performance replicate and add to previous research that found stability in overall imitation from 9 to 24 months of age (Heimann & Meltzoff, 1996; Kolling et al., 2009; Nielsen & Dissanayake, 2004; Sundqvist et al., 2016).

Our findings showed particularly strong overall imitation stability in the F/A-test, which implies that deferred imitation tests are reliable measures of general imitation ability in the second year of life. Deferred imitation tests have been proposed as a diagnostic tool to detect individual differences and developmental delays (Brito et al., 2019), both because of their strong empirical base and because deferred imitation performance is a good predictor of later cognitive outcomes (Riggins et al., 2013; Strid et al., 2006). The strong stability of overall imitation performance between the two versions of the F/A-test developed for the present study points to the potential of this test to be used for diagnostic purposes in future research.

Stability Correlations in the Same Model and in the Different Model Condition

Although the stability correlations of exact imitation in the whole sample were not significant, we tested whether they differed in magnitude between the same model and the different model conditions. Exact imitation was not more stable when toddlers met the same model compared to a new model on the two test days, which suggests that general aspects of the social context influenced toddlers' exact imitation stability more than their accumulated rapport with the model. Future studies could examine whether a more extended prior familiarization with the model would impact the stability of exact imitation differently. Similarly, the stability correlations of overall imitation performance did not differ significantly between the same model condition and the different model condition, either.

Relation Between Exact Imitation and Social-Emotional Development

Contrary to our hypothesis and previous findings (Hilbrink et al., 2013; Yu & Kushnir, 2020), we did not find any support for our social-emotional correlation hypothesis: Higher scores on the Social-Emotional Scale questionnaire (Bayley, 2006; Breinbauer et al., 2010) were not related to exact imitation in any of the experiments. This finding contrasts with our argument that relations between overall imitation performance and social development (e.g., Kolling & Knopf, 2015) are likely to be driven by exact imitation. Nevertheless, this null result could also be due to the measures used; a more proximal measure of social-emotional skills, instead of a parental questionnaire, might have better captured the relevant aspects of development.

Strengths and Limitations

Our study was the first to test the short-term stability of toddlers' imitation using a parallel test design. This design allowed us to investigate stability in imitation performance without the influence of memory retention effects. In addition, it was the first study that investigated the consistency of toddlers' selective vs. exact imitation across different imitation tests. Although previous findings obtained with all three test types are consistent with a developmental shift towards exact imitation in the second half of the second year of life (Hilbrink et al., 2013; Matheson et al., 2013; Nielsen, 2006; Óturai et al., 2013; Óturai et al., 2018; Óturai et al., 2012; Tennie et al., 2006), they have not been directly compared within the same sample before. Contrary to our expectations, instead of strengthening the idea that the NM-test, the N/UN-test, and the F/A test tap into the same processes underlying selective vs. exact imitation, our results emphasize the role of task-specific effects in toddlers' action selection in imitation tests.

The study also had some limitations that must be noted. The imitation rates of arbitrary actions in the F/A-test were notably lower than the findings of former research (Kim et al., 2018; Óturai et al., 2013; Óturai et al., 2018) and thus, we could not establish imitation effects for arbitrary actions. This could be due to our relatively long testing procedure with two immediate imitation tests prior to the deferred F/A-test. Imitation rates of the novel action in the NM test were also considerably lower than expected. The objects used in the present study were not exact replicas of the objects used in previous studies. Nevertheless, it is unlikely that the objects themselves were the reason for the low imitation rates, as toddlers did manipulate them to a similar degree as the objects in the two other tests, and many of them copied the action goals. Regardless of the reasons for low imitation rates of arbitrary actions in the F/A-test and novel actions in the NM-test, they might have impacted all further analyses, which therefore must be interpreted with caution.

Furthermore, we acknowledge that the binary exact imitation score used for testing our consistency hypothesis was not equally well suited for all test types. Converting the imitation rate of arbitrary actions in the F/A test led to a loss of variance in toddlers' degree of exact imitation. Nevertheless, to test consistency, the same scale was necessary to use for each test. Lastly, as our sample only included families from Norway, our findings may not be generalizable to the global population but are relatable to WEIRD populations (i.e., Western Educated Industrialized Rich and Democratic samples) such as European and US samples.

Conclusions

The findings of this study extend our understanding of 18-month-old toddlers' selective and exact imitation across time and different imitation tests in immediate and deferred imitation settings. Toddlers' selective vs. exact imitation was not consistent across conceptually similar imitation tests and lacked stability over time. These findings indicate that 18-month-old toddlers' selective vs. exact imitation is strongly influenced by task-specific and situational factors. This does not contradict the existence of a developmental shift from selective towards more exact imitation. Instead, it might indicate an ongoing developmental change that is not fully set and thus more influenced by external factors. Future research might consider testing older toddlers, closer to the age of two years, when exact imitation can be expected to have stabilized. Although the data did not support the expected stability and consistency of selective vs. exact imitation, we found strong stability correlations in toddlers' overall imitation performance in the F/A Test. This finding provides additional support for the diagnostic use of deferred imitation tests in memory assessment, and the parallel test versions offer a way to avoid test-retest effects in potential intervention studies.

Disclosure statement

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Data availability statement

The data that support the findings of these studies are available on the Open Science Framework: https://osf.io/9x3qy/?view_only=7359f038e87b45e58d72f46e37f3de5f

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Appendix A

Order Effects

Mann-Whitney tests demonstrated that the presentation order of action type in the F/A-test in E1 did not impact the imitation rates of functional actions and arbitrary actions or the overall imitation of both functional actions and arbitrary actions (see Table A.1).

Table A.1

Order Effects in the Functional vs. Arbitrary Test

	U	*z*	*p*	*r*	*Mdn*	range
Version A (*N*= 11)						
Functional actions	10.00	-0.97	.364	-0.29	4	3-6
Arbitrary actions	11.50	-0.71	.665	-0.21	2	0-2
All actions	12.00	-0.60	.630	-0.18	6	4-7
Version B (*N* = 11)						
Functional actions	11.00	-0.77	.537	-0.23	3	1-5
Arbitrary actions	11.50	-0.83	.545	-0.25	0	0-1
All actions	11.00	-0.76	.522	-0.23	3	1-5

Note. All actions = imitation of both functional and arbitrary actions.

Appendix B

Valid Data in all Versions of the Imitation Tests in both Experiments

	Experiment 1		Experiment 2		
Test & version	Baseline	Experimental	T1	T2	T1&T2
NM-test					
Lamp	24	22	33	28	
Bell	26	22	30	32	
Lamp & bell	24	22			
N/UN-test					
Box	26	23	33	28	
Birdhouse	23	23	30	32	
Box & birdhouse	23	23			
F/A-test					
Version A	12	11	33	29	
Version B	14	11	30	31	
All three tests	21	20	63	60	57

Note. For the NM-test and the N/UN-test to be counted as valid, toddlers needed valid data from both versions (and hence both conditions). Participants needed valid data for > 3 items of the F/A-test to be counted as valid. In E2, imitation effects were tested separately for T1 and T2. Thus, analyses of imitation effects only required valid data from the test day in question. However, for the analyses related to selective vs. exact imitation, valid data from both test days were needed in the NM and N/UN tests because, in these, toddlers only participated in one condition per test day and both appointments were needed to test stability.

Appendix B: Study 2

Flatebø, S., Óturai, G., & Hernik, M. (2024)

No evidence for adult smartphone use affecting attribution of communicative intention in toddlers: Online imitation study using the Sock Ball Task

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RESEARCH ARTICLE

No evidence for adult smartphone use affecting attribution of communicative intention in toddlers: Online imitation study using the Sock Ball Task

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Abstract

Adults infer others' communicative intentions, or lack thereof, from various types of information. Young children may be initially limited to attributions based on a small set of ostensive signals. It is unknown when richer pragmatic inferences about communicative intentions emerge in development. We sought novel type of evidence for such inferences in 17-to-19-month-olds. We hypothesized that toddlers recognize adults' smartphone use in face-to-face interactions as incongruous with ostension and would rely on this interpretation when inferring the communicative intention of a model in a new imitation task conducted entirely online, dubbed the Sock Ball Task. In Experiment 1 with a between-subject design, we tested the hypothesis by assessing toddlers' ($N = 48$) imitation of sub-efficient means and the goal-outcome presented by a model, who interrupted her ostensive demonstration either by using a smartphone or by fiddling with her wristwatch, depending on the condition. We expected toddlers to imitate the sub-efficient means more faithfully in the wristwatch condition than in the smartphone condition. But there was no significant effect of condition on imitation of neither means nor goal. Thus, our hypothesis was not borne out by the results. In Experiment 2, using a within-subject design, we first assessed toddlers' ($N = 24$) performance in a no-demonstration baseline and then again after a no-disruption ostensive demonstration. In all three conditions with ostensive demonstration (Experiment 1: smartphone, wristwatch; Experiment 2: no-disruption), toddlers produced the demonstrated sub-efficient means significantly above the baseline level. In the no-disruption condition, goals were also imitated significantly above the baseline level. We conclude that the Sock Ball Task is a valid research tool for studying toddler imitation of novel means actions with objects. We end by discussing suggestions for improving the task in future studies.

Introduction

When communicating with one another, adults rely on various sources to infer the speaker's intention to communicate [1, 2]. The richness of these sources and inferences is well captured

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in cases where the process eventually leads the recipient to abandon the initial stipulation about the speaker's communicative intention [3]. Imagine hearing a passer-by say "Hi. How are you?" as they approach you waiting at the bus stop. Even though they use a familiar phrase that typically opens a conversation, you may infer that they do not intend to communicate with you. What could support this conclusion? Perhaps while you turn to them with a confused smile, the rhythm and trajectory of their gait do not change at all. They rather avoid making eye contact with you than establish it. They burst out laughing and exclaim, "Yes, I am close. I am passing by the bus stop right now. Trzymaj się!" which–despite being true–is not what you would expect to hear next if they indeed had been addressing you: You do not see any reason for the laughter, the provided information has low relevance to you, and part of the message is in a language you do not speak. You eventually observe that they are wearing an earpiece, which confirms your suspicion that they are conversing with someone on the phone. You can even infer with some certainty that they are heading to a meeting and inform the interlocutor that they will be there soon. In this scenario, the inference is informed by the speaker's several verbal and non-verbal signals in relation to expectations evoked by (what could have been initially interpreted as) the opening ostensive addressing. It is also informed by context and semantic knowledge of earpieces and their use. It is an example of a complex inference of the kind adults routinely engage in as participants in ostensive-inferential communication [1]. But it is still unknown at what point in development children start engaging in this type of rich inferences about communicative intentions. In the current study, we sought to answer this question by investigating 18 – month-olds' imitation, when they are addressed by a model who uses a smartphone.

In the next three sections we will review the existing literature on the early sensitivity to communicative intentions in infancy, on smartphone use in face-to-face interactions in general and on its use in face-to-face adult-child interactions specifically. We will argue that the ubiquitous presence of smartphone use in face-to-face interactions creates a previously unexplored opportunity to further our understanding of toddlers' early inferences about communicative intentions.

Early sensitivity to communicative intentions

There is a growing interest in the early developmental roots of pragmatic inferences [4–6]. Research on very young children's abilities to attribute communicative intentions has focused on their sensitivity to specific behaviors that act as *ostensive signals* for adults and elicit responses consistent with this function in infants. Newborns orient preferentially to eye contact [7]. Infants in the first months of life show a preference for contingent responsivity [8] and for sources of infant-directed speech [9, 10]–a prosodic pattern that typically signals communicative intention directed specifically at babies [11]. By 4.5 months infants preferentially orient to sound patterns of their own name [12]. By 5 months hearing their own name may have similar effects on neuronal activation and object processing as detecting eye-contact [13, 14].

Ostensive signals may facilitate interpreting other behaviors as communicative referential signals. For instance, infants around 6 months of age followed shifts of head and gaze with their own gaze, when these were preceded by infant-directed speech, but not when they were preceded by adult-directed speech [15, 16]. However, the results were mixed when the role of eye contact was assessed [16–18]. Eight-, 10- and 12-month-olds follow with their own gaze the orientation changes of a completely novel agent that first reacted contingently to the child's behavior [19–21]. By 12 months of age, pointing may be a referential gesture for infants, if preceded by communicative speech [22]. By 14 months, toddlers may rely on the previous shared experience with the speaker to interpret her ambiguous referential pointing, suggesting early pragmatic inference in an ostensive context [23].

We know much less about the early ability to infer communicative intention based on sources other than the early available set of ostensive signals. This seems to take time to develop in the first two years of life. According to one study, young 2-year-olds can interpret an intentional action of lifting a bucket by pulling a rope, as a communicative act even in the absence of typical ostensive and referential signals and language [24]. But how and when, during the first two years of life, children enrich their repertoire of pragmatic inferences supporting attribution of communicative intentions is largely unknown.

In the present study, we sought novel type of evidence for toddlers engaging in rich inferences about communicative intentions. Specifically, we hypothesized that by 18 months, toddlers might be able to recognize one commonly observed category of adult behavior as incongruous with ostension, namely adults' smartphone use in face-to-face interactions. Consequently, toddlers may rely on this interpretation when inferring the communicative intentions of adults.

Smartphone use in face-to-face social interactions

Using smartphones during face-to-face interactions has become commonplace among the general urban population [25–28]. Despite its prevalence, such smartphone use is often perceived as having a negative impact on the quality of in-person interactions [26, 29–39]. Moreover, smartphone use in social interactions is often represented as socially unacceptable [40, 41] and as an impolite and annoying behavior [31, 35, 42–44]. These negative interpretations of mobile phone use are well captured by the term "phubbing", a portmanteau coined by a marketing campaign for the Macquarie Dictionary [45], reflecting how others' engagements with *phones* in face-to-face interactions may easily be interpreted as *snubbing* [28, 30].

Much of the literature examining the consequences of smartphone use in face-to-face interactions focuses on short- [26, 30, 31, 46, 47] and long-term [38, 48, 49] negative impacts on interpersonal relations and highlights the role of the negative feelings of being neglected and ostracized experienced by the partner, who does not use the phone [30, 40, 46, 47, 50–53]. Importantly for the topic of the current paper, several findings and theoretical themes in this literature are consistent also with the notion that adults detect how smartphone use during face-to-face interaction is at odds with what they expect from a communicative partner. It is often judged as going against various norms of social interactions [31, 35, 43, 54–58]. The person using the phone may be considered less responsive [46, 49, 59], inattentive to the partner [31, 35, 49], and not doing the due job of maintaining the common focus [49, 58, 60, 61]. Lack of access to the content that the phone-user focuses on is thought to affect the partner's response [62] and making the content of the smartphone a shared focus between the partners is considered a good strategy to remedy negative emotional impacts [58, 63]. Withholding eye-contact and contingent acknowledgements and responses is thought to be a typical part of phone use during in-person interactions [30, 53, 61, 64–66] and it is thought responsible for reflexive activation of feelings of being excluded and ostracized [30, 40, 53]. Notably, both eye-contact and contingent turn-taking are key behavioral signals regulating attribution of ostension and expectations related to them are indeed bound to be frustrated when the communication partner engages with a smartphone. For example, while eye contact is an important marker of shared attention throughout conversation [e.g., 67], the lack of or inconsistent eye contact caused by smartphone use signals inattentiveness [e.g., 35].

To our knowledge, the impact of the communicative partner's smartphone use specifically on the attribution of communicative intention and on related expectations has not been studied directly in adults. However, some factors thought to drive the emotional and interpersonal effects that have been studied are also likely to impact attributions of communicative intention and to frustrate expectations about the communicative partner's behaviors and contributions [68].

Smartphone use in face-to-face adult-child interactions

Just as smartphone use became commonplace in face-to-face interactions between adults, it became widespread in face-to-face interactions between adults and children. There is a growing body of literature exploring various aspects related to children's involvement in social situations where others use smartphones. In surveys, parents often report that their use of smartphones disrupts their face-to-face interactions with their children [69]. Observational studies have demonstrated that toddlers are frequently subjected to parents' smartphone use in environments such as restaurants, playgrounds, and waiting areas [70–76]. Moreover, the observational data show that in social situations with smartphones, children sometimes leave the parent-child interaction, misbehave, or express frustration or disappointment [71, 74]. Furthermore, McDaniel and Radesky [77] found an association between child behavior problems and parents' smartphone distractions in a survey using parental reports. Overall, smartphone use is assumed to impact parent-child communication negatively [71, 74, 77].

Some experimental studies hypothesized that adult phone use may impact learning negatively in young children. However, the results were mixed [78, 79]. For example, Konrad and colleagues [79] investigated the effect of parents' texting interruptions on toddlers' imitation learning and found no evidence for texting decreasing imitation rates. In contrast, Reed, Hirsh-Pasek, and Golinkoff [78] found that mothers' phone call disruption negatively affected toddlers' word learning, i.e., the toddlers showed no evidence of learning the novel words when the teaching session was interrupted by a phone call. However, as discussed by Reed, Hirsh-Pasek, and Golinkoff [78], it is unclear whether the underlying causes were specific to the phone disruption or whether they had to do with more general factors such as rate of eye contact, the mother's affect and body orientation, or the content of her communication. In this study, the lack of a control condition including a non-phone-related disruption precludes drawing firm conclusions about the specific effects of phone disruptions on learning in adult-child interactions.

Consistent with adults' negative responses to smartphone use during in-person interactions, several studies claimed that children tend to display negative emotions when they observe adults using smartphones [64–66, 80]. Modified still-face studies have shown that infants respond with increased negative affect when the parents pretend to use a smartphone [64–66]. However, because these studies did not use a matched control disruption without a smartphone, it remains unclear whether infants' negative responses were elicited by the appearance of smartphone use or if these were typical responses elicited in the still-face paradigm [for a review, see 81, 82]. Nevertheless, there is some evidence showing that young children react differently to phone disruptions than to other types of disruptions. For example, Rozenblatt-Perkal, Davidovitch, and Gueron-Sela [80] found a higher increase in infants' heart rates and negative affect (both of which can be interpreted as stress indicators) when a mother-child interaction was disrupted by maternal smartphone use compared to when the interaction was disturbed by the mother talking to someone present in person. It should be also noted that while several studies assume that still-face is a good model for adult behavior during smartphone use, it is not clear how well it approximates everyday smartphone use. Facial expressions during smartphone use do vary in frequency, valence, and intensity. For instance, a funny text message, or social-media content can make the reader frown, smile, or laugh [e.g., 83]. Furthermore, in real-life situations the degree of smartphone absorption varies depending on type of smartphone usage, e.g., quickly checking the time vs. reading a longer text on the smartphone [e.g., 74]. Finally, by assuming still-face as a model of parental smartphone use, researchers focus primarily on the emotional impact on the infant, potentially foregoing the chance to explore the impact on the child's representation of the adult's behavior.

Potential impact of parental smartphone use on toddler emotional development and the interplay with factors such as parental stress and support of the child's autonomy on one hand, and children's needs, temperament and emotional competencies on the other remain an important topic for future research. However, it lies beyond the scope of the current paper. This broad topic and specific literature [84–88] were brought to our attention by an anonymous reviewer. We come back to it briefly in the discussion.

To summarize this short review, the current literature on adult smartphone use in adult-child interactions and its impacts is dominated by observational and parental-survey studies [69–77]. The conclusions from the few experimental studies are often severely limited due to the lack of necessary controls [78]. One commonly assumed model of parental behavior during smartphone use derived from the still-face paradigm, is likely not capturing the complexity of phenomena that infants are exposed to in real life [64–66]. Our approach in the current study was to go beyond these limitations by investigating the potential impact of adult smartphone-use on infant attribution of communicative intention, in an experimental design with carefully matched control. Furthermore, the study was driven by a theoretical proposal that went beyond the current literature reviewed above. We will present it in the next section.

From exposure to adult smartphone use to early inferences about communicative intention: The hypothesis

When adults use their smartphones while interacting with young children, they are likely to behave in ways that are at odds with children's expectations about ostensive communication. We postulate that there are at least three ways in which this can happen.

First, studies have shown that smartphone use while being with children harms parents' contingency, sensitivity, and responsiveness to children's communicative bids [70, 71, 75, 89, 90]. Given young children's sensitivity to disrupted eye contact [91] and contingency [92, 93] in face-to-face interactions, inconsistent delivery of these ostensive signals during smartphone use is likely to affect their attributions of communicative intention.

Second, children are not able to identify the actual referent of many of the smartphone user's facial expressions and vocalizations. When these are taken as communicative behaviors produced for the child, this could lead to frustrated referential expectation [81, 94–96, for a related argument see 97]. Notably, in adult interactions engaging, with one's phone during a conversation leads to sharing the screen with the conversation partner only in a minority of cases [25, 63], and is presumably even less likely in adult-child interactions.

Third, if expectations related to relevance and common ground play a role at this age, these too may be frequently frustrated in interactions with a smartphone-using adult, whose communicative behaviors may often be delayed [70], have low or unclear relevance and provide poorly matched responses to the child's questions and requests. For example, Kelly and Ocular [89] found that smartphone-using parents more often reported being off-topic in conversations with their children at an aquarium than parents who did not use their smartphones. To sum up, we consider three ways in which adult phone use during in-person interactions with infants can go against infants' expectations in ostensive communication: (i) by crippling consistent delivery of ostensive signals and appropriate behavioral patterns, (ii) by failing to support fulfilment of referential expectation and (iii) potentially by frustrating burgeoning expectations of relevance and common ground.

Maintaining attribution of communicative intention to a smartphone-using adult may be further affected by how deeply absorbed they are with their device. It may be clearer–to children and adults alike–that someone deeply absorbed in reading something on their smartphone is not trying to communicate with them. On the other hand, when the use of the phone is interspersed with communicative contributions (or behaviors with a semblance of communicative contributions), it may become more challenging to determine whether one is the recipient of the ostensive communication. Some authors consider smartphone use in face-to-face interactions as "digital crosstalk" [65–67] akin to crosstalk, i.e., "a conversation or conversation-like activity maintained by persons who differentially share other interaction capacities" [Goffman 1963, as cited in 61]. Although this phenomenon is described for adults' face-to-face interactions with smartphone use, such crosstalk behaviors might as well be relevant to adults' interactions with children.

To sum up, (i) young children are frequently exposed to adult smartphone use in social situations [70–76]. (ii) Adults typically interpret such behaviors as counterproductive to high quality interactions and communication [26, 29–37]. (iii) Recent findings suggest negative emotional responses in young children to adult smartphone use [64–66, 80]. (iv) Our analyses suggested that adult smartphone use during in-person interactions may systematically frustrate infant expectations related to ostensive communication. Based on these premises, we hypothesized that children may from early on acquire a representation of smartphone use as incongruous with communicative intention. Furthermore, we expected that representing smartphone use this way may diminish children's certainty when attributing communicative intention to an adult who addresses them (i.e., signals intention to communicate) yet also uses a smartphone (i.e., engages in behavior incongruous with communicative intention). We chose to test this general hypothesis in toddlers around 18 months. By this age toddlers are known to consider a wider range of behaviors as communicative [98], to engage in early pragmatic inferences [23], and they may have ample experience with the disruptive effects of smartphone use in face-to-face communication.

In Experiment 1, we tested our general hypothesis, by relying on the assumption that ostensive communication facilitates imitation of novel means in toddlers [99–102]. We expected toddlers to imitate *less* faithfully, if the model, who addressed them ostensively, disrupted the demonstration by engaging in smartphone use, than if she engaged in a matched control behavior (fiddling with a wristwatch). In Experiment 2, we gathered data from two additional conditions: no-demonstration baseline and no-disruption condition, allowing us to assess the validity of our imitation paradigm further.

Experiment 1

Representation of smartphone use as incongruous with ostension

In Experiment 1, our main aim was to examine whether toddlers represent smartphone use as a behavior incongruous with ostension. If so, we expected them to be less certain (when compared to matched control participants) about attributing communicative intention to someone who addresses them ostensively but then uses a smartphone. To investigate this, we developed the Sock Ball Task—an online task assessing imitation of sub-efficient means and goal-outcome.

Sensitivity to ostensive signals is well established within imitation research [99–102]. It has been argued that in the imitation context, toddlers' sensitivity to the model's ostension allows them to infer that the model addresses them and through demonstrated actions conveys content that is relevant for them to learn [e.g., 103]. This relevance-guided interpretation of ostensively presented demonstrations, in which a model performs a goal-directed action, is thought to support faithful imitation of demonstrated means actions, even if they are sub-efficient, i.e., not the most effective way of achieving the demonstrated goal [104, 105]. Consistent with this hypothesis, Király and colleagues [100] found that toddlers imitated sub-efficient means actions at a high rate (and significantly more often than when the context rendered the very same actions efficient) after having received them ostensively demonstrated, but did not show this pattern after having witnessed the actions performed without ostension [for a broader context of this study and different interpretations see also: 106, 107].

In line with these findings and theoretical perspective, we predicted that toddlers would imitate sub-efficient means actions less faithfully if an ostensive demonstration was disrupted by smartphone use compared to if it was disrupted by a matched control behavior (fiddling with a wristwatch). To investigate this, we assessed 17- to-19-month-old toddlers' immediate imitation of a goal-outcome and sub-efficient means actions. The toddlers watched a video demonstration of a model who ostensively addressed them and later non-ostensively performed the target actions with novel objects. Crucially, after the ostensive greeting but before the modeling of actions, the model either used a smartphone (smartphone condition) or fiddled with a wristwatch (wristwatch condition). We assumed that if the ostensive addressing was followed by behavior that toddlers represent as incongruent with ostensive communication, this would lower their certainty that the subsequent goal-directed action is part of the ostensive demonstration. Thus, if toddlers represent smartphone use (but not fiddling with a wristwatch) as incongruous with ostension and rely on this representation to infer others' communicative intentions, we expected toddlers in the smartphone condition to imitate the demonstrated means actions less faithfully on average than the toddlers in the wristwatch condition.

Data collection for this study was bound to happen during the unpredictable times of Covid-19 lockdowns. To test our hypothesis, we had to design an imitation task that could be implemented entirely online with both the experimenter and all the families participating from their homes. It was critical that matched sets of props could be created by parents only from the materials available at home. In this case the materials were: paper and socks. This is how the online Sock Ball Task was created.

Materials and methods

Preregistration

Experiment 1 was preregistered on the Open Science Framework on April 06, 2021 (osf.io/jy8av).

Ethics statement

The study was ethically approved by the internal research ethics committee at the Department of Psychology, UiT The Arctic University of Norway (ref: 2017/1912) and by the Norwegian Centre for Research Data (NSD, ref: 973260). We obtained verbal informed consent from the participants' parents in an information meeting on Zoom.

Participants

The participants were healthy toddlers between 17 months and 0 days and 19 months and 0 days. They were born without any complications after ≥ 37 weeks of gestation and with a minimum birth weight of 2500 g. All participating toddlers and parents understood Norwegian. We recruited the participants from all over Norway by advertising through kindergartens, health stations, libraries, social media channels and media coverage in magazines, newspapers, and in radio interviews. The participating families received a small gift and a certificate.

The required estimated sample size was $N = 48$ based on sample sizes from previous research [78, 79, 102, 108–111]. The final sample consisted of 48 toddlers ($M_{Age} = 546.98$ days, $SD = 18.58$, range = 519 to 578 days) who were randomly assigned to one of the two conditions: the smartphone condition ($n = 24$, 12 girls, $M_{Age} = 548.25$ days, $SD = 19.92$, range = 519 to 578 days) and the wristwatch condition ($n = 24$, 11 girls, $M_{Age} = 545.71$, $SD = 17.48$, range = 520 to 578 days). Sixteen additional toddlers participated but were excluded from the analyses due to failing to complete the test phase: no manipulation of test objects ($n = 8$), major procedural disruptions such as extensive crying ($n = 3$) or parental interference ($n = 5$). None of the toddlers were excluded based on lack of attention to any of the important parts of the demonstration video in the demonstration phase.

Design and procedure

The data collection started during the COVID-19 lockdown and lasted between 7th of April and 9th of November 2021. The families participated in the study from their homes via Zoom using a computer with a web camera and microphone. The experimenter conducted the experiment from her apartment.

An information meeting with the parent alone on Zoom was conducted to explain the study's purpose and procedure, to interview the parent about the inclusion criteria of the study and to obtain verbal informed consent. The information meeting was scheduled either for the day of the appointment or a day close to it.

Data collection was scheduled for the time of day when the parent reported that their child was most alert. The toddlers were seated on the parent's lap at a table, facing the computer placed outside their reach. The parent adjusted the camera angle to make the toddler and the table visible in the video. The parents hid their video-feed window to prevent toddlers from being distracted by their own images. The data collection session involved watching a demonstration video in a demonstration phase and meeting the experimenter live on Zoom for a warm-up phase and a test phase. The toddlers' behavior during all the phases was video recorded for later coding off-line.

Demonstration phase. Depending on the condition that each toddler was assigned to, in the demonstration phase they watched a video either with a smartphone disruption or with a wristwatch disruption (described in the section Demonstration videos and props). The parents shared their screens before playing the demonstration video, to allow for relating the video recording of the child's behavior to the content of the video stimuli. The live feed from the experimenter was not visible to the child and muted during the demonstration phase. The parent was instructed not to interact with and not to direct the toddler's attention to the demonstration video.

Warm-up phase. Immediately after the demonstration phase, the parent and the toddler met the experimenter, who had been the model in the demonstration video, live on Zoom. In her video feed the experimenter was sitting in the same setting, in the same position and wearing the same clothes as in the demonstration video. The experimenter and the parent talked briefly (approximately 30 seconds). During this interaction, the experimenter did not talk directly to the toddler but checked if the toddler was comfortable, as indicated by a lack of negative behavioral signs, such as crying or back arching. If the toddler showed any negative behavioral signs, the experimenter extended the warm-up by initiating a short (approximately 30 seconds) exchange with the toddler, during which the parent introduced the toddler to the experimenter, and the experimenter greeted the toddler by smiling and waving. This was done for 12 children in the final sample (i.e., 25%; 6 in each condition). The experimenter told the parent when the warm-up phase ended, and the test phase was to begin.

Test phase. The parent put the test objects on the table when instructed by the experimenter. The experimenter pointed out that the toddler had the same test objects as her and said, "Look! We have the same things. [Toddler's name], it's your turn!". The test phase during which toddlers' imitation was scored offline lasted 1 minute counting either from the toddler's first touch of one of the test objects or from 30 seconds since all the test objects had been placed on the table, whichever came first. If the toddler did not touch the test objects during the first 15 seconds since placing the objects on the table, the experimenter repeated "[Toddler's name], it's your turn!". The experimenter repeated this instruction every 15 seconds until the toddler touched any of the test objects or until 1.5 minutes had passed since the objects were placed on the table. If the toddler showed any of the objects to the experimenter or the parent, the experimenter or the parent responded by saying, "Oh, how nice!". Fig 1 shows the procedure of Experiment 1.

Demonstration videos and props

Each demonstration video started with music and text on the screen instructing the parent to be silent while the video was playing, followed by a colorful animation to attract the toddler's attention. Next, each video showed the same female model sitting behind the table. A smartphone was lying on the left corner of the table, and the model wore a wristwatch on her right wrist. The smartphone in the demonstration videos was a black iPhone 4S (4.54 × 2.31 × 0.37 inches), and the wristwatch was a black analog quadrangular watch sold by Clas Ohlson (1.5 × 1.5 × 0.35 inches). The same phone and wristwatch were visible throughout the demonstration videos and the warm-up and test phases when toddlers met the model live on Zoom.

The model looked directly into the camera and greeted the toddler by smiling, waving, and saying "Hi." This initial greeting was the only time when there were ostensive signals in either of the videos. It was immediately followed by a disruption, where the model either used the smartphone or fiddled with the wristwatch. In the smartphone condition, the model texted and swiped. In the wristwatch video, the model adjusted the length of the band around the wrist. The model's facial expressions during the disruption were kept neutral in both videos, with one little smirk in the middle of the disruption.

Immediately after the disruption, the model brought three objects from under the table, which she laid on the table-top: two A5 sheets of wrinkled white paper and a soft green ball made of a pair of socks. Then, she took the paper on her right side and covered the sock ball with it. Next, she grasped the sock ball through the paper. She lifted the paper-wrapped sock ball and moved it through the air to the left until it was above the other paper. Finally, the model dropped the sock ball out of the wrapping and kept the paper in her hand. The outcome of this action-sequence was the sock ball lying on the paper. Next the model took the test objects away from the table, put a new set of two papers and a sock ball on the table, and performed the same demonstration with them. At the end she again removed the three props from the table. Each video proceeded to a series of attention-getters presented in the four corners and in the middle of the screen to gather recording of the child focusing on these locations. Finally, a text was shown informing the parent that the video is finished and asking them to close the video link, stop screen-sharing and to put the Zoom session on their screen. Fig 2 displays still-frames from the demonstration videos. All the stimuli are available at OSF (doi.org/10.17605/OSF.IO/E3W4Q).

Parents were instructed (through a pre-prepared instructional video shared with them before the information meeting on Zoom) to prepare two sets of props. Each set consisted of two wrinkled (first squashed and then flattened out) A5-sized white paper sheets and a colored soft ball made of rolled socks. One was a spare set to replace damaged or out-of-reach objects

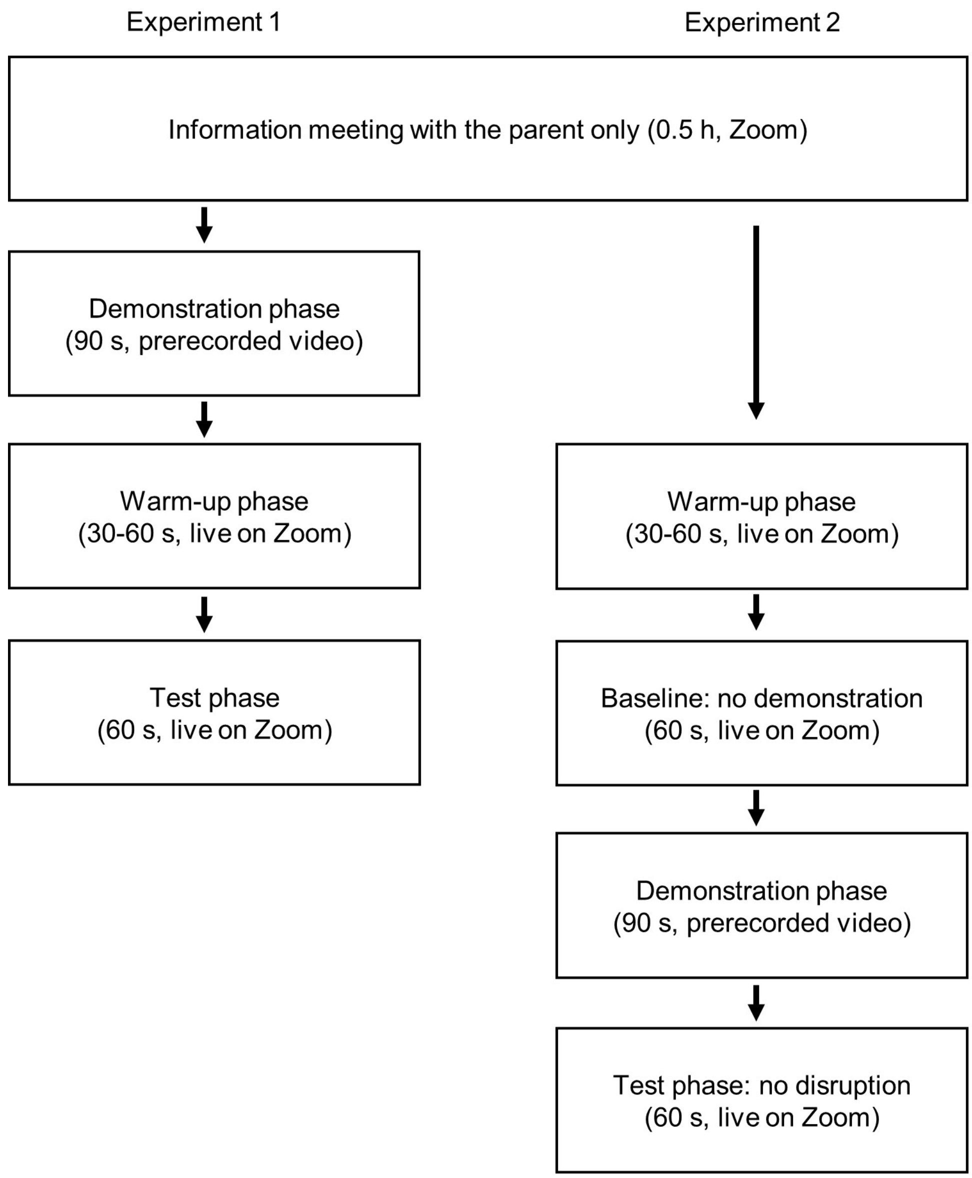

Fig 1. Procedures of Experiments 1 and 2. Note that the information meeting with the parent (uppermost row) always took place sometime before the data collection (the remaining rows).

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during the test phase. The experimenter quality-checked all the test objects during an online information meeting before the data collection session.

Coding

A naïve coder coded toddlers' looking to the demonstration videos to check for the exclusion criteria, i.e., that the toddlers saw at least 2 cumulative seconds of the ostensive greeting and the disruption, and at least one continuous demonstration of the action sequence.

We defined 4 action steps (cover, grasp, move, drop) and the main goal-outcome (ball on paper) to be coded from video recordings of the test phase. We operationalized each of the four action steps by specifying a sub-goal for each of them together with minimal specific criteria for the child's behavior, which would nevertheless help distinguish the target action steps

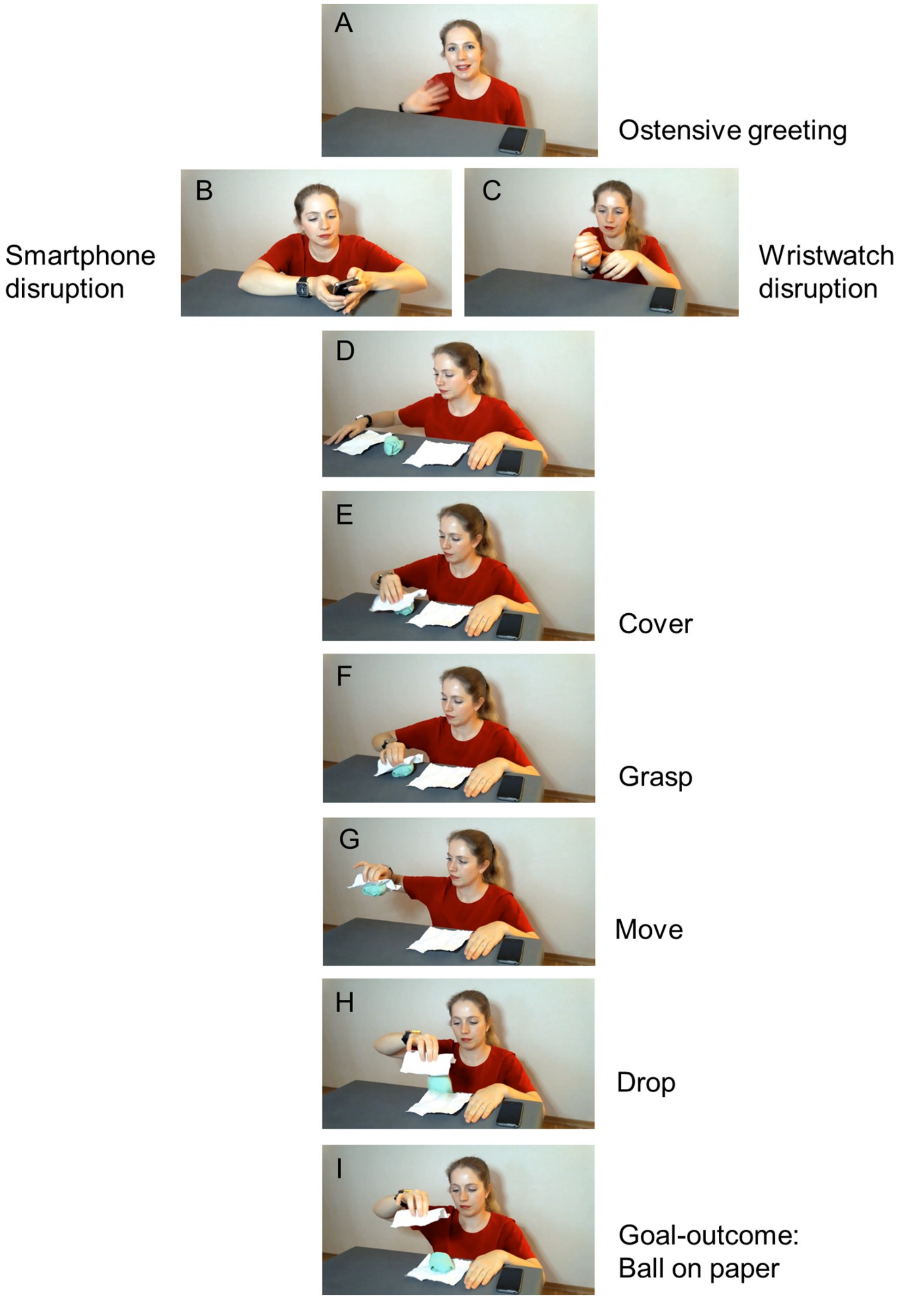

Fig 2. Stimuli in the demonstration phase. Still frames from the stimuli used in the demonstration phase. In Experiment 1, the stimuli for the two conditions (smartphone vs. wristwatch) were closely matched but differed in whether they showed smartphone disruption (B) or wristwatch disruption (C). After producing the goal-outcome (I), the model removed the three props from the table, put another identical set on and performed the sequence shown in still frames D-I once more. In Experiment 2, stimuli used in the demonstration phase of the no-disruption condition were closely matched to those in Experiment 1 but consisted only of steps A and D-I, with the sequence D-I also performed twice.

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Table 1. Coding scheme for the four action steps and the final goal-outcome with specified sub-goals, operational definitions, and additional coding instructions.

Action step /final goal-outcome	Sub-goal, operational definition, and additional coding instructions
Cover	**The paper is on the sock ball.** *The toddler places the paper on top of the sock ball so that it covers all of the top*. It does not matter where the sock ball is, e.g., on the table or in hand. Code "yes" if the ball was already in contact with the paper before it got into the position where the paper was on top of the ball. It is OK if "cover" results from grasping the ball.
Grasp	**The sock ball is being held through the paper**. *The toddler grasps and holds the sock ball so that at least part of the paper is between the hand and the sock ball.*
Move	**The location of the sock ball is changed by using paper.** *The toddler changes the location of the sock ball by making contact between the ball and the paper*. This is regardless of the length and direction of the movement, as well as the relative positions of the paper and ball (i.e., changing the location of the sock ball with the paper on top, underneath, or from the side). The child must act on the paper, not just on the ball. Although there is no explicit lower limit on the length of movement, micro-movements should not be coded as "yes."
Drop	**The sock ball is being dropped down.** *The toddler drops the sock ball by letting go of the ball before the ball touches a surface*. Throwing forward/away also counts as dropping (i.e., the fall doesn't have to start downwards), but throwing the ball up doesn't.
Ball on paper	**The sock ball is on one of the papers.** *The toddler makes contact between the sock ball and the paper, with the sock ball on top of the paper*. The exact means by which this goal is achieved (e.g., by putting, dropping, rolling, or banging it on the paper) does not matter. It doesn't matter whether the toddler lets go of the ball (e.g., opens their hand) once the sock ball is on the paper. It does not matter where the paper is when the ball is on it. Code as "no" if the outcome is a byproduct of handling the ball and paper together but do code as "yes" if it is an intended outcome. Code as "yes" if not all the ball is on the paper.

Note. Sub-goals are in **bold**. Operational definitions are in *italics*. Additional coding instructions are in plain text. The same coding scheme was used in both experiments.

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from superficially similar unintended events (Table 1). We formulated the operationalizations based on our analyses of the experimenter's action in the demonstration video (Fig 2) as well as the actual actions produced by toddlers participating in the pilot.

In formulating the operationalizations, we were guided by two general assumptions: First, we assumed that any emulation of the predefined sub-goals of the action steps (and the main goal-outcome) should count if it was successful (i.e., the sub-goal was produced), and if it satisfied the specific minimum criteria. Second, we assumed that production of any of the sub-goals (or the main goal-outcome) should count regardless of how long the state lasted (e.g., how long the paper stayed on the sock ball, or the sock ball stayed on the paper). Except for the *move* action step, in which case micromovements were to be ignored.

Children's behaviors during the test phase were coded offline from videos recorded at 25 frames per second viewed frame by frame using media player software (mpv). Each instance when the child performed a behavior falling into one of the coded categories was coded in the order of occurrence. There were two coders blinded to the condition that the toddlers were assigned to: the second and the last author. They first coded randomly chosen 21 videos (i.e., approximately 1/3 of the videos from all 65 toddlers tested) independently and reached excellent inter-rater reliability ($\kappa = .953$) on a total of 105 yes or no decisions about toddlers' target action performance (21 videos × (4 action steps + 1 goal state)). Next, they coded the remaining 2/3 of the videos together, resolving disagreements through discussion. Note that this procedure deviated from the preregistered coding procedure, where we planned for two independent coders blinded not only to the condition but also naïve to the study's hypothesis. The reason for this deviation was that we could not ensure that the same naïve coders would be available to code the data in Experiment 2. Consequently, we opted for the two authors who did not perform the data collection to code the videos while ensuring that they remained blinded to the condition (before coding, the videos were pre-edited by the first author, who collected the data, to remove any indicators of the experimental condition).

We computed three dependent measures based on offline coding: faithful imitation score, binary means score, and binary goal attainment score.

The faithful imitation score ranged from 0 to 8. It was the sum of the number of types of action steps produced (range: 0–4), and the best-sequence score (range: 0–4). For calculating the best-sequence score, each action step produced during the test phase received a numerical code according to its place in the modeled action sequence (cover = 1, grasp = 2, move = 3, drop = 4, main goal-outcome = 5). The best-sequence score was equal to the number of steps in the longest-produced sequence of ascending codes, minus one. Note that this procedure for calculating the faithful imitation score differed from our preregistered definition. See S1 Appendix for more details and for the results obtained using the preregistered definition.

The binary means action score equaled 1 if the child produced any of the target action steps at least once during the test phase. Otherwise, it equaled 0. The binary goal attainment score equaled 1 if the child produced the final goal-outcome at least once during the test phase. Otherwise, it equaled 0.

Results

SPSS (Statistical Package for Social Sciences 28.0) was used for all statistical analyses. For all statistical tests, p-values are reported for exact two-tailed tests. The distribution of the faithful imitation score was significantly different from normal, as indicated by a Kolmogorov-Smirnov test, $D(48) = 0.284$, $p < .001$. The skewness of the faithful imitation score was 1.22, indicating that the distribution was right-skewed. Therefore, non-parametric tests were used to analyze this variable.

There was no statistically significant difference in the faithful imitation score between the smartphone condition, $Mdn = .50$, range = 0–8, and the wristwatch condition, $Mdn = 1$, range = 0–7, Mann-Whitney $U(N_{smartphone.} = 24, N_{wristwatch.} = 24) = 238.50$, $z = -1.07$, $p = .291$, $r = -.15$ (see Fig 3). Since, as indicated in the methods section, the analysis reported here was based on a definition of faithful imitation score that differed from the definition preregistered for Experiment 1, please note that the overall pattern of statistical significance remains the same if the preregistered definition was to be used. For details, see S1 Appendix.

In total, 13 toddlers in the smartphone condition and 12 in the wristwatch condition produced the main goal-outcome, $p = 1.00$ (Fisher's exact test, $N = 48$) (see Fig 4). Twelve toddlers in the smartphone condition and 16 in the wristwatch condition produced at least one type of action step, $p = .380$ (Fisher's exact test, $N = 48$). The number of children producing means (i.e. action steps) over the final goal was not statistically different across the two conditions, as assessed by Generalized Estimating Equations with binary logistic model and an exchangeable covariance matrix structure on the binary means action score and the binary goal-attainment score, Wald Chi-Square test, $W(1) = 1.746$, $p = .186$.

Discussion

The findings from Experiment 1 were not consistent with our main hypothesis. We found no evidence that toddlers who watched the demonstration disrupted by smartphone use, imitated

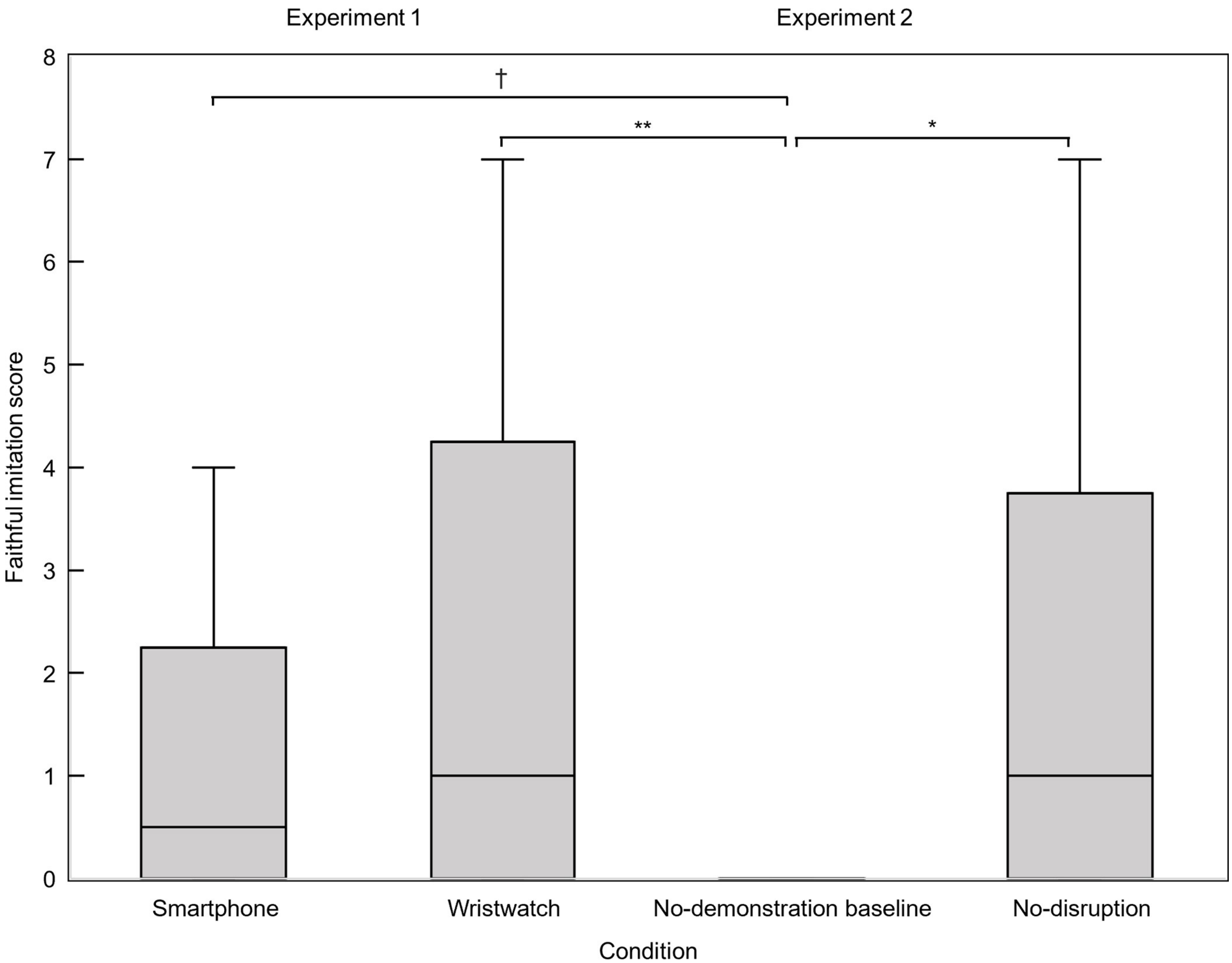

Fig 3. Faithful imitation scores in Experiments 1 and 2. Distribution of faithful imitation scores in the smartphone and wristwatch conditions of Experiment 1, and no-demonstration baseline and no-disruption conditions of Experiment 2. Each boxplot indicates condition median, midspread, and 1.5 interquartile range. Data points with values above 1.5 interquartile range not shown. * $p < .05$ and ** $p < .001$ by exact two-tailed Wilcoxon signed-rank test. † $p < .05$, by exact two-tailed test Mann-Whitney test.

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the modelled means less faithfully than those who watched the demonstration disrupted by fiddling with a wristwatch. Thus, our hypothesis that toddlers represent smartphone use as incongruous with ostension and rely on this representation when inferring communicative intention, was not supported by the results of Experiment 1.

Null results are notoriously difficult to interpret. They may reflect lack of the hypothesized effect. But they may also stem from problems in, e. g., the operationalization of the hypothesis and in the measurement. We considered two such explanations of the results of Experiment 1.

First, the test of the hypothesis in Experiment 1 relied on the assumption that the faithful imitation score indeed measures imitation. One explanation for why there was no hypothesized difference between conditions in Experiment 1 is that contrary to our assumption, the procedure might have not measured imitation but rather spontaneous production of the target behaviors, possibly unrelated to the demonstration videos. The design of Experiment 1 alone could not provide data in support of the assumption that the faithful-imitation score measured imitation, because the baseline level of this key measure was not assessed.

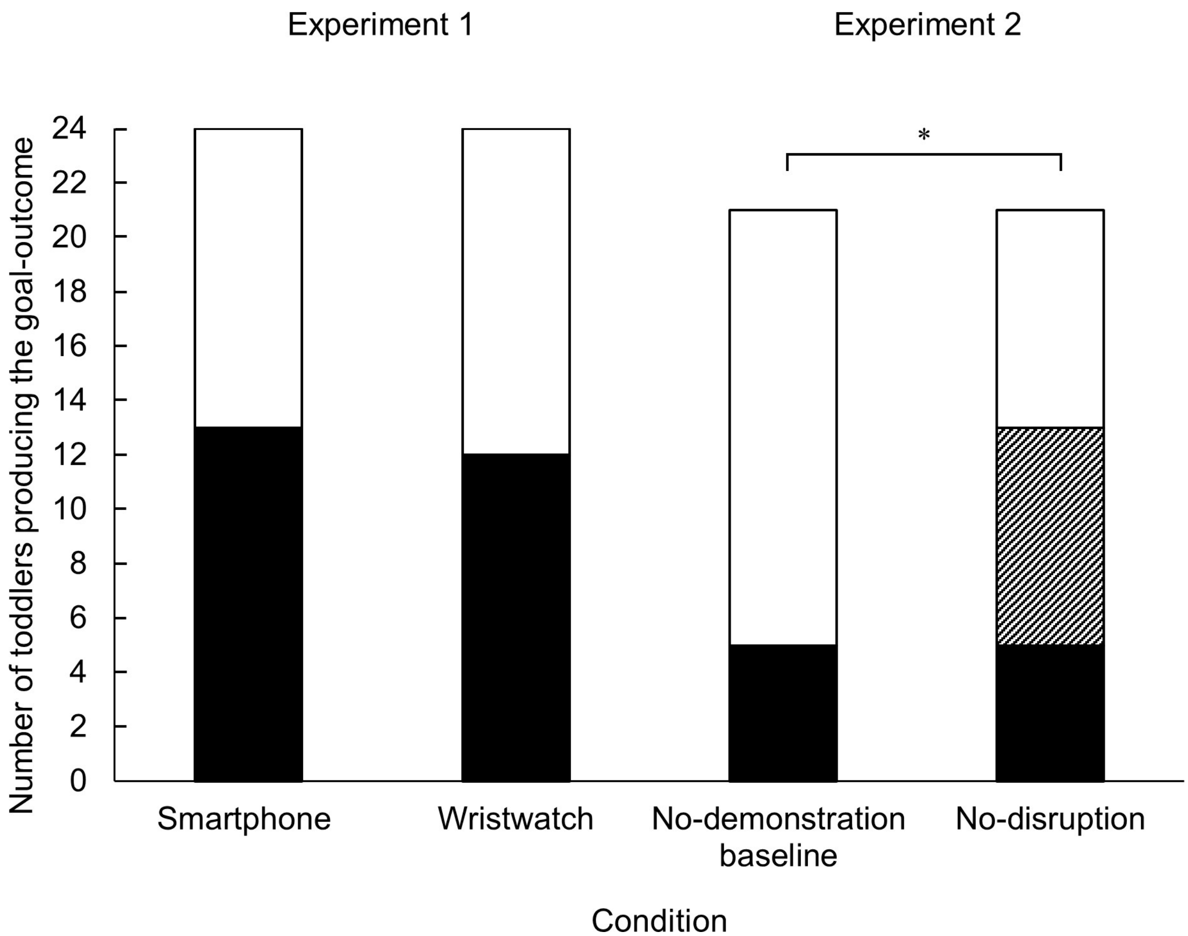

Fig 4. Goal-outcome imitation in Experiments 1 and 2. Number of children producing the final goal-outcome in the smartphone ($n = 24$) and wristwatch ($n = 24$) conditions of Experiment 1 (between subject design), and no-demonstration baseline ($n = 21$) and no-disruption baseline ($n = 21$) conditions of Experiment 2 (within-subject design). Note that in Experiment 2 only children who produced valid data in both conditions were included in this analysis. White bars indicate toddlers who did not produce the goal-outcome. Black bars indicate toddlers who produced the goal-outcome. Stripped bar indicates children who produced the goal-outcome only in no-disruption condition, but not in baseline. * $p < .05$ by exact two-sided McNemar's test.

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Second, if toddlers indeed imitated and our measure indeed captured their imitation, the effect of the type of disruption on imitation might have not been detected in statistical tests, because the procedure was ill-suited to capturing it. This could have been the case, for instance, if some elements of the procedure common to both conditions were affecting toddlers' imitation negatively in both conditions to start with. The disruption of the demonstration might have impacted imitation, both when it involved phone use and when it did not, for instance, because it led toddlers to process first the model's actions on an irrelevant object (the smartphone, the wristwatch), which later was not available to them to act on during the test phase. Knopf and colleagues [112] reported that when the presentation order of items differed between the demonstration and the test phase in a deferred imitation task, 10-to-11-month-old infants' imitation performance decreased. Task and age-group differences aside, one can speculate that if the toddlers in the current study encoded the smartphone and the wristwatch as first objects in the demonstrations, then their imitation performance might have been impacted, as a result, because the test phase did not start with these objects. Furthermore, imitation levels in Experiment 1 could have been dampened down because the participants in both conditions had little interaction with the experimenter prior to the test phase. For example, Kim and colleagues [113] found that 18-month-old toddlers were more likely to imitate after interacting with the experimenter in a warm-up phase prior to the imitation test, compared to a warm-up phase where the experimenter did not interact with them.

Experiment 2 was conducted to address these two concerns.

Experiment 2

Assessing baseline performance and imitation after an undisrupted demonstration

The aim of Experiment 2 was to gather empirical evidence that could further inform the interpretation of the null result of Experiment 1. Specifically, we assessed toddlers' performance using the same Sock Ball online task as in Experiment 1 but in two new conditions: no-demonstration (baseline) and no-disruption (Fig 1). As these labels suggest, in the no-demonstration condition we assessed toddlers' spontaneous production of the key behaviors. In the no-disruption condition toddlers' performance was assessed after they watched a demonstration video. Like in Experient 1, the video showed the ostensive greeting followed by a non-ostensive demonstration of the modelled actions. But unlike in Experient 1, the model proceeded to the demonstration immediately after greeting the toddler (Fig 2). Importantly, each child participated in both conditions in a fixed order: no-demonstration baseline first, no-disruption condition second (Fig 1). Thus, the procedure of the baseline condition closely matched the procedure of the two conditions in Experiment 1, except for the lack of demonstration video. The procedure in the no-disruption condition also closely matched those in Experiment 1, except for the different video stimulus (Fig 2) and for the fact that by the time of the test phase toddlers had extensive opportunity to warm up to the experimenter during the preceding baseline and that they manipulated the target objects in the baseline condition.

The main preregistered hypothesis for Experient 2 was the following. If our Sock Ball online task indeed measured imitation, we expected that the goal-outcome would be produced less frequently in the baseline than in each of the conditions of Experiment 1. Furthermore, we anticipated that the faithful-imitation score would be significantly lower in the baseline than in the wristwatch condition of Experiment 1, where we had expected toddlers to express unaffected imitation of the modeled means. Likewise, we also expected both production of the goal-outcome and of the modelled means to be significantly lower in the baseline than in the no-disruption condition. Furthermore, if factors such as the lack of extended warm-up and the presence of task-irrelevant object-use indeed dampened toddlers' imitation in Experiment 1, one would expect the goal-outcome production and the faithful-imitation of means to be significantly higher in the no-disruption condition than in the two conditions of Experiment 1. Because our preregistered "stopping rule" was tied to completing the full sample for the baseline, all the comparisons involving the no-disruption condition were preregistered as secondary analyses.

Materials and methods

Preregistration

Experiment 2 was preregistered on the Open Science Framework on August 17, 2022 (osf.io/jytrg).

Ethics statement

The study was ethically approved by the internal research ethics committee at the Department of Psychology, UiT The Arctic University of Norway (ref: 2017/1912) and by the Norwegian

Centre for Research Data (NSD, ref: 973260). We obtained verbal informed consent from the participants' parents in an information meeting on Zoom.

Participants

The participants were healthy 17- to 19-month-old toddlers, recruited in the same manner as in Experiment 1. Each participant was assigned to both the no-demonstration baseline condition and to the no-disruption condition. Data collection ended when the preregistered sample size (after exclusions and replacements) was reached in the baseline condition. Thus, the final sample in the baseline condition was $N = 24$ toddlers (14 = girls, $M_{Age} = 548.21$ days, $SD = 19.18$, range = 518 to 577 days). Three more participants were tested in the baseline condition but excluded from the analyses because of parental interference (1), incorrect test objects (1), and for not completing the baseline phase and no manipulation of the test objects (1). The final sample in the no-disruption condition was $N = 22$ toddlers (12 = girls, $M_{Age} = 547.91$ days, $SD = 18.72$, range = 518 to 577 days). Twenty-one of these toddlers had valid data for both the baseline and the no-disruption conditions. Five toddlers were tested in the no-disruption condition but excluded from the analyses due to technical error (1), parental interference (1), or not completing the test phase (no manipulation of test objects ($n = 1$) or major procedural disruptions such as extensive crying ($n = 2$). All participants met the inclusion criteria for attention in the demonstration phase of the non-disruption condition. The data collection was conducted between August and November 2022.

Design and procedure

The data collection lasted between 23rd of August and 5th of November 2022. Each toddler participated first in the baseline condition and next in the no-disruption condition. The procedures for these two conditions differed from that of Experiment 1 in the following ways (Fig 1). In the baseline condition there was no demonstration phase. The session started with a warm-up phase. Similar to Experiment 1, for 4 out of 24 toddlers (16.7%) the warm-up phase was extended with a short toddler-experimenter interaction. Warm-up was followed immediately by a test phase. Next, in the no-disruption condition there was a demonstration phase, followed by a test phase.

Demonstration videos and props

The props and the procedure for preparing them by the parents were the same as in Experiment 1. The experimenter (who was also the model in the demonstration video) was also the same as in Experiment 1. The only difference was that in the video shown in the demonstration phase of the no-disruption condition the model produced ostensive greeting and proceeded immediately to the non-ostensive demonstration (Fig 2).

Coding

The coding procedure was identical to the one used in Experiment 1, and it had been preregistered for Experiment 2. The second author coded toddlers' looking to the demonstration videos to check for the exclusion criteria. The second and the third author, blinded to the condition, coded the participants' behavior during the test phase together and resolved differences through discussion.

Results

SPSS (Statistical Package for Social Sciences 28.0) was used for all statistical analyses. For all statistical tests, p-values are reported for exact two-tailed tests. A Kolmogorov-Smirnov test was conducted to assess the normality assumption on the faithful imitation score, and it indicated that the distribution of the faithful imitation score was significantly different from normal, $D(94) = 0.297$, $p \leq .001$. The distribution was right skewed as indicated by a positive skewness value of 1.36. Therefore, non-parametric tests were used to analyze this variable.

The faithful imitation score was significantly lower in the baseline condition, Mdn_{baseline} = 0, $\text{range}_{\text{baseline}}$: 0–6, than in the wristwatch condition of Experiment 1, $Mdn_{\text{wristwatch}}$ = 1, $\text{range}_{\text{wristwatch}}$: 0–7 (Mann-Whitney test, $U[N_{\text{baseline}} = 24, N_{\text{wristwatch}} = 24] = 151.50$, $z = -3.12$, $p = .001$, $r = -.45$). The faithful imitation score was also significantly lower in the baseline condition, Mdn_{baseline} = 0, $\text{range}_{\text{baseline}}$: 0–6, than in the smartphone condition of Experiment 1, $Mdn_{\text{smartphone}}$ = .50, $\text{range}_{\text{smartphone}}$: 0–8 (Mann-Whitney test, $U[\text{N}_{\text{baseline}} = 24, N_{\text{smartphone}} = 24] = 200.50$, z = -2.12, $p = .035$, $r = -.43$). This post-hoc comparison was not preregistered because of lack of clear hypothesis. We report it here for completeness.

On the other hand, a Fisher's exact test indicated that the production of the goal-outcome was not significantly different between the baseline and the wristwatch condition ($p = .135$). Moreover, a Fisher's exact test indicated that the production of the goal-outcome was not significantly different between the baseline and the smartphone condition ($p = .075$). In total, 6 out of 24 toddlers produced the goal-outcome in the baseline condition, whereas 12 toddlers did in the wristwatch condition and 13 toddlers did in the smartphone condition.

Of the 24 toddlers in the final sample, $N = 21$ toddlers had valid data for both baseline and no-disruption conditions. The faithful imitation score was significantly higher in the no-disruption condition ($Mdn = 1$, range = 0–7) than in the baseline ($Mdn = 0$, range = 0–6), Wilcoxon signed-rank test, $z = -2.16$, $p = .029$, $r = -.47$ (See Fig 3). Furthermore, there was a statistically significant difference in production of the main goal-outcome between the baseline condition and the no-disruption condition (McNemar's test, $p = .008$). Of the 21 toddlers who provided valid data in both conditions only 5 (24%) produced the goal-outcome in the no-demonstration baseline condition (1 additional child also did but was excluded from the no-disruption condition) with none of them doing so in the baseline only. On the other hand, 13 (62%) of the 21 produced the goal-outcome in the no-disruption condition with 8 of them (i.e., 62% of the goal producers in this condition and 38% of the whole sample of 21) produced the goal only in the no-disruption condition but not in the baseline (See Fig 4).

There were no other statistically significant differences in the production of faithful imitation scores nor in goal production between the no-disruption condition and neither the smartphone nor the wristwatch conditions of Experiment 1. More specifically, the performance on the faithful imitation score was not significantly different between the no-disruption condition ($Mdn_{no\text{-}disruption}$ = 1, $\text{range}_{\text{no-disruption}}$ = 0–7) and the smartphone condition ($Mdn_{smartphone}$ = .50, $\text{range}_{\text{smartphone}}$ = 0–8), Mann-Whitney test, $U[N_{\text{no-disruption}} = 22, N_{\text{smartphone}} = 24] = 240.00$, $z = -.56$, $p = .583$, $r = -.08$), nor between the no-disruption condition and the wristwatch condition, Mann-Whitney test, $U[N_{\text{no-disruption}} = 22, N_{\text{wristwatch}} = 24] = 244.50$, $z = -.45$, $p = .663$, $r = -.07$). Fisher's exact tests indicated no statical difference in goal production between the no-disruption condition and the smartphone condition ($p = .774$), nor between the no-disruption condition and the wristwatch condition ($p = .568$).

Discussion

The aim of Experiment 2 was to gather further evidence to inform the interpretation of the null results of Experiment 1. The results leave little doubt that the online Sock Ball Task indeed captured–as assumed—toddlers' imitation of the modelled means. This is evident in the faithful imitation score being lower in the no-demonstration baseline condition than in the wristwatch condition (preregistered primary comparison), the no-disruption condition (preregistered secondary comparison) and in the smartphone condition (post-hoc comparison). The results concerning imitation of the main goal-outcome were less clear. Even though production of the goal-outcome was numerically lower in the baseline than in all the other three conditions, only the within-subjects comparison between the baseline and the no-disruption condition brought a statistically significant result.

The lack of statistically significant differences in imitation between the no-disruption condition of Experiment 2 and neither of the conditions in Experiment 1 speaks against the possibility that the imitation levels in Experiment 1 had been dampened down because of insufficient warm-up or because of exposure to task-irrelevant object-use during the disruptions.

General discussion and conclusions

In two experiments, we assessed toddlers' imitation of novel means actions as well as goal-outcomes using a new Sock Ball Task conducted entirely online. Experiment 1 was designed to test the hypothesis that toddlers represent smartphone use as incongruous with ostensive communication and rely on this representation when inferring communicative intention. Consistent with this hypothesis and in accordance with previous literature, we expected toddlers to imitate the novel means less faithfully when ostensive demonstration was disrupted by smartphone use, than when it was disrupted by a matched control behavior. We did not find the expected difference. Comparisons to the baseline performance assessed in Experiment 2 confirmed that as a group, 17-to-19-month-olds imitated the novel means actions presented on the video. Moreover, their faithful imitation was not affected by factors which in principle could have dampened it down, such as the length of warm-up and the presence of task-irrelevant information. We conclude that: (i) the Sock Ball Task is a valid tool for assessing toddlers' imitation of novel means-actions. (ii) The current study found no empirical support for the initial hypothesis regarding toddlers' representation of smartphone use.

In what follows we consider several ways in which these results can be reconciled with the general pattern of findings suggesting that in adults smartphone use in social interactions goes against conventions and expectations of well-formed communicative interactions [29–37].

The age group

Could the 1.5-year-olds participating in our study be too young an age-group for testing our hypothesis? We do not find this plausible. The effect of ostension on imitation of novel means has been reported even in younger children [100]. Furthermore, numerous studies suggest that 1.5-year-old toddlers likely have ample experiences with communication partners being distracted by smartphone use [70–76]. These experiences might have been even more frequent during the COVID-19 pandemic. Studies using retrospective parent reports suggest that many parents increased their smartphone use compared to pre-pandemic smartphone use [e.g., 114, 115].

Could the 1.5-year-olds then be too old of an age group for testing our hypothesis? This we find more plausible for two reasons. First, although various studies suggested that ostensive demonstration may facilitate imitation of sub-efficient means actions in toddlers between 14 and 18 months of age [99–102], there are also reports of age trends in imitation of the sub-sufficient means. For instance, situational constraints were found to affect imitation of ostensively presented means in 12- and 14-month-olds [100, 116]. But at 18 months, the effect was much weaker and seemed to vane in older children, who tended to imitate more overall and to a similar extent both when the situational constraints rendered the action sub-efficient with respect to the goal, and when they did not [117]. Thus, currently, the existing literature does not give a clear picture about the interplay of communicative context and sub-efficiency of the modelled actions on the imitation around 1.5 years of age. In hindsight, a younger age group, e. g., 14-month-olds, might have been a better choice for testing the hypothesis of the current study.

Second, because smartphone use is omnipresent in everyday interactions, adults tend to habituate to face-to-face interactions disrupted by smartphone use [37, 47, 118, 119], and so could infants and toddlers. It should also be noted that adults' opinions about smartphone use related disruptions are not uniformly negative, but rather depend on context [120], type of usage [43, 120, 121], attitudes [47], and quantity of smartphone disruptions [25]. Moreover, age might play an important role in the perceived appropriateness of smartphone use in face-to-face interactions [121]. For example, Forgays and colleagues [121] found that younger adults tend to perceive smartphone texting in various social scenarios as more acceptable compared to middle-aged and older individuals.

Adults can learn to adjust their expectations about communicative face-to-face interactions based on experiences with individual smartphone users [28, 47, 122] and it seems likely that children may go through a similar process in the developmental perspective. Cross-cultural comparisons suggest that the processes that allow infants to "tune into" the culture-specific interactional patterns start very early on in ontogeny [123]. Furthermore, one study [65] found no association between mothers' self-reported smartphone habits and infants' behaviors in a modified still-face phase with a mobile device. As discussed in the paper, the lack of association could be explained by infants adjusting to their environment. Relatedly, children's past experiences with how parents respond to their behavior in emotionally demanding situations, such as parental scaffolding and autonomy support, might foster emotional self-regulation (e.g., ability to wait) when children encounter similar events in the future [85, 88, 124]. We can speculate that in environments where smartphone use is frequent in face-to-face adult-child communication, infants learn the smartphone-use-heavy interactional patterns present in those environments from early on. On this account, at 1.5 years toddlers in the smartphone condition of the present study might have been well attuned to treating ostensive addressing followed by smartphone use as a straightforward case of ongoing communication directed at them. Younger toddlers, or even infants, could be a more suitable age-group to test the hypothesis that smart-phone use is represented as incongruous with ostensive communication, as they are earlier in the process of learning the behavioral patterns of communication common in their environments and attribution of communicative intention may rely more on the developmentally prior sensitivity to ostensive signals and on the expectations that they elicit when detected [e.g., 125].

The procedure

Toddlers in the no-disruption condition of Experiment 2 imitated to a comparable degree to those in the smartphone and the wristwatch conditions of Experiment 1. Thus, we found no evidence for the role of some procedural factors that in principle could have affected imitation levels *negatively*. But perhaps some aspects of our procedure could have affected performance *positively*, and consequently made it harder to detect the effect of interest?

Some recent studies suggest that for young children one function of imitation is facilitating social affiliation [126, 127]. For the toddlers in our study, imitating the modeled actions might have been a way of communicating and affiliating with the model on the computer screen. Crucially, this function was available in all conditions except for the no-demonstration baseline. At this point we can only speculate what aspects of the procedure, common across conditions, might have played a role in facilitating it. We note here two possible factors. (i) Because of the prerecorded demonstration stimuli, the test-phase was the first opportunity to interact with the model. Before that, during the demonstration phase, many toddlers might have tried unsuccessfully other ways of communicating with the pre-recorded model or attracting her attention through vocalizing or waving. Anecdotal observations indicated that some of the toddlers greeted and waved back when watching the demonstration video of the model's ostensive greeting. (ii) As reported, most toddlers did not need any extra warm-up with experimenter-child interaction before the test phase. Consequently, for most participants the test phase was preceded by an interaction between mostly the experimenter and the parent, that excluded the child. This might have mattered given, e.g., that imitation fidelity in young children increases when exposed to ostracism [128–130]. Notably, smartphone disruptions in face-to-face interactions are associated with feelings of being ostracized in adults [32]. If they evoke similar emotional response in toddlers, then on this account they might have in fact motivated the toddlers in the smartphone condition to imitate for affiliative gains, thus counteracting the effect we had originally hypothesized. Future studies building on the current paradigm may take these hypothetical factors into consideration.

Limitations, strengths, and reflections on online testing

We want to point out some further limitations of our study. One of the assumptions behind our hypothesis was that infant experiences with adult smartphone use in everyday life prior to participating in the study drove their representations of smartphone use. However, participants were recruited from the general population and there was no assessment of the actual exposure of participating toddlers to adult smartphone use. This was done for two reasons. First, because data had to be collected during the Covid-19 pandemic, the available measures of smartphone use would be parental self-reports [28, 39, 131–133] or data from phone-use tracking applications [134–136]. Self-reports are known to be unreliable and highly susceptible to social desirability factors [137], and studies suggest that adults' retrospective self-reports of their own smartphone use can be susceptible to both underestimation and overestimation [135, 136, 138–140]. By a similar token, we reasoned that asking parents to use an application that tracks their phone-use is likely to affect their typical smartphone habits. Second, by now many studies document high levels of smartphone use in everyday parent-child interactions [70–76]. Moreover, it has been suggested that adults often use their smartphones during in-person communication with those who are closest to them [27]. Therefore, we assumed that as a group, participating toddlers likely had sufficient experiences with this behavior. But the procedure did not allow us to verify this assumption.

Another limitation is related to how we operationalized smartphone use in the demonstration stimuli. We tried to mimic how smartphone use disruption may occur in a real-life social interaction. But neither the length of the smartphone disruption (10 seconds) nor the details of the action (swiping and texting) were derived from any real-life data on typical adult behaviors, nor independent interpretation of this behavior by adult viewers. Of course, in doing this we followed in the footsteps of many developmental researchers before us, who also relied on common sense judgement and intuition, when designing the stimuli for infants and toddlers. Still, we want to acknowledge this as one of the limitations of the current attempt.

A further point to note is that both our general hypothesis and its proposed test through means-imitation task were designed for typically developing children, and it is uncertain whether they may generalize to non-typically developing populations and contexts, for at least two reasons. First, imitation behaviors involving novel actions on objects can vary significantly between typically and non-typically developing children [e.g., 141]. Second, children's prior exposure to adult smartphone use could be influenced by parental factors such as maternal depression [142]. Notably in the current study we did not collect any data about the parenting context. Lastly, all the participating toddlers and families were Norwegian speakers living in Norway, thus our sample is not representative of the broader population. Although smartphone ownership is increasing globally, with one internet source estimating that 85% of the global population owns a smartphone [143], the majority of people in developing countries do not have a smartphone [144]. In contrast, but similar to many other Western countries [143], in Norway, the majority (98%) of the population (between 9–79 years) is estimated to have access to a smartphone [145].

On the other hand, we consider it a valuable contribution of the current study that it introduces a new online imitation paradigm, the Sock Ball Task. We developed the task during the COVID-19 lockdown, which restricted data collection in the lab. This limitation forced us to design an imitation task for which reasonably matching sets of props could be produced by individual participating families with materials available to them at home: two wrinkled A5 sheets of paper and a pair of socks rolled into a ball. We found evidence for imitation of novel sub-efficient means actions in three separate groups of 17-to-19-month-olds. Evidence for the imitation of goal-outcome is less clear as it was found in only one, within-subject comparison. It seems likely that the simple action of grasping the soft sock ball and placing it back on the table, often resulted in the target end-state (ball on paper) being achieved inadvertently in the baseline condition. It may also be that the presence of a paper facilitated placing the ball at these locations. The current data does not allow us to distinguish between these accounts. In future applications of the task, the experimenters may consider making the goal-locations less immediately accessible to the child, e. g. by instructing caregivers to place the papers further apart.

Finally, since this study is, to our knowledge, among the first to use online data collection in an imitation paradigm, we would like to end by providing some notes that could help future application of such methods. The present study, and several other developmental psychology studies during the COVID-19 pandemic [e.g., 146], was initially designed for in-lab research and later adapted to online testing. We conducted this study via Zoom due to its availability and popularity during lockdown. Before beginning our primary data collection, we encountered and learned from challenges associated with online testing by piloting. Similar to other online developmental psychology studies [e.g., 146], we observed challenges during the pilot related to environmental distractions in the household, and technical issues related to using the online platform Zoom (e.g., mainly the parents struggling with Zoom). We were able to address these issues during the main data collection for the study by providing Zoom training to the parents during the initial information meeting (Fig 1) and by giving them detailed instructions on how to minimize environmental distractions during the information meeting. For example, they were advised to prevent other family members from entering the room, to tidy up the table used during the test, and to hide any attractive toys within proximity.

As discussed by other developmental researchers [e.g., 147] it might be more difficult to ensure good stimuli presentation in online studies compared to in-lab studies. Indeed, we also found that one limitation of our online procedure was that the researcher could not bring the props to the child herself. We lost data-points due to parents either providing incorrect test objects or accidentally producing the goal-outcome (e.g., ball on paper) when putting the props on the table.

To ensure good quality of presentation of the demonstration videos and to prevent lags that might occur during screen sharing on Zoom, the participating families viewed the videos on their own computer. However, to ensure that the child's web camera captured the child's attention and their object manipulation on the table, the toddlers often viewed the video stimuli and the live experimenter on a laptop screen that was tilted. Thus, the viewing angle was not optimal, and future online studies could consider ensuring other setups.

On the other hand, one of the major advantages of conducting online testing was the ability to recruit participants from across the country and not just in the city where our lab is located, and thus shortening the period of data collection. Additionally, scheduling multiple appointments on the same day was much easier than in-lab testing, e.g., preparing the experimental set-up was quick with no need for clean up between appointments. Moreover, online testing made it easy to adjust and re-schedule the timing of the appointment to best suit the needs of the child and their family as the family did not have to travel to a lab.

Conclusion

We sought new type of evidence of toddlers' rich pragmatic inferences about communicative intention. Contrary to our hypothesis, our study did not find evidence that toddlers represent smartphone use as incongruous with ostensive communication and use this representation to infer communicative intention. We indicated how testing of this hypothesis can be improved in the future. A key contribution of this study is the new online imitation paradigm. We have demonstrated that the Sock Ball Task has a potential to become a useful measure of novel sub-efficient means and goal imitation.

Supporting information

S1 Appendix. The faithful imitation score preregistered for Experiment 1.
(DOCX)

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Appendix C: Study 3

Flatebø, S., Tran, V. N.-N., Wang, C. E. A., & Bongo, L. A. (2024)

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RESEARCH ARTICLE

Social robots in research on social and cognitive development in infants and toddlers: A scoping review

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Abstract

There is currently no systematic review of the growing body of literature on using social robots in early developmental research. Designing appropriate methods for early childhood research is crucial for broadening our understanding of young children's social and cognitive development. This scoping review systematically examines the existing literature on using social robots to study social and cognitive development in infants and toddlers aged between 2 and 35 months. Moreover, it aims to identify the research focus, findings, and reported gaps and challenges when using robots in research. We included empirical studies published between 1990 and May 29, 2023. We searched for literature in PsychINFO, ERIC, Web of Science, and PsyArXiv. Twenty-nine studies met the inclusion criteria and were mapped using the scoping review method. Our findings reveal that most studies were quantitative, with experimental designs conducted in a laboratory setting where children were exposed to physically present or virtual robots in a one-to-one situation. We found that robots were used to investigate four main concepts: animacy concept, action understanding, imitation, and early conversational skills. Many studies focused on whether young children regard robots as agents or social partners. The studies demonstrated that young children could learn from and understand social robots in some situations but not always. For instance, children's understanding of social robots was often facilitated by robots that behaved interactively and contingently. This scoping review highlights the need to design social robots that can engage in interactive and contingent social behaviors for early developmental research.

Introduction

Early childhood encompasses the infant and toddler years, marked by gradual but rapid growth in both social and cognitive development [1, 2]. Social development involves acquiring skills to interact and build social bonds with others, whereas cognitive development refers to developing skills related to thinking and reasoning processes [1, 2]. Research in these two

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subdisciplines focuses on a diverse range of abilities, such as attachment [3], imitation [4], play [5, 6], memory [7], theory of mind [8], social cognition [4], and language acquisition [9, 10]. Theory of Mind (ToM), the ability to attribute underlying mental states like beliefs, desires, and intentions to others [11–13], has not previously been studied in pre-verbal infants [14, 15]. However, recent advances in methods have demonstrated that a rudimentary ToM may emerge earlier than the traditional assumption at the age of four [14, 15]. In line with this research, an interesting question is whether infants attribute mental states to non-human agents. Similarly, animacy understanding, the ability to classify entities as animate or inanimate [16–18], has been demonstrated in infants as young as two months [19–22], and by three years of age, children are good at understanding this distinction. Research on animacy examines how young children distinguish living beings and objects based on featural and dynamic cues such as faces, contingency behavior, and goal-directed or self-generated movement, which may involve using non-human agents possessing such cues [16, 23–27].

Developmental psychology uses diverse methodologies, designs, data-gathering instruments and materials, and formats for stimuli presentation, and the research can be conducted in various research settings [28]. Using social robots as part of research methods has emerged as a promising way to gain social and cognitive developmental insights [29–31]. Some pioneering studies have also demonstrated that social robots can contribute to cognitive assessments of elderly people and children with autism [32, 33]. These robots are designed for social interactions with humans, and they are often physically embodied, with human or animal-like qualities, and can be autonomous or pre-programmed to perform specific actions, and they engage in social interactions [34, 35]. Social robots often have an anthropomorphic design with human-like appearance and behavior. For example, they commonly have heads with facial features and can display various social behaviors such as facial expressions, eye contact, pointing, or postural cues [36–38]. Two social robots commonly used for research on social and cognitive development skills are Robovie [39] and NAO [40]. In research settings, social robots can serve various roles, such as social partners in interactions [e.g., 40, 41], teaching aids delivering learning content [40, 42, 43], and they can be equipped with sensors and cameras to record child behaviors [39].

There are several research advantages of using social robots that are not easily achievable through other means when studying young children. Firstly, they provide a level of control and consistency that can be challenging to achieve with human experimenters [32, 44]. Secondly, because social robots are designed for social interactions, they might have potential in research on social learning situations such as imitation studies. Third, the socialness of robots in appearance and behavior [45], in addition to their novelty, make them potentially more suited to capture a child's attention and sustain their engagement over longer time periods for a variety of testing purposes. Lastly, social robots offer a compelling avenue for advancing our understanding of young children's early ToM and animacy understanding related to non-human agents with rich social properties and how they represent social robots specifically.

The current review

Although social robots are increasingly used in various settings with children, little is known about their utility as a research tool investigating social and cognitive concepts in infants and toddlers. We need to determine at which stages in early childhood children are receptive to and can learn from these robots. Currently, there is no available scoping review or systematic review of the available body of literature in this field. A review of the existing literature is needed to advance our understanding of social robots' relevance in research with younger age groups and map the current state of knowledge in this field. Given the potential diversity in methodologies, research designs, and the wide range of developmental topics and concepts in the present research field, we decided to do a scoping review. Consequently, the main objective of the current scoping review is to provide a comprehensive overview and summary of the available literature on the use of social robots as research tools for studying the social and cognitive development of typically developing infants and toddlers aged 2 to 35 months.

Our focus is on research using social robots to inform child development, rather than research exclusively focusing on robot skills and application. We focus on typically developing children in the infancy and toddler years, younger than 3 years. We exclude neonates (0–2 months) and preschoolers (3–5 years) due to the notable distinctions in their developmental stages, which may necessitate different research methods compared to those used for infants and toddlers. Our definition of social robots is broad, encompassing all embodied robots exposed to children in a research context, irrespective of form and presentation format. However, we recognize the significance of eyes in early childhood communication [46] and, consequently, restrict our inclusion to only robots featuring eyes. Our definition covers both robots commonly defined as social robots as well as robots with social features in form and/or behavior. We chose this definition because both types of robots might be relevant for how non-human agents with richer social features can inform social and cognitive development.

This review will provide an overview of the research literature, covering research on concepts of social and cognitive development using robots, the research methods employed, and the types of robots used and their purposes. Also, our aim is to summarize the research trends by identifying the primary research focuses and findings. Finally, we want to summarize the reported gaps and challenges in this research field. Hopefully, the current review can be valuable for future research, helping to decide how to employ social robots in research settings with infants and toddlers and to support the development of age-appropriate robots for children.

Method

We conducted a scoping review, which aimed to explore and map the concepts and available literature in a given field of research [47]. Like systematic reviews, scoping reviews follow rigorous and transparent methods [47, 48]. But, differently from systematic reviews, scoping reviews ask broader rather than specific research questions to encompass the extent and breadth of the available literature of a given field [47, 48]. We used The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) (S1 Checklist) to improve this scoping review's methodological and reporting quality. We preregistered the protocol for this study on Open Science Framework on May 19, 2023 (see updated version of the protocol: https://osf.io/2vwpn/). We followed the recommendations of the Johanna Briggs Institute (JBI) [49] and the first five stages in the methodological framework of Arksey and O'Malley [47] and Levac and O'Brien's advancements of this framework [50].

Stage 1: Identifying the research questions

The review was guided by three research questions: 1) What is the extent and nature of using social robots as a research tool to study social and cognitive development in infants and toddlers? 2) What are the primary research focus and findings? 3) What are the reported research gaps and challenges when using social robots as a research tool?

Stage 2: Identifying relevant studies

Inclusion criteria. We developed inclusion criteria related to the publication type, target child population, the robot type, and the research focus (Table 1) to focus the scope of the review.

Table 1. Inclusion criteria. In the full-text screening, we excluded studies by the first unmet inclusion criteria, i.e., we checked if the publication met the criteria for publication type first, then for the target population, robot type, and finally, the research focus.

Criterion	Included
1. Publication type	
Time frame	1990 until May 29/05/2023
Availability	Full texts available through open access or through our university subscription
Publication type	Peer-reviewed journal articles, journal magazine articles, preprints, and conference proceedings with full papers for empirical studies
Language	English
Research methodology	Empirical studies using quantitative, qualitative, or mixed methods
2. Target child population	
Participants	Publications with an exclusive focus on typically developing children between 2 to 35 months of age
3. Robot type	
Robot	Humanoid or non-humanoid form. Embodied robots, including partly animated robots. Full or partly autonomous. The robot must have eyes. The robot can be physically or virtually present in the child's environment, either as a physical robot or appearing in a video. The authors of the studies do not need to define the robot as social
4. Research focus	
Focus	Focus on child development, i.e., the robot is used to assess social and/or cognitive development in children. The publication includes an experiment, a pilot study, or a trial to test social and/or cognitive child development

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We consulted multiple databases to identify studies, as social robotics is an interdisciplinary field. We included conference proceedings and preprints because studies within robotics are often published in this format [51–53].

Search strategy

We searched for literature in PsychINFO (OVID), Education Resources Information Center (ERIC, EMBASE), and Web of Science. We searched for preprints using the Preprint Citation Index in Web of Science and in PsyArXiv. All searches were done on 29 May 2023. In consultation with an academic librarian, we developed a search strategy and search terms, which are presented in the S1 File. We used controlled vocabulary in addition to keywords when searching in PsychINFO and ERIC. Web of Science and PsyArXiv lack their own controlled vocabulary, so PsychINFO and ERIC keywords were used in the searches. We categorized the search terms into three categories: robot type, target child population, and social and cognitive developmental concepts. For a comprehensive search, we used the search terms "robot*", "robotics", "social robotics", and "human robot interaction" related to robot type category. Moreover, for the target child population category we used terms like "infan*", "toddler*", "child*", "infant development", and "childhood development". Lastly, for developmental concepts we used terms such as "cognitive development", "social development", "social cognition", and "psychological development".

Stage 3: Study selection

We developed a screening questionnaire a priori (doi.org/10.17605/OSF.IO/4BGX6), which all reviewers (SF, LAB, and VT) piloted initially on a random sample of studies. After revising the screening questionnaire, we started screening studies for eligibility in the web-based software Covidence [54]. We removed duplications manually and by using the Covidence duplicate check tool. All studies were screened by two reviewers independently using the screening questionnaire. The first author (SF) screened all studies, whereas LAB and VT screened half of the studies each. We resolved disagreements by team discussion. The studies were screened through a two-step process: 1) screening of titles and abstracts; 2) screening of full texts. In full-text screening, we followed the exclusion reason order in Table 1 and excluded studies by the first unmet inclusion criteria.

Stage 4: Data charting

We developed a data charting template a priori in Covidence and we used it to chart data from the studies included. The first author (SF) piloted the data charting template on five studies and iteratively modified it based on recommendations [50]. The main revisions included changes to the template layout, adding entities (i.e., final sample size and physical CRI contact), and providing more charting instructions and explanations of the entities. The details about the newest version of the charting template and charted entities are available at OSF (doi.org/10.17605/OSF.IO/B32R6). The first author (SF) charted data from each publication, and a second reviewer (LAB or VT) checked the charted data for completeness and accuracy in Covidence. Disagreements were resolved by discussion in the research team. We charted data regarding general study characteristics (e.g., authors, publication year, publication type, and country of the first author), research aims, developmental concepts, methods (e.g., research methodology and design, research setting, procedure and conditions, material, outcome measures, and type of CRI), child population characteristics (e.g., sample size, age, and socioeconomic background), robot characteristics (e.g., robotic platform, developer, exposition, physical CRI contact, purpose of use, form, appearance, autonomy, and behavior), reported gaps and limitations, research findings and conclusions. We exported the charted data from Covidence to Excel. All charted data is available at OSF (doi.org/10.17605/OSF.IO/WF48R).

Stage 5: Collation, summarizing, and reporting results

The reviewed studies are summarized, reported, and discussed in line with the fifth stage of Arksey and O'Malley's scoping review framework in the following sections. We classified the studies based on the type of developmental concepts they involved.

Results

Search results

Overall, we identified 1747 studies from all database searches. After removing duplicates, and screening titles and abstracts, we screened 187 full texts for eligibility. Out of these, 158 studies were excluded. Finally, we included 29 studies in the review. Fig 1 shows the details of the search results and the study selection process in the PRISMA flowchart diagram [55].

General characteristics

S1 Table provides an overview of all reviewed studies, including general characteristics, research methods, aims, sample characteristics, the robotic platform and other measures used, and a summary of the main findings and conclusions. There were 25 journal articles, three conference papers, and one magazine article. None of the studies were preprints. Studies were published between 1991 to 2023, and the research activity slightly grew over the past three decades (Fig 2).

The authors came from different countries, and most studies were conducted in Japan, followed by the United States and Canada (Table 2).

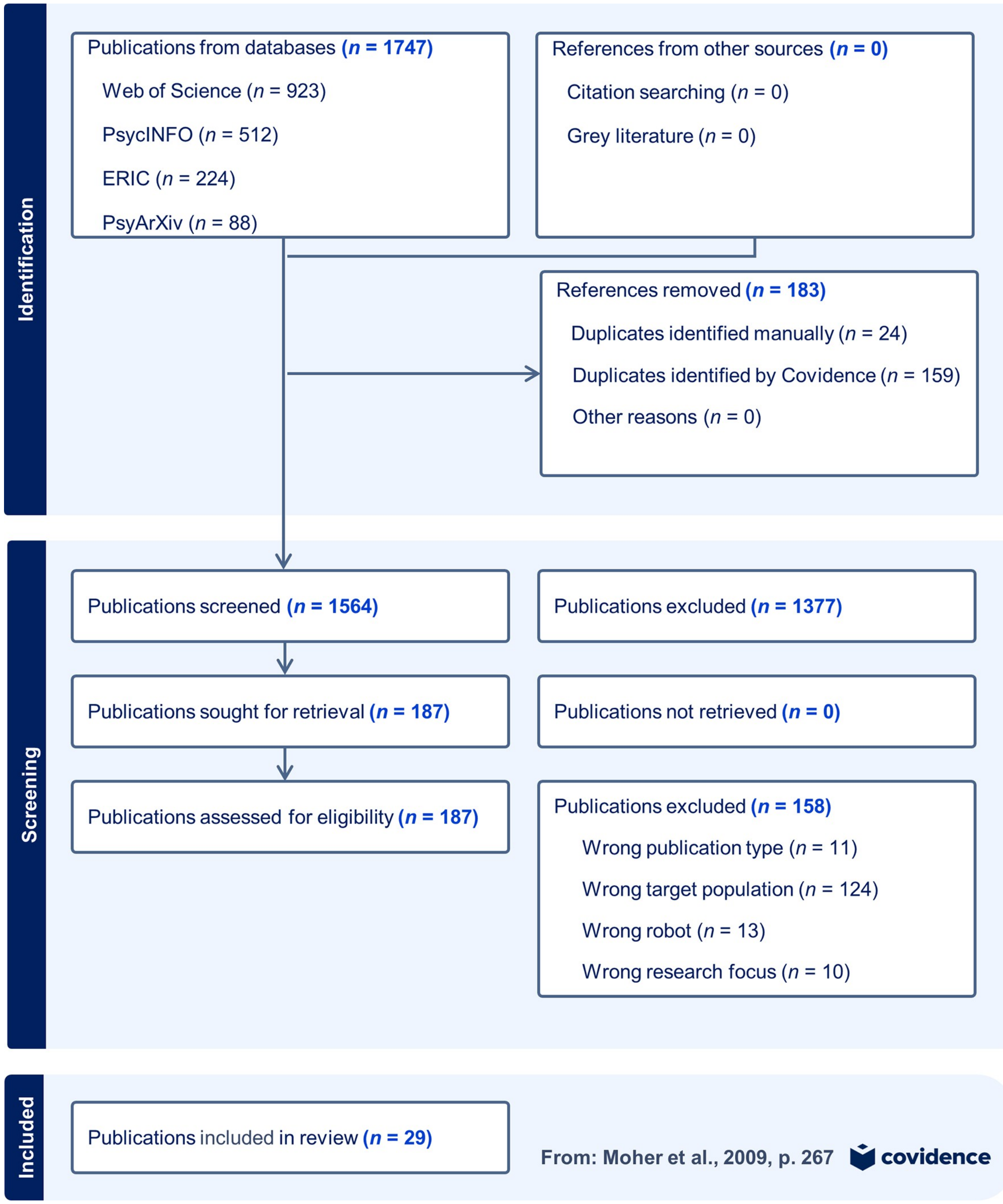

Fig 1. PRISMA 2009 flowchart diagram. The study selection process, including procedures of identification, and screening of studies. Studies were excluded based on a fixed order of exclusion reasons, including only the first incident of an unmet reason in this diagram.

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Research methods

Almost all studies (*n* = 25) used quantitative methodology, while only two studies used qualitative methodology and one used a mixed approach. Twenty-five of the studies used an experimental design, while the remaining four used a descriptive, correlational, case study, or ethnomethodology design. Twenty-four studies were conducted in a laboratory or in a

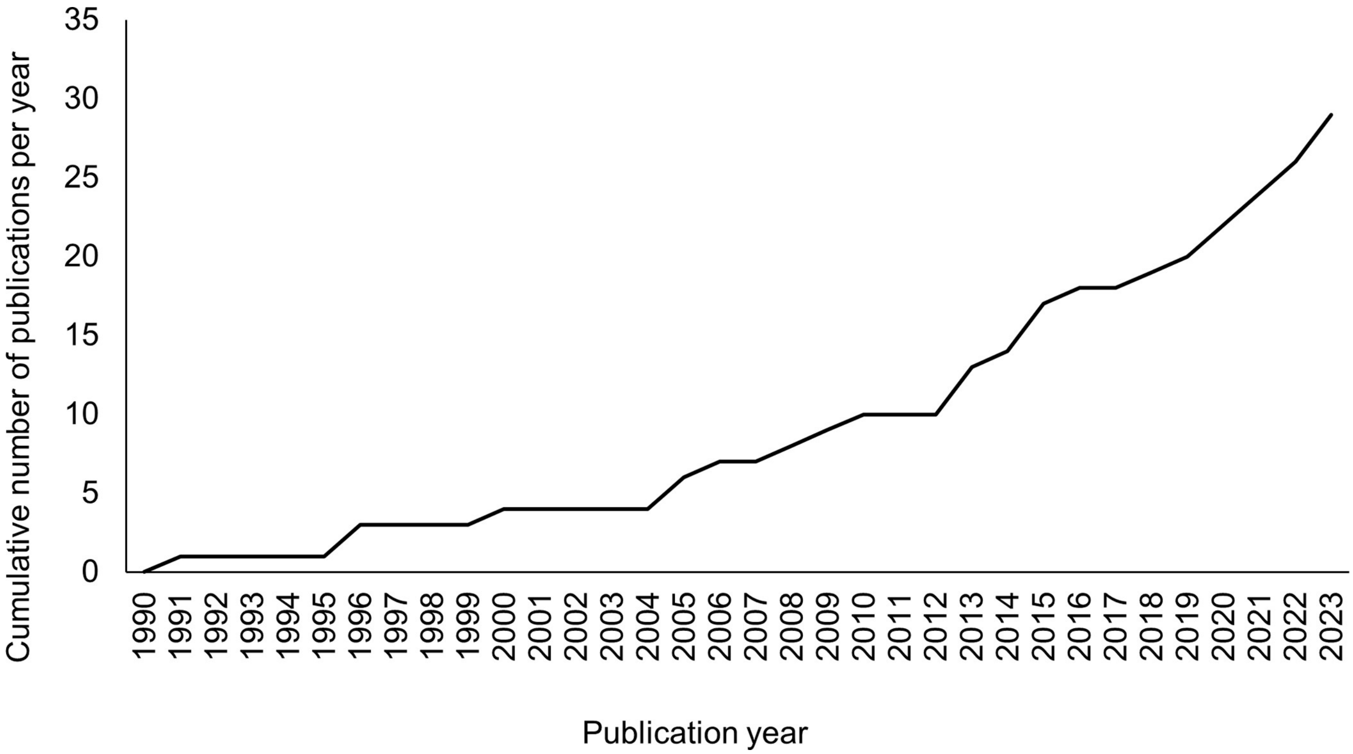

Fig 2. Studies per year. The cumulative number of studies per year between 1990 to 29. May 2023.

https://doi.org/10.1371/journal.pone.0303704.g002

controlled laboratory setting. Two studies were conducted in ecological settings, such as classrooms. The remaining three studies were conducted in different locations, one study in a naturalistic setting at a science museum, and two studies used various locations (i.e., laboratory, ecological and/or naturalistic location).

Child characteristics

The final sample sizes of the studies ranged from 6 to 230 participants, with the ages of participants ranging from 2 to 35 months. While some studies [56–62] included participants older than the target age, this review only focuses on findings related to children in the target age group. Twenty studies included toddlers who were 12 months or older, while seven studies included infants under 12 months. Five studies reported the socioeconomic status of the families [63–67], all belonging to the middle-class. For more details about the samples, see S1 Table.

Table 2. Country distribution. Countries of the lead authors (N = 29).

Country	*n*
Japan	8
Taiwan	1
Italy	3
Romania	1
United Kingdom	2
Canada	5
United States	6
Australia	3

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Robot characteristics and interaction types

We identified 16 social robots (Table 3 and Fig 3), most having a humanoid appearance ($n = 24$), whereas the remaining were animal-like ($n = 4$) and a ball-shaped robot ($n = 1$). The robots used were Robie Sr., Robovie, Robovie2, NAO, Dr. Robot Inc, HOAP-2, RUBI, RUBI-6, iRobiQ, Sphero, ReplieeQ2, MyKeepon, Bee-Bot, 210 AIBO, MiRoE, and Opie. Robovie (versions 1 and 2) was most frequently used ($n = 8$). Most robots were pre-programmed to perform specific behaviors to examine children's responses to these acts ($n = 24$), such as making eye contact or gazing in the direction of an object [e.g., 68], or performing specific actions with objects [e.g., 62]. Two studies used autonomous robot dogs that acted by themselves and reacted to the children's behavior [60, 61]. Additionally, some [57, 58, 69] exposed children to robots that were autonomous or pre-programmed at different phases of the experiment.

In most studies, the robots were present in the same physical location as the child ($n = 18$), whereas the remaining robots were presented in video ($n = 11$). In most cases, the child-robot interaction did not involve any physical contact with the robot ($n = 19$). A total of 34 experiments were conducted in the 29 reviewed articles in which children were exposed to robots in some way. Most commonly, the robot was exposed to the child in a one-to-one interaction or situation ($n = 20$), including both live interactions and passive observations without social exchange. The remaining were bystander interactions ($n = 5$), where the child observed the robot interact with someone else, children-robot interactions in groups ($n = 4$), or a mixture of different interaction types ($n = 5$).

Outcome measures and other instruments and material

Details of the outcome measures are presented in the S1 Table. The most frequent measure in the studies was children's looking behavior during stimuli presentation ($n = 12$). Looking behavior was measured using different instruments, such as eye tracking methods, video recordings captured by cameras, or observational notes. Various techniques were used to analyze looking behavior, such as visual habituation, preferential looking, violation of expectation, and anticipatory looking. Another common measure was children's imitation behavior assessed in imitation tests by analyzing the performance of target actions ($n = 7$).

Research focus, key findings, and conclusions

The studies focused on several social and cognitive skills that we clustered into 4 main categories (Table 4). The key findings and conclusions of all studies are presented in the S1 Table.

Animacy understanding. Seven studies investigated children's understanding of animacy (Table 4). They examined how children classify robots as animate or inanimate based on their appearance [77, 91], movements [81], and interactive behaviors [60, 61, 82, 91], using both humanoid and animal-like robots (Table 3 and Fig 3). The findings were diverse, with children sometimes perceiving robots as more like living beings when the robots had a highly human-like appearance [77] or behaved contingently [82, 91, 92]. For example, infants aged 6 to 14 months did not differentiate between a highly human-like android and a human, viewing both as animate, but they recognized the difference between a human and a mechanical-looking robot (Fig 3) [77]. Contingency behavior influenced children's animacy understanding, with children's reactions to robots varying depending on the robots' contingency [82, 92]. Children aged 9 to 17 months who observed contingent interactions between a robot and a human were more likely to perceive the robot as a social being, suggesting the importance of responsive behavior in animacy perception [82, 92]. Nine- and twelve-month-old infants showed different expectations for human and robot movement, demonstrating increased negative affect when robots moved autonomously, suggesting that infants might consider robots inanimate

Table 3. Robots used in the studies. H = humanoid; NH = non-humanoid; *n* = number of studies using a given robot.

Robot	Developer	Purpose	Form	Appearance	*n*	Representative studies
Robie Sr.	Radio Shack	Animacy concept, early conversational skills	H	Small toy robot with a head, ears, eyes, and a mouth. Wore a sweater/T-shirt and a cap/hat. Mounted on a wheeled base with a single unit body, arms, and hands.	4	[63–65, 81]
Robovie	ATR Media Information Science Laboratories; ATR Intelligence Robotics Laboratory	Action understanding (e.g., gaze following, goal attribution, attribution of intention to failed actions)	H	Large robot with a moveable head, eyes with pupils, body, torso, arms, and hands. Mounted on a wheeled base.	7	[68, 82–87]
Robovie2	Hiroshi Ishiguro Laboratories	Animacy concept, early conversational skills, action understanding (e.g., gaze following)	H	Large robot with a movable head, movable eyes with pupils, body, torso, arms, hands, and fingers. Wore white gloves.	2	[72, 88]
NAO	SoftBank Robotics; Aldebaran	Motor imitation, contingency learning	H	Medium-sized robot with a head, mouth, LED-eyes, body, torso, shoulders, arms, hands, fingers, legs, and feet.	3	[69, 89, 90]
Dr. Robot Inc.	NR	Action understanding (e.g., gaze following)	H	Medium-sized robot mounted on a wheeled base, with body, torso, fixed arms, moveable head, mouth, and eyes with pupils. Wore a red shirt.	1	[66]
HOAP-2	Fujitsu Laboratories	Action understanding (e.g., gaze following)	H	Medium-sized robot with body, torso, arms, legs, hands that open/close, pan-tilt moveable head, black-circled eyes (rims of cameras), and a nose.	1	[67]
RUBI	NR	Animacy concept	H	Large robot with body, torso, arms, hands, head, eyes (cameras), a fixed nose, and a fixed mouth. Equipped with a computer screen on its torso.	1	[91]
RUBI-6	Movellan et al., (2009, 2005); Tanaka et al., (2006)	Action imitation with objects	H	Medium-sized robot with body, torso, moveable arms, pincer hands, moveable head with an Apple iPad mini displaying an animated cartoon face with eyes, pupils, nose, mouth, and eyebrows. Mounted on a base. Equipped with a computer screen on its torso.	2	[58, 62]
iRobiQ	Yujin Robots, Yujin Robot Co., Ltd	Reading skills and interest	H	Medium-sized robot mounted on a base, with body, torso, moveable arms, moveable head with eyes and mouth. The face has LEDs and sounds.	1	[56]
Sphero	NR	Physical play and emotions	NH	Small, white-colored robotic ball. Blue drawing of a head with eyes.	1	[57]
ReplieeQ2	Osaka University and KOKORO Co. Ltd., Japan	Animacy concept	H	1) Android: Human-like head with black hair, a face with silicone skin, eyes, black eyebrows, a nose, and a mouth with lips. 2) Robot: Wore a plastic mask with a human-like appearance. Has eyebrows, fixed black eyes, a nose, and a mouth with lips. Both robots have bodies with necks, shoulders, arms, hands, fingers, and legs.	1	[77]
MyKeepon	Kozima, Nakagawa, and Yano (2004)	Animacy concept	NH	Small yellow snowman-shaped and creature-like robot in soft silicone rubber. Head with fixed eyes with pupils. Mounted on a base.	1	[92]
Bee-Bot	TTS Group Ltd, 2021	Computational thinking, programming, and coding skills	NH	Small and bee-like robot with black and yellow stripes on its body. Colorful buttons on top. Head with a fixed mouth and fixed eyes with pupils.	1	[59]
210 AIBO	Sony	Animacy concept	NH	Small and dog-like robot with a head, eyes, nose, ears, legs, and a tail. Metallic form in black color.	1	[61]
MiRoE	Consequential Robots	Animacy concept	NH	Small and dog-like robot with a head, ears, eyes with pupils, moveable eyelids, body, neck, two wheeled legs. Wore a collar.	1	[60]
Opie	NR	Action imitation with objects	H	Large robot with an upper body, a head, animated eyes with pupils and eyelids, neck, torso, shoulders, arms, and hands. A head with a black-colored screen face.	1	[93]

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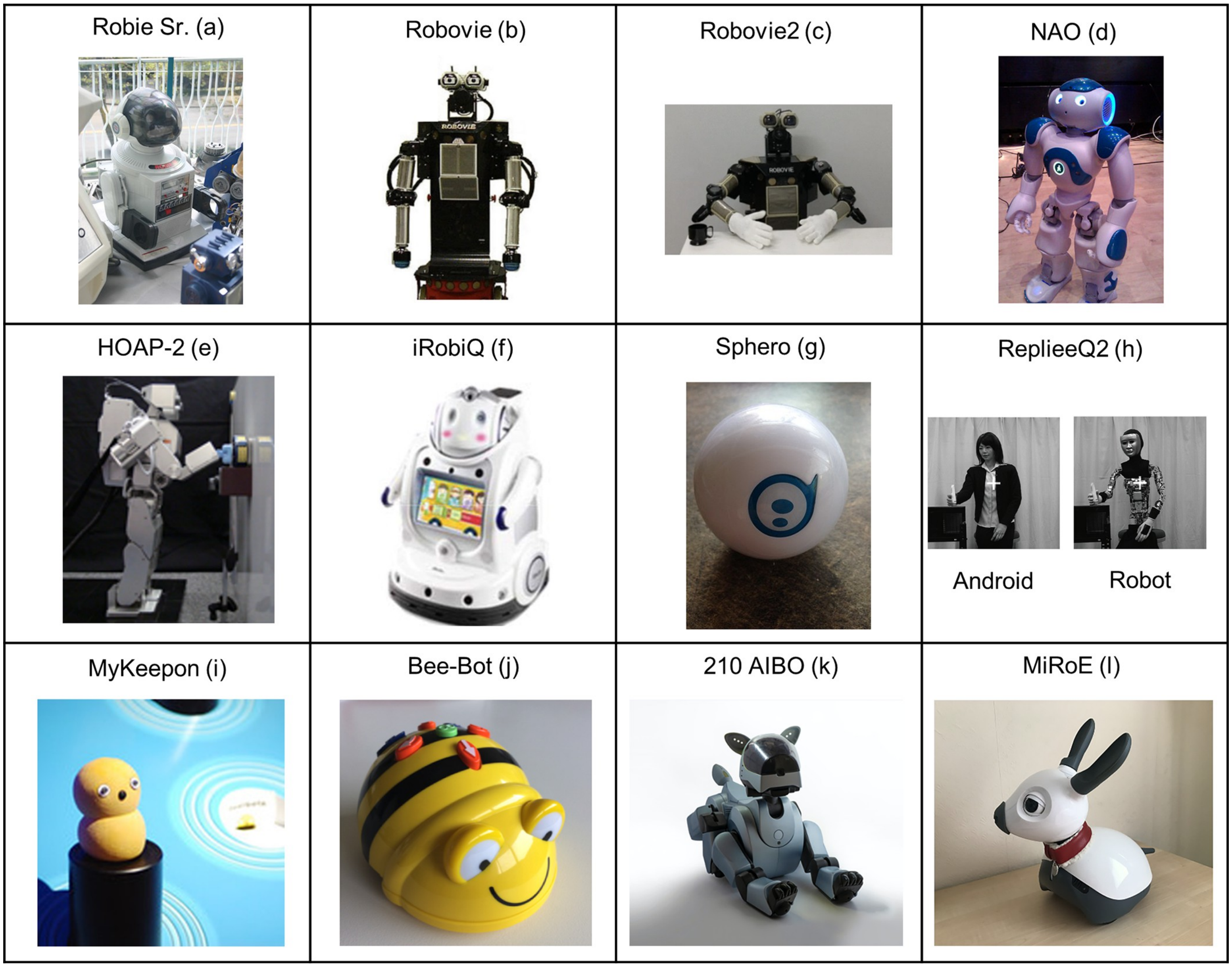

Fig 3. Most of the robots in the review. Images b, c, e, f, h, j, k, and l are modified cropped versions of the original work. Original images are licensed under CC-BY. For the robots Dr. Robot Inc., Opie, RUBI, and RUBI-6, we could not find images with a CC-BY (or similar) license. The Android and mechanical configurations of the same robot are shown in image (h). The image sources are: a) [70]; b) [71]; c) [72]; d) [73]; e) [74]; f) [75]; g) [76]; h) [77]; i) [78]; j) [79]; k & l); [80].

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regardless of self-generated motion [81]. Studies with robot dogs showed that children differentiated between robotic dogs and toy dogs, but they did not necessarily view the robotic dog as a living animal [60, 61]. However, they did engage with the robotic dog in a manner

Table 4. Research focus in the studies. The other category includes the concepts of computational thinking ($n = 1$), reading interest and skills ($n = 1$), and physical play and emotions during robot interaction ($n = 1$).

Social and cognitive concepts	Frequency	Representative studies
Animacy concept	7	[60, 77, 81, 82, 91, 92, 94]
Action understanding	10	[66–68, 72, 83–88]
Imitation	6	[58, 62, 69, 89, 90, 93]
Early conversational skills	3	[63–65]
Other	3	[56, 57, 59]

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suggesting that they perceived it as a social partner [60, 61]. Observations of 12- to 24-month-old toddlers' long-term interactions with a social robot indicated that they perceived the robot as a social partner [91]. The robot's interactivity, appearance, and inscriptions of gender and social roles influenced toddlers' attribution of animacy [91]. One study discussed anecdotal observations suggesting that toddlers may ascribe animacy to robots based on reciprocal vocalizations and social behaviors, such as inviting the robot to dance or apologizing to it after accidental contact [63]. Two studies connected children's concepts of animacy with their understanding of actions, particularly goal-directed and contingent actions [77, 91], which will be discussed in the section below on action understanding.

Action understanding. Ten studies used humanoid social robots to examine children's understanding of various actions (Tables 3 and 4), including referential actions [66, 67, 72, 84–86], goal-directed actions [83, 87, 88], and intentions behind failed actions [68]. Action understanding refers to the ability to recognize and respond appropriately to other's actions, infer the goals of actions, and detect the intention underlying the actions [95].

Studies on referential actions [66, 67, 72, 84–86] showed that children aged 10 to 18 months can follow the gaze of humanoid robots, but their understanding of the robot's intentions varied. For example, 12-month-olds respond to robot gaze, and it is not just an attentional reflex to its head movements [84], but they do not anticipate object appearance following robot gaze as they do for humans [84, 85]. Similarly, one study [72] found that 17-month-olds more frequently followed the human gaze than the robot gaze, suggesting that toddlers did not understand the referential intention of the robot's gaze. Yet, toddlers may still understand the robot's referential intentions, such as when the robots provide verbal cues during object learning [66, 86] or when the robot has previously engaged socially with adults [67]. Studies on goal-directed actions [83, 87, 88] showed that infants from 6.5 months could identify the goals of a humanoid robot as it is moving towards a goal destination, and they evaluate whether the robot is performing the most efficient path to reach its goal [83]. However, they do not attribute goals to a featureless box, suggesting that the human-like appearance of an agent influences infants' reasoning about an agent's actions [83]. Moreover, 13-month-old toddlers did not expect cooperative actions between humans and robots, even with social cues present [87]. By 17 months, toddlers showed signs of predicting the goal-directed reaching actions towards a target of both humans and humanoid robots, indicating an understanding of goal-directed behavior irrespective of the agent [106]. Finally, toddlers aged 24 to 35 months recognized the intention behind a robot's failed attempts to place beads inside a cup, but only when the robot made eye contact [68].

Imitation. Social robots were used to study two kinds of imitation in young children, i.e., their ability to learn by observing and imitating others [96]. Half of the studies focused on infants aged 2–8 months and their imitation of the humanoid robot's bodily movements, also known as motor imitation, and contingency learning in a face-to-face interaction [69, 89, 90]. Although 2- to 5-month-olds paid more attention to the robot when it moved, only 6- to 8-month-olds imitated its motor movements and demonstrated contingency learning [69, 89, 90]. The remaining studies investigated 1- to 3-year-old toddlers' imitation of a robot's actions with objects, such as assembling a rattle and shaking it to make a sound [58, 62, 93]. The studies found that toddlers imitate both physically present [58] and on-screen robots [62] and that their imitation of robots increased with age [58, 62]. Toddlers who interacted more with the robot prior to the imitation test were more likely to imitate it [58], though they still imitated humans more frequently [58, 62]. Moreover, toddlers' imitation from on-screen demonstrations of a human experimenter performing actions is not facilitated by presenting such videos embedded in robots behaving socially [93].

Early conversational skills. Three studies used a toy robot to investigate early conversational skills in toddlers (Tables 3 and 4). The robot provided constant verbal stimulation through an in-built speaker. By using a robot, the researchers aimed to eliminate potential confounding nonverbal cues (e.g., gaze, gestures) inevitably present in human conversation that could affect toddlers' responses [63–65]. For 24-month-olds, when the robot reciprocated toddlers' utterances by repeating and expanding the topic, it led to more topic-maintaining conversation and increased linguistically mediated social play [63]. Moreover, 24-month-olds recognized when the robot's responses were semantically relevant and on-topic, and in these situations, toddlers were more likely to continue and expand the conversational topic compared to when the robot was off-topic [64]. Older toddlers, aged 27 and 33 months, demonstrated an understanding of pragmatic quantity rules in conversations by responding appropriately to specific and general queries when conversing with the robot [65].

Other concepts and related findings. The remaining studies used various social robots (Table 3) to examine: reading ability [56], computational thinking programming, coding skills [59], and physical play and emotional responses [57]. For more details about these studies, see the S1 Table.

Gaps and challenges

To address our third research question, we summarize gaps and challenges in using social robots as a research tool reported by the authors of the studies in the review. The most reported gaps by the authors were related to children's familiarity with robots, testing the effect of specific robot appearance and/or behavior cues, the design of the robot, and testing across different settings. Many studies [58, 62, 72, 82, 85, 87, 88] discussed that future work should investigate whether children's familiarity with robots might influence their understanding of and response to robots. For example, Okumura discusses [85] that infants might have stronger expectations for referential cues, such as gaze, from humans rather than robots due to their familiarity with human interaction. Moreover, future studies should investigate whether children's increased exposure to robots can enhance their ability to understand and respond to a robot's referential communication [85]. Several studies suggest that further research should investigate how a robot's physical appearance and behavior impact children's perception, comprehension, and learning from robots [66, 81–83, 85, 87]. For instance, Okumura et al. [86] suggest that future research should examine whether verbal cues provided by robots influence infants' object learning. Regarding gaps related to robotic design, one study [92] elucidated that robotic developers should aim to make robots that can interact autonomously without interference from a human operator. Related to the robot's design, Peca and colleagues [92] propose that future work should try to make robots that can interact autonomously with the child without the need for an operator. Most of the studies were conducted in experimental settings, and some studies [69, 72] suggest that future work should examine child-robot interactions in more naturalistic settings.

Most studies ($n = 24$) reported some challenges or limitations related to using social robots as a research tool. Many studies ($n = 10$) reported challenges related to the robot's design, such as issues related to its appearance and functionality. For example, additional human operators are required in the experimental procedures due to the technical constraints of the robots, difficulty in making the robots' movements resemble human movements, or challenges with using robots in live tasks because robots fail to provide the stimuli correctly or do not respond appropriately during interactions. Several studies ($n = 7$) reported children having challenges understanding the robot, such as its actions, communicative cues, and underlying intentions. Relatedly, some studies discussed that children's lack of familiarity and experience with robots

Table 5. Reported challenges in using robots as a research tool in the included studies. The category "no limitations reported" refers to studies that have not reported any challenges relevant to using social robots as a research tool.

Challenges reported	Frequency	Representative studies
Child		
Fear of robot	3	[58, 81, 93]
Novelty of robot	4	[66, 72, 84, 87]
Understanding the robot	7	[58, 66, 69, 72, 85–87]
On-task engagement	5	[58, 59, 87, 89, 90]
Sample bias	1	[65]
Robot		
Design	10	[58, 61, 62, 66, 67, 72, 77, 91, 92]
Cost	2	[56, 69]
Safety hazards	1	[62]
Stimuli presentation	2	[66, 77]
Research design		
Ecological validity	3	[63, 69, 88]
Chosen design	1	[92]
Operationalizing	2	[61, 92]
Setting or set-up	3	[60, 85, 90]
No limitations reported	5	[57, 64, 68, 82, 83]

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may contribute to difficulty understanding them and make them more distracting ($n = 4$). Several studies ($n = 5$) reported children experiencing challenges with task focus, including little or too much interest in the robot, irritability during robot inactivity, or children being distracted and leaving the task activity. Some studies ($n = 3$) discussed ecological validity issues, such as the generalization of findings across settings and with specific robots to other robot types or humans. Relatedly, we noticed that few studies used control groups with human or non-human agents for the robots they used, and there is limited discussion on the absence of these controls. An overview of commonly reported challenges is presented in Table 5.

Discussion

This scoping review is a novel contribution to the field as it is the first to systematically cover the breadth of the literature on how social robots have been used in early development research to investigate social and cognitive development. Our review provides an overview of general characteristics, methods, research focus, findings, and the reported gaps and challenges when social robots are used in early developmental research. Previous systematic reviews and scoping reviews have focused on using social robots with older children in other settings, such as in education [97], supporting autism development [98–102], or various health care contexts [103–106]. Although we maintained the wide approach of a scoping review, we found that an overarching research focus in the reviewed literature was to determine if social robots can act as social partners for young children. According to this literature, children sometimes classify social robots as social partners and can interpret the social cues and actions of robots in certain situations. Thus, the studies demonstrate the potential of using various social robots in early developmental research, but do not suggest that social robots can replace humans in research settings.

General characteristics and methods

We found that the use of social robots in early development research is a small research field, and we found 29 studies for the review. Most studies were quantitative with experimental designs and conducted in controlled laboratory settings, in which the children were exposed to the robots in a one-to-one situation. Few studies used qualitative methodology [59, 60, 91], and only one study [91] observed child-robot interactions in a long-term context. Most robots were humanoid and pre-programmed to perform a specific social behavior of interest. We had a broad definition of social robots, including robots that fit typical descriptions of social robots, such as Robie Sr., Robovie, Robovie2, NAO, Dr. Robot Inc., HOAP-2, RUBI, RUBI-6, iRobiQ, ReplieeQ2, MyKeepon, 210 AIBO, MiRoE, and Opie (Table 3 and Fig 3). However, we also found robots not typically considered social robots, such as the robotic ball Sphero and Bee-Bot (Table 3 and Fig 3). Notably, the robots used in the studies varied in their level of advancement. Some were relatively simple and immobile, like the Robie Sr. robot, while others were capable of autonomous action, such as the NAO robot (Table 3 and Fig 3). Naturally, some of the more advanced robots were unavailable when the first studies were conducted, and therefore, we found that more simplistic robots were used in the studies that were first published.

Research focus and key findings

Our review shows research trends in using social robots to study social and cognitive concepts such as animacy understanding, action understanding, imitation, and early conversational skills. Some studies also used robots to examine reading abilities, computational thinking, and emotions. We found that most studies focused on whether children classify robots as social partners to interact with and acquire information from or whether humans are a privileged source of information at these developmental stages [58, 60, 62, 66–69, 72, 77, 81–94]. Only a few studies [63–65] used robots to provide more constant stimuli instead of humans, with a main focus on the developmental concepts examined. Furthermore, some had an additional focus on the application of robots [56, 59, 60], such as the therapeutic potential of robot dogs [60] or as a learning tool to improve reading [56]. Lastly, one study used a robot providing socially contingent behaviors to facilitate children's imitation learning from a human experimenter [93].

The limited number of studies means that caution is necessary when interpreting the findings. Furthermore, research findings from one age group cannot be generalized to others. However, some key findings indicate that infants are attentive to robots and can learn from them at an early stage of development in several situations. Thus, humans are not necessarily the only information source for young children. For instance, 2-month-olds tend to be more attentive to robots that move [90], while 6-month-olds imitate robots [69]. Furthermore, 6.5-month-olds can attribute goals to a robot's moving actions toward a specific destination [83]. Another key finding was that as children grow older, they show signs of becoming better at recognizing and interpreting the social cues provided by robots, and their learning from robots is enhanced. For example, 24- to 35-month-old showed early signs of attributing intentions to robots by detecting what a robot intended to do when it failed to put beads inside a cup [68]. Additionally, 1-to-3-year-olds were able to imitate a robot's actions with objects both on-screen and in real life, and imitation increased with age [58, 62]. Yet, in several situations, children in the reviewed studies did not understand the robots' social behaviors and were not able to learn from them [66, 72, 84, 85, 87, 90]. Taken together, toddlers and infants may view robots as social partners, attributing mental states to them like older children do [107–110]. Moreover, this literature provides information on the ages at which young children can socially engage with social robots.

Yet another key finding was that it was not just the appearance of social robots but also how the robots behave that plays an important role in how young children perceive, understand, and respond to them [56, 58, 63, 64, 67, 82, 86, 91]. Especially, contingency and interactivity behaviors facilitated how the robots were understood. For example, when young infants observed another person talking to or contingently interacting with a robot, they tended to classify the robot as animate [82, 92], and they showed increased sensitivity to its social cues such as eye gaze [67]. Additionally, toddlers who interacted more with the robot prior to the imitation test were more likely to imitate it [58]. In conversations with robots, toddlers tended to stay more engaged in the conversation when the robot reciprocated their verbalizations and stayed on-topic [63, 64]. Moreover, adding more social factors to the robot, such as verbal cuinging, increases 12-month-old infants' ability to follow a robot's gaze to an object [86]. Relatedly, Csibra [111] proposes that it is not how an agent looks that is important for children to identify it as an agent, but how it behaves. It is possible that social robots having appearances and social behaviors like living beings blur the lines between living and non-living beings and that social robots are represented as a new ontological category in children. As a result, young children might perceive and treat these robots as social partners and not just machines. Relatedly, Manzi [88] et al. discuss robots with human-like characteristics might activate social mechanisms in young infants. Yet, in some cases, appearance and contingency behaviors were not enough to elicit an understanding of the robot's intention [66].

Gaps and challenges

The authors reported several gaps and challenges related to using social robots in early developmental research. Most commonly, the authors reported that future work should investigate whether children's familiarity with robots impacts their responses. Although social robots possess human-like qualities and behaviors already familiar to the child, their novelty may result in different responses from children when compared to interactions with human agents. Frequently reported challenges were related to robot design. For instance, in some studies, a human experimenter had to accompany the robot during an experiment because of the technical constraints of the robots [66, 92]. Relatedly, Peca and colleagues [92] discuss that future work should aim to make robots that do not require human operators.

Limitations

This scoping review is not without limitations. Although we conducted extensive searches across multiple databases, it is possible that some relevant studies were not included. Our inclusion criteria were limited to studies published in English, and we did not manually search reference lists to identify additional studies, which may have resulted in the exclusion of relevant studies. Furthermore, as scoping reviews do not typically aim to assess the quality of evidence, we did not perform a formal quality assessment of the studies included.

Future directions

This review has allowed us to identify important directions for future research, primarily within developmental psychology but also in social robotics. Firstly, it is unclear how efficient social robots are when acting as agents in early developmental research. This is indicated by diverse findings related to how children classify them as animate or inanimate and how children interpret their social cues and behaviors. Notably, few studies used any human or non-human controls for robots. Thus, future studies should use other agent types in addition to robots to determine the efficiency of using social robots, humans, and other types of agents in early developmental research. Findings on what robot behaviors are crucial for young children may have implications for future work within social robotics when aiming to develop age-appropriate robots. Secondly, we found that multiple robots were rarely used within the same study, and thus, it is unclear if their findings generalize to other types of robots or if the findings are specific to a particular robot type. Future work could use several robots to test generalizability across different robot types. Thirdly, most studies investigated child-robot interactions in highly controlled settings that do not easily generalize to other environments. Future work should investigate naturalistic interactions between children and robots, in which the robots respond to the child's behavior at the moment rather than being pre-programmed to do a specific task. Fourth, we noticed that the included studies rarely reported the reasons behind their choice of a specific robot type and the amount of time spent preparing the robot, such as learning to program it or having a skilled programmer do it. We suggest reporting such information to ease replication and to improve planning for future studies.

Conclusion

Our scoping review of 29 studies shows a small and emerging field of using social robots to study social and cognitive development in infants and toddlers. We identified four main areas of focus: animacy understanding, action understanding, imitation, and early conversational skills. An important question in the field is whether young children perceive social robots as social partners or agents. Findings vary on how children classify and understand the behaviors of social robots. According to the studies, young children can, from an early age, pay attention to social robots, learn from them, and recognize their social signals, but not always. The studies suggest that certain robot behaviors, particularly those that are interactive and contingent, are critical for enhancing children's perception of robots as social entities. Moreover, it seems like children's understanding of robots improves with age. Our review indicates that even in infancy, social robots can be regarded as social partners, a perception that is essential in research settings that depend on social interaction. Consequently, our review highlights the need for careful selection of social robots that exhibit interactive and contingent behaviors to be effective in early developmental research. Furthermore, this review contributes knowledge on how children socially interact with and learn from non-human agents with rich social features. These insights are important for future studies within developmental psychology involving social robots and young children and future work within social robotics on designing appropriate robot behaviors to facilitate social interaction with robots in early childhood.

Supporting information

S1 Checklist. Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist.
(DOCX)

S1 File. Search strategy. Search queries and search terms used in the databases and preprint repository.
(DOCX)

S1 Table. Overview of the included studies.
(DOCX)

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Appendix D: Study 1, information letter for Experiment 1

Request for participation in a research project

"Towards an early detection of delays in social-cognitive development – A new battery of imitation tests"

Background and purpose

This is a request for you to participate with your child in a research study that intends to test 18-month-old infants' imitation with a newly developed material. You receive this request for participation and information sheet because you have expressed your interest in our study. The institution responsible for the study is the Department of Psychology at UiT – The Arctic University of Norway.

What does the study entail?

If you decide to participate, you and your child will be invited to a short visit to our lab at the university. After a warm-up period spent in a friendly waiting room, you, your child and the experimenter will go to the lab room where the study will be conducted. If your child is assigned to the control condition, (s)he will play with a number of colourful objects. If your child is assigned to the experimental condition, (s)he will first watch the experimenter perform some actions on the objects, and after a 30 minutes break (s)he will get the opportunity to play with the objects. You will be present but asked not to play with your child and not to comment on her/his actions. Your child's object manipulation will be videotaped for subsequent analysis. Additionally, you will be asked to fill in a short questionnaire concerning your child's social-emotional development (e.g., how easily you can calm him/her when (s)he is upset).

Potential advantages and disadvantages

Imitation studies are usually enjoyable for infants, for them it is merely playing with nice toys and interacting with a friendly person, with a parent present all the time. The study has no more risks than any other social situation children might encounter in their everyday lives.

What will happen to the information about you?

The data that are registered about your child will only be used in accordance with the purpose of the study as described above. All the data will be processed without name, ID number or other directly recognisable type of information. It will not be possible to identify you in the results of the study when these are published. A code number will link your child to his/her data through a list of names. Only authorised project personnel will have access to the list of names and be able to identify your child. This code list will be destroyed 6 months after the end of the study.

Voluntary participation

Participation in the study is voluntary. You can withdraw your consent to participate in the study without stating any particular reason up to 6 months after the study has ended. After this time, the code list will be destroyed so it will not be possible to identify and retract your child's data from the data files. If you wish to participate, please sign the declaration of consent on the final page. If you later on wish to withdraw your consent or have any questions concerning the study, you may contact Dr. Gabriella Óturai, tel. 776 46818, e-mail: gabriella.oturai@uit.no.

Further information on the study can be found in Chapter A – *Further elaboration of what the study entails.*

Further information about biobank, privacy and insurance can be found in Chapter B – *Privacy, biobank, funding and insurance.*

The declaration of consent follows Chapter B.

Chapter A – Further elaboration of what the study entails

Criteria for participation

Participants of the study are typically developing, 18 months old infants. Your child may participate in a time window of ± 2 weeks from his/her 18 months birthday if (s)he was born after at least 37 weeks of gestation with a weight of min. 2500 g and max. 4500 g, if there were no complications during or shortly after birth that could have affected the baby, and if (s)he has no diagnosed sensory, motor or neurological impairment. Additionally, we ask you to reschedule the appointment if your child gets sick.

Background information about the study

Imitation studies have been widely used to assess different social-cognitive processes such as memory or action understanding. This study will involve different types of imitation tests, which will enable the investigation of the relations between these processes. Additionally, infants' socio-emotional development will be assessed as one of the possible underlying factors of inter-individual differences in imitation performance.

Compensation

As a compensation for your time and commute, you will receive a gift card (150 kr). Your child will receive a small toy as a thank you gift.

Chapter B – Privacy, biobank, funding and insurance

Privacy

Information that is registered about you and your child will include your answers to the questions regarding the inclusion criteria, a video recording about your child's object manipulation in the lab, as well as your answers to the questionnaire about your child's social-emotional development. The Department of Psychology at UiT – The Arctic University of Norway, represented by the Head of Department, is responsible for the data processing.

Releasing data to other parties

Your data will not be released to other parties.

Right to access and right to delete your data

If you agree to participate in the study, you are entitled to have access to what information is registered about you. You are further entitled to correct any mistakes in the information we have registered. If you withdraw from the study, you are entitled to demand that the collected data are deleted. Please bear in mind that at this point aggregated data might already have been presented or published.

Funding and the role of Helse Nord

The study is funded by a research grant from Helse Nord. There are no conflicts of interest.

Insurance

Not relevant for the present study.

Information about the outcome of the study

We will inform about the findings of the study on the webpage of our lab. Please bear in mind that we are not able to provide any individual feedback.

Consent for participation in the study

I am willing to participate with my child.

(Signed by the participating child's parent, date)

I am willing to participate with my child.

(Signed by the participating child's parent, date)

Appendix E: Study 1, information letter for Experiment 2

Request for participation in a research project

"Towards an early detection of delays in social-cognitive development – A new battery of imitation tests"

Background and purpose

This is a request for you to participate with your child in a research study that intends to test 18-month-old infants' imitation with a newly developed material. You receive this request for participation and information sheet because you have expressed your interest in our study. The institution responsible for the study is the Department of Psychology at UiT – The Arctic University of Norway.

What does the study entail?

If you decide to participate, you and your child will be invited to two short visits to our lab at the university. The basic procedure will be identical on both days: After a warm-up period spent in a friendly waiting room, you, your child and the experimenter will go to the lab room where the study will be conducted. Your child will first watch the experimenter perform some actions on the objects, and after a 30 minutes break (s)he will get the opportunity to play with the objects. You will be present but asked not to play with your child and not to comment on her/his actions. Your child's object manipulation will be videotaped for subsequent analysis. Additionally, on the first appointment you will be asked to fill in a short questionnaire concerning your child's social-emotional development (e.g., how easily you can calm him/her when (s)he is upset). Depending on the condition your child is assigned to, you will meet either the same or different experimenters at the two appointments.

Potential advantages and disadvantages

Imitation studies are usually enjoyable for infants, for them it is merely playing with nice toys and interacting with a friendly person, with a parent present all the time. The study has no more risks than any other social situation children might encounter in their everyday lives.

What will happen to the information about you?

The data that are registered about your child will only be used in accordance with the purpose of the study as described above. All the data will be processed without name, ID number or other directly recognisable type of information. It will not be possible to identify you in the results of the study when these are published. A code number will link your child to his/her data through a list of names. Only authorised project personnel will have access to the list of names and be able to identify your child. This code list will be destroyed 6 months after the end of the study.

Voluntary participation

Participation in the study is voluntary. You can withdraw your consent to participate in the study without stating any particular reason up to 6 months after the study has ended. After this time, the code list will be destroyed so it will not be possible to identify and retract your child's data from the data files. If you wish to participate, please sign the declaration of consent on the final page. If you later on wish to withdraw your consent or have any questions concerning the study, you may contact Dr. Gabriella Óturai, tel. 776 46818, e-mail: gabriella.oturai@uit.no.

Further information on the study can be found in Chapter A – *Further elaboration of what the study entails.*

Further information about biobank, privacy and insurance can be found in Chapter B – *Privacy, biobank, funding and insurance.*

The declaration of consent follows Chapter B.

Chapter A – Further elaboration of what the study entails

Criteria for participation

Participants of the study are typically developing, 18 months old infants. Your child may participate in a time window of ± 2 weeks from his/her 18 months birthday if (s)he was born after at least 37 weeks of gestation with a weight of min. 2500 g and max. 4500 g, if there were no complications during or shortly after birth that could have affected the baby, and if (s)he has no diagnosed sensory, motor or neurological impairment. Additionally, we ask you to reschedule the appointment if your child gets sick.

Background information about the study

Imitation studies have been widely used to assess different social-cognitive processes such as memory or action understanding. Besides investigating the relations between these processes, this study will also tackle the stability of imitation performance, both over time and across social contexts. Additionally, infants' socio-emotional development will be assessed as one of the possible underlying factors of inter-individual differences in imitation performance.

Compensation

As a compensation for your time and commute, you will receive a gift card (150 kr). Your child will receive a small toy as a thank you gift.

Chapter B – Privacy, biobank, funding and insurance

Privacy

Information that is registered about you and your child will include your answers to the questions regarding the inclusion criteria, a video recording about your child's object manipulation in the lab, as well as your answers to the questionnaire about your child's social-emotional development. The Department of Psychology at UiT – The Arctic University of Norway, represented by the Head of Department, is responsible for the data processing.

Releasing data to other parties

Your data will not be released to other parties.

Right to access and right to delete your data

If you agree to participate in the study, you are entitled to have access to what information is registered about you. You are further entitled to correct any mistakes in the information we have registered. If you withdraw from the study, you are entitled to demand that the collected data are deleted. Please bear in mind that at this point aggregated data might already have been presented or published.

Funding and the role of Helse Nord

The study is funded by a research grant from Helse Nord. There are no conflicts of interest.

Insurance

Not relevant for the present study.

Information about the outcome of the study

We will inform about the findings of the study on the webpage of our lab. Please bear in mind that we are not able to provide any individual feedback.

Consent for participation in the study

I am willing to participate with my child.

(Signed by the participating child's parent, date)

I am willing to participate with my child.

(Signed by the participating child's parent, date)

Appendix F: Study 2, information letter for Experiment 1

Are you interested in taking part in the research study *”Infants’ imitation in different social contexts”?*

This a request for you to participate with your child in a research study whose main purpose is to examine how different social contexts influence 17- to 19-month-old infants’ imitation behavior. You receive this request for participation and information sheet because you have expressed your interest in our study. The institution responsible for the study is the Department of Psychology (IPS) at UiT – The Arctic University of Norway, represented by the head of department. In this letter, we will give you information about the purpose of the project and about what your participation will involve.

Background and purpose of the study

Imitation is one of the earliest learning mechanisms in infants. Imitation studies have been widely used to assess different social-cognitive processes such as memory or action understanding. During the second year of life, infants’ imitation is in a “transition phase” whereby they become more affected by the social context in which the learning happens. More research is needed to understand how imitation in the second year of life is affected by different social contexts, such as when the adult is less available and occupied with something else than the child (for example, a smartphone). In the present study, therefore, imitation behavior in 17- to 19-month-old infants will be examined across different social contexts where the experimenter’s social availability is varied. This study is a good first step in the direction of promoting better learning contexts for infants.

What does participation in the study involve?

The study takes place on Zoom, so you need to have a good Internet connection and a computer with microphone and camera. In imitation studies it is common to use test objects, and infants’ manipulation of these objects is used to measure social-cognitive processes. Since this study happens in your own home on the Internet (and not in a lab), we need help from you to make some simple test objects. You will receive a link to a YouTube video that shows you how to make these objects. It is important that you make the objects as similar as possible to the objects in the video, so that all infants who participate in the study can play with similar objects. Prior to the imitation test, you will receive an invitation by e-mail with a link to a short information meeting with the experimenter on Zoom. Please make the test objects prior to this information meeting (remember to make an extra set), so that the experimenter can do a quality check of the objects. Your verbal consent to participate in the study with your child will be obtained in this information meeting. The experimenter will read all the statements in the consent form, and you can give your consent by answering *yes* to each statement. You and your child will be invited to another appointment on Zoom for the actual imitation test. The duration of the imitation test is approximately 10 minutes, and the test consists of a demonstration phase and a test phase. Your child will be seated on your lap in front of the computer in both phases of the test. In the demonstration phase, your child will watch a YouTube video of the experimenter perform different actions with the test objects. After watching the video, you will meet the experimenter on Zoom for the test phase. Initially, there will be a short interaction between the parent and the experimenter in order to make your child comfortable. Then, the experimenter will tell you when to put the test objects on the table. Your child will get the opportunity to play with the objects on the table in front of the computer. It is important that you do not name the test objects or comment on your child's actions with the test objects. The Zoom meetings will be recorded for subsequent analysis of the child's attention to the video and manipulation of the test objects. The study entails two different groups, and your child will randomly be assigned to one of them. The social availability of the experimenter will be varied during the imitation test, but in a different way dependent on which group your child is assigned to.

Participation is voluntary

Participation in the project is voluntary. You can withdraw your consent at any time without giving a reason. If you withdraw your consent before 15.07.2033, we will also delete the numeric data (in addition to the raw data, i.e., video recordings). Please bear in mind that at this time it is very likely that the collected data already have been presented or published in anonymized form. If you want to participate with your child, you can give your verbal consent to the experimenter in the information meeting on Zoom. The experimenter will read out loud the statements on the consent form on the last page, and you can consent by answering *yes* to all statements. There will be no negative consequences for you if you choose not to participate or later decide to withdraw.

Potential advantages and disadvantages

Imitation studies and online studies are usually enjoyable for children. For them it is merely playing with simple objects and interacting with a friendly person, with a parent present all the time. The study has no more risks than any other social situation children might encounter in their everyday lives. The results of the study will be presented on a group level in research articles, academic presentations, and in popular scientific communications.

Compensation

As a thank you gift, your child will receive a nice certificate by e-mail, and if desired also a small toy by mail.

Who can participate?

Participants of the study are typically developing, 17-19 months old infants. **Your child must be born after at least 37 weeks of gestation with a weight of min. 2500 g.** Your child can participate if (s)he has no diagnosed motor, sensory, neurological or developmental impairments. The imitation study takes place in Norwegian, and it is thus required that your child understands Norwegian. The experimenter speaks both Norwegian and English, and it is therefore possible to participate even if you are not Norwegian-speaking. We ask you to reschedule your appointment if your child gets sick. It is OK to participate if your child has a cold, but is otherwise in a good general condition.

Your privacy: How we will store and use your personal data

The personal data we register about you and your child will only be used for the purpose of the study (specified above). We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). All data will be processed without names or other recognizable information. A code number will link your child to his/her data through a list of names. It is only the PhD student MA in Psychology Solveig Flatebø and the project leader Dr. Gabriella Óturai, and other project personnel who have access to the list of names, contact details and respective codes. Some anonymized data will be shared on Open Science Framework (OSF) with other researchers. We will only share data in which it is impossible to identify you or your child: data related to children's behavior coded from the video recordings (the video recordings will *not* be shared). All identifiable data (recordings and verbal consent) will be saved on a password protected extern hard disk that is kept private, in a way that is in line with requirements for information security and protection at UiT The Arctic University of Norway.

What will happen to your personal data at the end of the research project?
The video recordings are our raw data, and they will be analyzed and coded into numeric data. This means that the data we use further on in, for example, published research articles or conference presentations, are in anonymized form. It will not be possible to recognize you or your child in such numeric data. Since the organization APA (American Psychological Association) has a standard that raw data should be kept **at least** for 5 years after the research report is published, we are going to keep the video recordings for 10 years after the end of the study. After 10 years all video recordings will be deleted. You can request the deletion of your video recordings whenever you wish. The list of names with the code list that connect you and your child to the video recordings will be kept until 15.07.2033. This means that until this date, you also **have the opportunity to request deletion of the numeric data** that is derived from your video recordings. When the code list is deleted, it is no longer possible to identify you or withdraw your or the child's data from the numeric data.

Your and your child's rights
We will process your and your child's personal data based on your consent. Based on an agreement with the Department of Psychology at UiT The Arctic University of Norway, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation. This study has also been approved by the ethical committee at the Department of Psychology at UiT The Arctic University of Norway.

As long as you and your child can be identified in the collected data, you have the right to:
- access the personal data that is being processed about you and your child,
- request that your and your child's personal data is deleted (such as the video recordings)
- request that incorrect personal data about you and your child is corrected/rectified,
- receive a copy of you and your child's personal data if you meet up personally at the university with your own memory stick (data portability), and
- to send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your and your child's personal data.

Contact information
If you have more questions about the study, or want to withdraw your consent or access your or your child's personal data, contact either PhD student Solveig Flatebø through e-mail: solveig.flatebo@uit.no or project leader Dr. Gabriella Óturai through e-mail: gabriella.oturai@uit.no.

- Our Data Protection Officer, e-mail: personvernombud@uit.no
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.

Infants' imitation in different social contexts

- Link to Open Science Forum, where anonymized data will be shared: https://osf.io/

Yours sincerely,

Gabriella Óturai
Project leader

Solveig Flatebø
PhD Student

Consent form

Your consent (will be obtained verbally in the information meeting on Zoom)
I have received and understood information about the project *"Infants' imitation in different social contexts"* and have been given the opportunity to ask questions. I give consent to the following:

- ☐ I consent to participate with my child in the study described in the information letter.
- ☐ I consent to that my child's attention to the video in the demonstration phase and my child's manipulation of the test objects is recorded for subsequent analysis, and that I am visible in the video recording.
- ☐ I consent to that some anonymized data, such as characteristics from the video recordings (anonymous numeric data), will be shared with other researchers outside UiT The Arctic University of Norway through the Open Science Framework repository.
- ☐ I consent to that my and my child's personal data will be processed until the end of the project, 15.07.2023, and that the raw data (video recordings) will be kept for 10 years after the end of the project.

I confirm that my child fulfils the criteria to participate, that is, my child:

- ☐ was born after at least 37 weeks of gestation,
- ☐ had a birth weight of min 2500 g,
- ☐ does not have any diagnosed motor, sensory (it is OK to participate if the child can follow the study with his/her sight and hearing), neurological or developmental impairments,
- ☐ understands Norwegian.

Appendix G: Study 2 information letter for Experiment 2

Are you interested in taking part in the research study *"Infants' imitation in different social contexts"?*

This a request for you to participate with your child in a research study whose main purpose is to examine how different social contexts influence 17- to 19-month-old infants' imitation behavior. You receive this request for participation and information sheet because you have expressed your interest in our study. The institution responsible for the study is the Department of Psychology (IPS) at UiT – The Arctic University of Norway, represented by the head of department. In this letter, we will give you information about the purpose of the project and about what your participation will involve.

Background and purpose of the study

Imitation is one of the earliest learning mechanisms in infants. Imitation studies have been widely used to assess different social-cognitive processes such as memory or action understanding. During the second year of life, infants' imitation is in a "transition phase" whereby they become more affected by the social context in which the learning happens. More research is needed to understand how imitation in the second year of life is affected by different social contexts, such as when the adult is less available and occupied with something else than the child (for example, a smartphone). In the present study, therefore, imitation behavior in 17- to 19-month-old infants will be examined across different social contexts where the experimenter's social availability is varied. This study is a good first step in the direction of promoting better learning contexts for infants.

What does participation in the study involve?

The study takes place on Zoom, so you need to have a good Internet connection and a computer with microphone and camera. In imitation studies it is common to use test objects, and infants' manipulation of these objects is used to measure social-cognitive processes. Since this study happens in your own home on the Internet (and not in a lab), we need help from you to make some simple test objects. You will receive a link to a YouTube video that shows you how to make these objects. It is important that you make the objects as similar as possible to the objects in the video, so that all infants who participate in the study can play with similar objects. Prior to the imitation test, you will receive an invitation by e-mail with a link to a short information meeting with the experimenter on Zoom. Please make the test objects prior to this information meeting (remember to make an extra set), so that the experimenter can do a quality check of the objects. Your verbal consent to participate in the study with your child will be obtained in this information meeting. The experimenter will read all the statements in the consent form, and you can give your consent by answering *yes* to each statement. You and your child will be invited to another appointment on Zoom for the actual imitation test. The duration of the imitation test is approximately 10 minutes, and the test consists of a control phase, a demonstration phase, and a test phase. Your child will be seated on your lap in front of the computer all the time. The imitation test starts with you meeting the experimenter live on Zoom. Initially, there will be a short interaction between the parent and the experimenter to make your child comfortable. In the control phase, the experimenter will ask you to put the test objects on the table and your child will get the opportunity to play with the test objects. The experimenter will let you know when the control phase is finished and ask you to put away the test objects. Then, in the demonstration phase, your child will watch a YouTube video of the experimenter perform different actions with the test objects. After watching the video, you will meet the experimenter on Zoom for the test phase. Then, the experimenter will tell you when to put the test objects on the table. Your child will get the opportunity to play with the objects once more. It is important that you do not name the test objects or comment on your child's actions with the test objects. The Zoom meeting will be recorded for subsequent analysis of the child's attention to the video and manipulation of the test objects. The study entails three different groups, and your child will randomly be assigned to one of them. The social availability of the experimenter will be varied during the imitation test, but in a different way dependent on which group your child is assigned to.

Participation is voluntary
Participation in the project is voluntary. You can withdraw your consent at any time without giving a reason. If you withdraw your consent before 15.07.2033, we will also delete the numeric data (in addition to the raw data, i.e., video recordings). Please bear in mind that at this time it is very likely that the collected data already have been presented or published in anonymized form. If you want to participate with your child, you can give your verbal consent to the experimenter in the information meeting on Zoom. The experimenter will read out loud the statements on the consent form on the last page, and you can consent by answering *yes* to all statements. There will be no negative consequences for you if you choose not to participate or later decide to withdraw.

Potential advantages and disadvantages
Imitation studies and online studies are usually enjoyable for children. For them it is merely playing with simple objects and interacting with a friendly person, with a parent present all the time. The study has no more risks than any other social situation children might encounter in their everyday lives. The results of the study will be presented on a group level in research articles, academic presentations, and in popular scientific communications.

Compensation
As a thank you gift, your child will receive a nice certificate by e-mail, and if desired also a small toy by mail.

Who can participate?
Participants of the study are typically developing, 17-19 months old infants. **Your child must be born after at least 37 weeks of gestation with a weight of min. 2500 g.** Your child can participate if (s)he has no diagnosed motor, sensory, neurological or developmental impairments. The imitation study takes place in Norwegian, and it is thus required that your child understands Norwegian. The experimenter speaks both Norwegian and English, and it is therefore possible to participate even if you are not Norwegian-speaking. We ask you to reschedule your appointment if your child gets sick. It is OK to participate if your child has a cold, but is otherwise in a good general condition.

Your privacy: How we will store and use your personal data

The personal data we register about you and your child will only be used for the purpose of the study (specified above). We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). All data will be processed without names or other recognizable information. A code number will link your child to his/her data through a list of names. It is only the PhD student MA in Psychology Solveig Flatebø and the project leader Dr. Gabriella Óturai, and other project personnel who have access to the list of names, contact details and respective codes. Some anonymized data will be shared on Open Science Framework (OSF) with other researchers. We will only share data in which it is impossible to identify you or your child: data related to children's behavior coded from the video recordings (the video recordings will *not* be shared). All identifiable data (recordings and verbal consent) will be saved on a password protected extern hard disk that is kept private, in a way that is in line with requirements for information security and protection at UiT The Arctic University of Norway.

What will happen to your personal data at the end of the research project?
The video recordings are our raw data, and they will be analyzed and coded into numeric data. This means that the data we use further on in, for example, published research articles or conference presentations, are in anonymized form. It will not be possible to recognize you or your child in such numeric data. Since the organization APA (American Psychological Association) has a standard that raw data should be kept **at least** for 5 years after the research report is published, we are going to keep the video recordings for 10 years after the end of the study. After 10 years all video recordings will be deleted. You can request the deletion of your video recordings whenever you wish. The list of names with the code list that connect you and your child to the video recordings will be kept until 15.07.2033. This means that until this date, you also **have the opportunity to request deletion of the numeric data** that is derived from your video recordings. When the code list is deleted, it is no longer possible to identify you or withdraw your or the child's data from the numeric data.

Your and your child's rights
We will process your and your child's personal data based on your consent. Based on an agreement with the Department of Psychology at UiT The Arctic University of Norway, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation. This study has also been approved by the ethical committee at the Department of Psychology at UiT The Arctic University of Norway.

As long as you and your child can be identified in the collected data, you have the right to:
- access the personal data that is being processed about you and your child,
- request that your and your child's personal data is deleted (such as the video recordings)
- request that incorrect personal data about you and your child is corrected/rectified,
- receive a copy of you and your child's personal data if you meet up personally at the university with your own memory stick (data portability), and
- to send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your and your child's personal data.

Contact information
If you have more questions about the study, or want to withdraw your consent or access your or your child's personal data, contact either PhD student Solveig Flatebø through e-mail: solveig.flatebo@uit.no or project leader Dr. Gabriella Óturai through e-mail: gabriella.oturai@uit.no.

- Our Data Protection Officer, e-mail: personvernombud@uit.no
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.
- Link to Open Science Forum, where anonymized data will be shared: https://osf.io/

Yours sincerely,

Gabriella Óturai	Solveig Flatebø
Project leader	PhD Student

Consent form

Your consent (will be obtained verbally in the information meeting on Zoom)
I have received and understood information about the project *"Infants' imitation in different social contexts"* and have been given the opportunity to ask questions. I give consent to the following:

- ☐ I consent to participate with my child in the study described in the information letter.
- ☐ I consent to that my child's attention to the video in the demonstration phase and my child's manipulation of the test objects is recorded for subsequent analysis, and that I am visible in the video recording.
- ☐ I consent to that some anonymized data, such as characteristics from the video recordings (anonymous numeric data), will be shared with other researchers outside UiT The Arctic University of Norway through the Open Science Framework repository.
- ☐ I consent to that my and my child's personal data will be processed until the end of the project, 15.07.2023, and that the raw data (video recordings) will be kept for 10 years after the end of the project.

I confirm that my child fulfils the criteria to participate, that is, my child:

- ☐ was born after at least 37 weeks of gestation,
- ☐ had a birth weight of min 2500 g,
- ☐ does not have any diagnosed motor, sensory (it is OK to participate if the child can follow the study with his/her sight and hearing), neurological or developmental impairments,
- ☐ understands Norwegian.