Social Touch in Mother-Infant Interactions – Behavioral Patterns and Neural Correlates

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Uminho | 2023

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outubro 2023

FCT Fundação para a Ciência e a Tecnologia

REPÚBLICA PORTUGUESA | CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

NORTE2020 PROGRAMA OPERACIONAL REGIONAL DO NORTE

PORTUGAL 2020

UNIÃO EUROPEIA Fundo Social Europeu

Universidade do Minho
Escola de Psicologia

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Tese de Doutoramento
Doutoramento em Psicologia Básica

Trabalho efetuado sob a orientação da
Professora Doutora Adriana da Conceição Soares Sampaio
e do
Professor Doutor Alfredo Manuel Feliciano Pereira

outubro de 2023

Agradecimentos

Aos meus orientadores, professor Jorge Santos, que já não se encontra entre nós, por todas sugestões e comentários que marcaram o início desta viagem. Ao professor Alfredo Pereira por ter acreditado em mim deste o primeiro momento, por me ter guiado nos muitos altos e baixos que caraterizaram no meu percurso e, por ter ajudado o cientista que existe dentro de mim a crescer metodologicamente, intelectualmente e até emocionalmente. À professora Adriana por todas oportunidades de crescimento que me proporcionou e valioso feedback que foram fundamentais para chegar ao final deste percurso. Ao Centro de Investigação em Psicologia (CIPsi) por ter acolhido e promovido o desenvolvimento do meu trabalho, e à Fundação para a Ciência e Tecnologia (FCT) pelo apoio financeiro concedido[1].

À Dra. Helga Miguel por toda ajuda e feedback que me proporcionou ao longo da elaboração deste trabalho. To Joy and Catlin, for the patience, encouragement, and affection that unlocked the talkative "Gal" within me.

Aos meus colegas de doutoramento tenho a agradecer os momentos de partilha, validação e companheirismo. Especialmente a ti Dani, pelo carinho, longas conversas e por seres a minha âncora na escola, que sempre me ajudou a fazer a coisas no momento certo.

Aos meus colegas de laboratório, que hoje posso chamar de amigos, é difícil encontrar palavras para definir o quão importantes vocês foram ao longo deste processo, mas vou tentar. Ao Filipe e à Xana pela valiosa ajuda na cotação dos vídeos. Ao Daniel pelas longas conversas e por sempre me ajudares a encontrar o lado racional dos problemas complexos. À Isabel pela amizade e por sempre teres acreditado que conseguia mesmo quando eu própria achava que não era capaz. Ao Vladimiro, por ser a bússola que me orientou na busca do caminho certo sempre que me encontrava perdida.

A todos e cada um dos meus amigos, a minha família de coração, por me acompanhar não só no meu percurso académico, mas também na vida. À minha mãe, ao meu pai, e ao meu irmão, por serem o meu porto seguro, sem o qual eu não seria capaz de chegar aqui.

[1] This work was funded by the Portuguese Foundation for Science and Technology (FCT, Portugal) and the Portuguese Ministry of Science, Technology and Higher Education through national funds, and co-financed by FEDER through COMPETE2020 under the PT2020 Partnership Agreement (POCI-01-0145-FEDER-007653)., with the doctoral Grant reference PD/BD/142819/2018 and the COVID/BD/152740/2022

Statement of Integrity

I hereby declare have conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Toque Social nas Interações Mãe-Bebé - Padrões Comportamentais e Correlatos Neurais

Resumo

O toque é uma modalidade central no desenvolvimento humano, particularmente na primeira infância, onde as interações táteis com os cuidadores são vitais para o desenvolvimento do bebé. Esta tese inclui quatro estudos que examinaram o comportamento do toque materno em interações de brincadeira, bem como a associação entre o comportamento do toque materno e as respostas neurais do bebé a estímulos táteis.

O toque nas interações cuidador-bebé tem sido predominantemente medido usando instrumentos observacionais, que apresentam variações significativas entre si, o que torna as comparações diretas desafiadoras. Como tal, o primeiro estudo desta tese é uma revisão sistemática que analisou os instrumentos observacionais disponíveis para medir o toque. Delineamos as principais características destes instrumentos e oferecemos insights sobre suas aplicações anteriores. Três abordagens principais para avaliar o comportamento do toque do cuidador emergiram desta revisão: estritamente observacional, funcional ou métodos mistos. Também observamos que essas ferramentas foram principalmente usadas para medir o toque materno durante procedimentos de interação face a face ou "Still-Face" e com bebés com menos de 6 meses de idade.

O segundo e terceiro estudos utilizam um sistema de codificação microanalítico do toque materno para examinar como as mães estruturam as atividades de jogo dos bebés, incluindo tarefas orientadas para objetos e não orientadas para objetos, na segunda metade do primeiro ano do bebé. No segundo estudo, examinamos os padrões de toque materno com bebés de 12 meses e descobrimos que a natureza das tarefas de jogo influenciou os padrões de toque materno. No terceiro estudo, examinamos longitudinalmente a trajetória do comportamento de toque materno ao longo do tempo, quando o bebé tinha 7 e 12 meses. Os nossos resultados sugerem que a trajetória do comportamento de toque materno é moldada pelas necessidades desenvolvimentais do bebé e pelos desafios apresentados pelas tarefas de jogo orientadas para objetos versus não orientadas para objetos.

O quarto estudo explora a associação entre a exposição do bebé ao toque materno, medida pela frequência do toque durante uma tarefa de jogo livre sem objetos, e as respostas cerebrais ao toque afetivo e ao discriminativo. As medições foram feitas longitudinalmente aos 7 e 12 meses de idade, e a ativação cerebral no córtex somatossensorial esquerdo (SS) e no sulco temporal superior posterior direito (pSTS) foi registada utilizando a espectroscopia

funcional em infravermelho próximo (fNIRS). Bebés de mães que tocam mais tiveram uma redução na ativação no SS, mas níveis mais elevados de ativação no pSTS quando expostos ao toque afetivo. Além disso, descobrimos que um aumento no toque materno estava positivamente associado a uma maior resposta cerebral ao toque discriminativo no pSTS. Esse efeito foi observado aos 7 meses, mas não aos 12 meses. Os nossos resultados sugerem também que a frequência do toque materno está associada às respostas cerebrais do bebé a toque afetivo e discriminativo. A exposição consistente a níveis mais elevados de toque materno durante o desenvolvimento inicial pode estar envolvida em mudanças neurodesenvolvimentais no pSTS dos 7 aos 12 meses.
Palavras-chave: fNIRS; Interações mãe-bebé; Medidas observacionais; Processamento do toque; Toque social.

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Abstract

Touch is a core modality in human development, particularly in early infancy where tactile interactions with caregivers are vital for developmental outcomes. This thesis includes four studies that examined maternal touch behavior in play interactions, as well as the association between maternal touch behavior and the infant's neural responses to touch stimuli.

The assessment of touch in caregiver-infant interactions has predominantly relied on observational tools, which exhibit substantial variations, making direct comparisons challenging. As such, the first study of this thesis is a systematic review that surveyed existing observational tools for assessing touch. We outline these instruments' main characteristics and offer insights into their previous applications. Three main approaches for assessing the caregiver's touch behavior emerged from this review: strictly observational, functional, or mixed methods. We also observed that these tools were primarily used to measure maternal touch during face-to-face or "Still-Face" procedures, and with infants under 6 months of age.

The second and third studies use a microanalytic coding system of maternal touch to examine how mothers structure infant play activities - including object-oriented and non-object-oriented tasks - in the second semester of the infant's first year. In the second study, we examined maternal touch patterns with 12-month-olds and found that the nature of the play tasks influenced maternal touch patterns. In the third study, we examined longitudinally the trajectory of maternal touch behavior over time, when the infant was 7 and 12 months. Our findings suggest that the trajectory of maternal touch behavior is shaped by the evolving needs of the infant, and the distinct challenges of object-oriented versus non-object play tasks.

The fourth study explores the association between the infant's exposure to maternal touch, as measured by the frequency of touch during a free play task without objects, and their brain responses to affective and discriminative touch. Measurements were made longitudinally at 7 and 12 months of age and brain activation in the left somatosensory cortex (SS) and the right posterior Superior Temporal Sulcus (pSTS) was recorded using functional near-infrared spectroscopy (fNIRS). Infants of mothers that touch more had reduced activation in SS but higher levels of activation in the pSTS when exposed to affective touch. Also, we found that increased maternal touch was positively associated with heightened brain responses to discriminative touch in the STS. This effect was observed at 7 months but not at 12 months. Our results suggest that the frequency of maternal touch is associated with the infant's brain responses to both affective and discriminative touch. Consistent exposure to higher levels of maternal touch during early development may be implicated in the neurodevelopmental changes in the STS from 7 to 12 months.

Keywords: fNIRS; Mother-infant interactions; Observational measures; Social touch; Touch processing

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Abbreviations

AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
APA	America Psychological Association
Bayley-III	Bayley Scales of Infant and Toddler Development, Third Edition
CI	Credible Interval
CITS	Caregiver Infant Touch Scale (Stack et al., 1996; Stack et al., 2001)
CITS-Adapted	Caregiver-Infant Touch Scale - Adapted (Mercuri et al., 2019)
CT(s)	C-Tactile-Fibers
CTCS	Caregiver Touch Coding System (Koester & Paradis, 2010; Paradis & Koester, 2015)
DOT	Diffuse Optical Tomography
elpd_diff	Log Pointwise Predictive Density Difference
ESS	Effective Sample Size
FFTCS	Face-to-face Touch Coding System (Koester et al., 2000)
fMRI	Functional Magnetic Resonance Imaging
FMTS	The Functions of Mother-Infant Mutual Touch Scale (Mantis et al., 2013; Mantis & Stack, 2018)
fNIRS	Functional Near-Infrared Spectroscopy
FTS	Functions of Touch Scale (Jean et al., 2005; Jean et al., 2007; Jean & Stack, 2009)
Griffiths 0-2	Griffiths Mental Development Scales (0-2 years)
HbO2	Oxy-Hemoglobin
HDI(s)	Highest-Density Intervals
HHb	Deoxy-Hemoglobin
HPD	Highest Posterior Density Region
k	Kappa
LOOIC	Leave-One-Out Information Criterion
M	Mean
MCMC	Markov Chain Monte Carlo
mPFC	Medial Prefrontal Cortex
MTCS	Maternal Touch Coding System (Provenzi et al., 2020)

MTS	Maternal Touch Scale (Stepakoff, 1999; Stepakoff et al., 2000; Beebe et al., 2010)
OMTS	Ordinalized Maternal Touch Scale
PCA	Principal Component Analysis
PICTS	Parent-Infant Caregiving Touch Scale Koukounari et al., 2015)
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PSIS	Pareto Smoothed Importance Sampling
pSTS	Posterior Superior Temporal Sulcus
QPTP	Quality of Parent-to-Infant Touch Protocol (Moreno et al., 2006)
QQ-plot	Quantile–Quantile Plot
Rhat	Gelman-Rubin Statistics
rpSTS	Right Posterior Superior Temporal Sulcus
SE	Standard Error
se_diff	Standard Error of elpd Difference
SS	Somatosensory Cortex
TEAQ	Touch Experiences and Attitudes Questionnaire (Trotter et al., 2018)
TII	Tactile Interaction Index (Weiss, 1992; Weiss & Niemann, 2011)
TPJ	Temporoparietal Junction
TMITS	The Mother-Infant Touch Scale (Crucianelli et al., 2019)
TSI	Touch-Scoring Instrument (Polan & Ward, 1994)
UK	United Kingdom
USA	United States of America

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Thesis Overview

This thesis aims to analyze behavioral patterns and brain correlates of social touch within mother-infant interactions in the second half of the infant's first year of life. This is especially important since there is limited research during this critical developmental phase - with significant milestones, such as object exploration and joint attention - on how mothers employ touch to structure infant play activities, including both object-oriented and non-object-oriented tasks. In addition, we also aimed to expand our knowledge about how these early experiences of touch are associated with the infant's brain responses to tactile stimuli.

This work comprises six chapters. Chapter 1 offers a summary of pivotal research on touch during caregiver-infant interactions, elucidating the conceptual and methodological approaches used in this field. It also conducts a recent overview of behavioral and neurophysiological studies related to social touch in infancy. Chapter 2 presents a systematic review to identify and categorize available observational tools for assessing touch in caregiver-infant interactions, outlining their key features and applications in prior research. The majority of the studies included in the review examined only infant samples under six months, in face-to-face interactions and Still-Face procedures. Chapters 3 and 4 address these gaps by presenting two behavioral studies that employed a naturalistic procedure using a microanalytic coding system to examine how mothers used touch to interact with their infant in object and non-object-oriented play tasks at 7 and 12 months. Chapter 5 examined if these infant's early caregiving experiences, specifically maternal touch behavior at 7 and 12 months of age, are associated with infants' cortical responses to affective and discriminative touch in the somatosensory and pSTS cortex regions, as measured by functional Near-Infrared Spectroscopy (fNIRS). Finally, Chapter 6 provides a general discussion of the four studies, as well as the studies limitations and future directions.

Taking it all together, this thesis centers on studying maternal touch patterns, their variations with infant age and demand of the play task, and their influence on infant's brain responses during the second half of the infant's first year. The findings contribute to our understanding of the maternal touch trajectory over time and its connection to infant neural responses to tactile stimuli, offering valuable insights into maternal touch interactions with infants and their impact on brain development.

CHAPTER 1

General Introduction

CHAPTER 1

1.1 Tactile Stimulation in Infant's Early Development

Infants' sensitivity to touch starts prenatally, with touch being one of the first sensory systems to develop during pregnancy. The classic studies of Hooker and colleagues demonstrated that the embryo responds to tactile stimulation around the lips as early as eight weeks of gestation (Hooker, 1952; Humphrey & Hooker, 1959). At this stage, reflexive reactions can be observed such as fetal movements in response to touch on the lips or nose (Hooker, 1952). Except for the back of the head, practically the entire body responds to touch by the 14th week of pregnancy (Hepper, 2015; Hepper, 2008). As sensory systems continue to develop, more nuanced responses to touch stimulation emerge; for instance, between twenty-one and thirty-three weeks of gestation, fetuses respond to maternal touch on the abdomen or vibroacoustic stimuli by increasing their arm, mouth, and head movements (Marx & Nagy, 2015). In the third trimester, when a mother touches her abdomen, the fetus reacts to the touch more slowly than it does during the second trimester (Marx & Nagy, 2017). Altogether, these findings show that the somesthetic system is well-developed before birth and that there is sensitivity to social contact even in the earliest stages of gestation.

Following birth, touch is vital in parent-infant interactions. Human neonates are born altricial and depend heavily on parental support for the regulation of basic physiological functions (Moore et al., 2016) and for essential activities such as feeding, sleeping, hygiene, and soothing (Faust et al., 2020). Touch assumes a critical role in these early interactions, as evidenced by studies quantifying touch behaviors in mother-infant interactions during the first 6 months of life (Field, 1984; Kaye & Fogel, 1980; Stack & Jean, 2011). The frequency of touch in social exchanges, between caregivers and infants during face-to-face exchanges, is high, ranging from 33% to 81% of the time (Stack & Muir, 1990; 1992; Jean et al., 2009). Given that the skin is the body's largest sensory organ, and touch is the first sensory system to develop in infants, being quite mature at birth (Kisilevsky et al., 1992; Marx & Nagy, 2015), it is perhaps not surprising that touch assumes a critical role in fostering communication, bonding, and nurturing in parent-infant interactions, particularly in the early postnatal period.

Results from studies of touch consistently show that the caregiver's tactile interactions with their infants are a major crucial influence in infant's physical, emotional, and social development (Cascio et al., 2019; Dunbar, 2010; Field et al., 2010; Field, 2014, 2019; Jablonski, 2021). To enhance our comprehension of how these interactions impact infants' development and well-being, we will begin by providing an overview of key human-based studies in this field.

1.2 A Retrospective Overview of Research on Touch in Early Infancy

The seminal work in the 1970s of Klaus, Kennell, and colleagues was instrumental in producing evidence for the existence of a sensitive period, essential in the development of mother-infant bonding, within the first few minutes and hours after birth (e.g., Kennell & Klaus, 1976; Kennell et al., 1975; Kennell et al., 1974; Klaus et al., 1972). While some of these studies' reliability was later put into question (Myers, 1984), they had a substantial impact on obstetric care procedures by highlighting the importance of skin-to-skin contact right after birth. They also played a central role in emphasizing the significance of investigating tactile contact immediately following birth, to promote the bonding between mothers and infants, and understand its subsequent impact on the infant's development (Kostandy & Ludington-Hoe, 2019).

In parallel with this work, Kangaroo Care emerged as a touch-based intervention for preterm infants (Kostandy & Ludington-Hoe, 2019). This practice encourages parents, typically mothers, to hold their newborns against their naked chest for a portion of the day. Numerous studies have demonstrated the physiological and neuroprotective benefits of Kangaroo Care, including improved sleep quality, pain control, neurodevelopmental support, physical growth, parental bonding, and breastfeeding outcomes for both preterm and full-term infants (e.g., Campbell-Yeo et al., 2015; Moore et al., 2016; Conde-Agudelo & Díaz-Rossello, 2016; Johnston et al., 2017; Moberg et al., 2020; Norholt, 2020; World Health Organization, 2022). Similarly, infant massage therapy, a targeted application of tactile stimulation, has shown positive outcomes for both infants and caregivers, including increased weight, reduced hospitalization time, improved neurodevelopment, pain relief, and reduced parental stress and anxiety (e.g., Field, 2018; Field, 2019; Field et al., 2010; Mrljak et al., 2022; Chen et al., 2021; Li-Chin et al., 2020, Álvarez et al., 2017; Pados & McGlothen-Bell, 2019). Overall, these touch-based interventions have clarified the unique contribution of proximity behaviors, such as tactile contact and stimulation, to parent-infant interactions and infants well-being (Mantis et al., 2014; Stack, 2001; Botero, 2016; Botero et al., 2020).

Another significant line of research involves experimental studies that utilize an adapted version of the still-face paradigm (Tronick et al., 1978). The still-face procedure, originally consisting of three parent-infant interactions: normal interaction, still-face, and reunion periods (Tronick et al., 1978). During the second interaction, known as the classic still-face effect, infants typically show a decrease in their engagement with the mother, such as reduced gaze and smiling, as well as an increase in neutral to negative affect and vocalizations when compared to a normal face-to-face interaction (e.g., Ellsworth et al., 1993; Gusella et al., 1988; Lamb & Malkin, 1986; Stack & Muir, 1990; Mesman et al., 2009). This procedure has been instrumental in studying how infants respond to disruptions in social interaction (Jones-Mason et al., 2018). In the context of comprehending touch, it is noteworthy that mothers tend to incorporate greater tactile-kinesthetic behaviors following the still-face period (Field et al., 1986). These results underscore the significance of touch in interactions, indicating that mothers adjust their tactile interactions to meet the soothing and comforting needs of the infant.

Stack and colleague’s work utilizing an adapted version of the still-face paradigm has contributed with additional work to our understanding of the role of touch in infant development and communication. In the adapted still-face paradigm mothers are allowed to touch their infants during the still-face period; this resulted in more positive infant responses, including increased smiling and contentment, alongside reduced grimacing (Stack & Muir 1990, 1992). These findings suggest that infants are touch-sensitive, and maternal touch can support the infant in emotional and attentional regulation.

However, the previous studies only offered partial insights into infant sensitivity to subtler alterations in maternal touch and whether mothers could employ touch to elicit specific responses from their infants. To address these questions Stack & LePage, (1996) conducted a study where mothers interacted with their 5.5-month-old infants in an adapted still-face design. This study found that mothers adjusted their touch according to the instructions and elicited different infant responses. For instance, infants smiled more when mothers were instructed to elicit smiles using touch during the still-face period. A similar study by Stack & Arnold (1998) found that infants smiled more in the still-face period in which mothers were instructed to encourage smiling from the infant, than in both other still-face conditions (still-face while touching and still-face while touching only one chosen part of the infant’s body). This study also suggested that maternal touch and gestures can engage infants and draw their attention to the mother's face Stack & Arnold (1998). These findings indicated that infants are sensitive to different maternal touch behaviors, and mothers adapt their touch to communicate specific messages to their infants (Góis-Eanes et al., 2012; Hertenstein, 2002; Jean et al., 2009).

In sum, touch-based interventions, such as massage and kangaroo care, have advanced our understanding of social touch's role in infant development, while research using the modified still-face procedure has led to methodological improvements in measuring social touch during infancy and the development of tools for assessing touch behaviors in caregiver-infant interactions.

Nevertheless, despite this significant progress, our grasp of social touch remains fragmented due to varying focus of the different research areas, multiple methodologies and measures, and the disparities in the frequent study of clinical samples vs. less frequent study of normative samples across disciplines and research groups (Field, 2019). This lack of consensus and definition is evident when considering the construct of social touch (Cascio et al., 2019; Gliga et al., 2019). We discussed this in the next section.

1.3 Social Touch: from Neurophysiology to Behavior

In this dissertation, a comprehensive approach to the construct of "social touch" was adopted encompassing any type of touch performed by a partner in a social context. This enabled us to accommodate different uses of the term "social touch", namely, from two distinct fields of study: (1) a neurophysiological based approach, oriented to affective touch, and centered on a specific class of skin mechanoreceptors, the C-tactile-fibers (CTs) (Cascio et al., 2019; Gliga et al., 2019; Saarinen et al., 2021) and (2) a behavioral approach that is concerned with examining the interpersonal and interactional aspects of touch behavior. Whereas the C-tactile-fibers system has been linked to the neurophysiological underpinnings of affective touch, higher-order factors have also been discovered to play a role in the definition of touch as social (Cascio et al., 2019), including the relationship between the members of the dyad, the social context, and the diversity of stimulus types and modalities of delivery (Gallace & Spence, 2010). Both approaches provided the conceptual and methodological foundation for this dissertation.

1.3.1 Neurophysiological Basis of Tactile Experiences

Regarding the neurophysiological processes underpinning tactile experiences, our understanding has made significant strides. Research in this area has delineated two key facets of tactile experience: discriminative touch and affective touch. Discriminative touch, mediated by low-threshold myelinated Aβ fibers, is responsive to rapid tactile stimuli, allowing for the detection of changes in properties such as vibration, texture, and shape (McGlone et al., 2014). This function facilitates exploratory activities and the ability to differentiate stimuli in the environment, including object recognition (McGlone et al., 2007, 2014).

In contrast, affective touch engages distinct afferents known as C-tactile fibers, primarily found in hairy skin and sparsely distributed in glabrous skin (Watkins et al., 2021). These specialized fibers respond most strongly to gentle and slow stroking, that could be described as a caress, with an optimal speed range of 1-10 cm/s (Essick et al., 2010; Löken et al., 2009; H. Olausson et al., 2010). These fibers exhibit particular sensitivity to light pressure and are activated within the approximate temperature range of human hands, around 32ºC (Ackerley et al., 2014; H. Olausson et al., 2010). Their activation is linked to the encoding of stimulus valence, spanning from "pleasant" to "unpleasant," a crucial factor in shaping social interactions (Morrison et al., 2010). As such, CT fiber stimulation has been closely associated with affiliative interactions and affective touch exchanges between individuals (Croy et al., 2022; Fairhurst et al., 2022; Gallace & Spence, 2010), including the intimate bond shared between mothers and their infants.

Exploring these two dimensions of tactile experience, discriminative and affective touch, has been performed in several age groups, encompassing adults, adolescents, and children. This comprehensive research endeavor has contributed to unveil the unique activation patterns linked to each dimension. In healthy adults, neuroimaging studies have revealed the activation of somatosensory cortex I and II by discriminative fibers (McGlone et al., 2014; Morrison, 2016). Furthermore, in addition to the somatosensory cortex CT fibers recruit brain regions within the so-called "social brain" network, associated with the processing of social stimuli (e.g., Björnsdotter et al., 2014; Gordon et al., 2013; Olausson et al., 2010; Olausson et al., 2008). This network includes brain regions such as the insula, medial prefrontal cortex (mPFC), temporoparietal junction (TPJ), and posterior superior temporal sulcus (pSTS) (Adolphs, 2009; Frith, 2007; Morrison, 2016; Bennett et al., 2014; Gordon et al., 2013; Voos et al., 2013; Davidovic et al., 2019).

Research focusing on infants, children and adolescents has shown similar neural responses to affective touch in brain regions associated with adults, such as the somatosensory cortex, insula, and pSTS. For example, conducted an fMRI study and found that the social-brain network is already established in the cortex postcentral gyrus and posterior insular cortex of infants aged 11 to 36 days when administering gentle brush stroking to the right anterior shin region of newborns. Similarly, Jönsson et al., (2018) used diffuse optical tomography (DOT) and observed significant activation in the insular cortex and temporal lobe of two-month-old infants when their forearm was slowly stroked with a soft brush compared to fast stroking. Additionally, Kida & Shinohara, (2013) in an fNIRS study, discovered that gentle touching of the palm (with a velvet fabric) resulted in bilateral activation of the anterior prefrontal cortex in 10-month-old infants but not in 3- and 6-month-old infants when compared to touch with a rounded wood (i.e., discriminative touch). Pirazzoli et al., (2019) conducted a study with fNIRS and did not observe specific cortical activation in the posterior superior temporal sulcus (pSTS) region in response to affective touch (human touch strokes) versus non-affective touch stimuli (cold metallic spoon strokes) in five-month-old infants. However, they did not measure the infant's response in the somatosensory area. In a separate fNIRS study by Miguel, Lisboa, et al., (2019) involving 7-month-old infants, similar results were observed regarding the lack of activation in the pSTS region when comparing affective touch (soft brush strokes) to discriminative touch (light taps with a wooden block) on the infants' forearm. However, in this study, was detected activation in the somatosensory brain region. In a longitudinal study, Miguel, Gonçalves, et al., (2019) showed that the response to affective touch emerge at 12 months, with recruitment of the somatosensory cortex and the posterior superior temporal sulcus (pSTS) region, mirroring the neural response observed in children and adults. Furthermore, a study conducted by Maria et al., (2022) used diffuse optical tomography (DOT) to investigate the processing of affective touch, specifically CT-optimal brushing in the right forearm at 3 cm/s, in two-year-old children. The findings revealed insular activation in response to CT-optimal stimulation, comparable to that observed in adults (Maria et al., 2022). Similarly, Björnsdotter et al., (2014) measured using fMRI affective touch in adult-defined brain regions (somatosensory cortex, insula, and pSTS) in children and adolescents (5-17 years) and adults (25-35 years). The study revealed comparable levels of activation in these regions across the different age groups (Björnsdotter et al., 2014).

These findings highlight the importance of affective touch in processing social stimuli during early human development and the need for further research in order to clarify the developmental trajectory of affective touch. This includes the role of various psychosocial and contextual factors, including parental touch behavior, in shaping affective touch (Cascio et al., 2019; Saarinen et al., 2021).

This is confirmed by recent studies that found infants enhanced psychophysiological reactivity to tactile stimuli, especially when exposed to affective touch. Studies have consistently demonstrated that affective stimulations lead to a decrease in heart rate, increased oxygenation, and altered respiratory rate in infants (Aguirre et al., 2019; Croy et al., 2016; Fairhurst et al., 2014; Manzotti et al., 2023; Van Puyvelde, Collette, et al., 2019; Van Puyvelde, Gorissen, et al., 2019; Bytomski et al., 2020). This positive impact on parasympathetic regulation is more pronounced when provided by parents or experimenters (human touchers) targeting the CT system. The regulation of the parasympathetic system is influenced by the social bond between the infant and the touch provider, with parents naturally adjusting their touch speed for CT stimulation (Croy et al., 2016; Croy et al., 2016).

In conclusion, research on tactile experiences across various age groups has uncovered unique neural activation patterns associated with discriminative and affective touch. While adults predominantly activate somatosensory cortex regions with discriminative touch, affective touch engages the "social brain" network. Understanding the processing of affective touch in infants presents challenges, highlighting the need for further research into its developmental trajectory and the impact of psychosocial and contextual factors, including parental touch behavior.

1.3.2 Behavioral Approach of Social Touch in parent-infant interactions

On the other hand, behavioral research has delved into the contextual aspects of social touch and has been concerned with two notably inquiries: (1) the agent responsible for delivering the touch, and (2) the purpose or intention behind tactile stimulation (Cascio et al., 2019).

Regarding the first question, researchers have investigated how individuals respond to social touch delivered by different sources. For instance, Lew-Williams et al., (2017) conducted a study involving 7-month-old infants to assess their ability to learn auditory tone sequences using a head-turn preference procedure. Their findings revealed that infants exhibited sequence learning when the experimenter provided tactile information that was synchronized with the auditory sequence by tapping the infants' elbows and knees following the auditory cues (Lew-Williams et al., 2017).

The second topic of research delves into the functional roles of various interpersonal touch patterns and explores how touch agents, most notably mothers, employ tactile stimulation for different purposes (Cascio et al., 2019). Typically, these studies assess maternal touch behaviors on a second-by-second basis using predefined inventories that categorize the different touch actions performed by the mother (Weiss & Niemann, 2011). However, measuring caregiver touch behavior during parent-infant interactions presents significant challenges (Beebe, 2006, 2017; Lourenço et al., 2021). These studies often involve the detailed assessment of maternal touch behaviors, breaking them down into specific actions such as holding, tickling, caressing, and kissing. Furthermore, frequently they take into account multiple aspects, including the intensity, speed, and location of these tactile interactions (Hertenstein, 2002; Weiss, 1992), along with their functional role within a particular context (e.g., Beebe et al., 2010; Jean & Stack, 2009; Koester & Paradis, 2010). Additionally, and often overlooked, it's crucial to underscore that the understanding of touch can greatly differ based on a particular context, considering elements such as the immediate surroundings, and the response touch elicits in the other social partner.

Observational tools are the most commonly use method to assess touch in parent infant nteractions and, in contrast with self-report instruments, offer a more objective assessment of touch dynamics within interactions, supported by video recording and behavioral coding (Brzozowska et al., 2021; Weiss & Niemann, 2011). Several observational tools have been developed to evaluate various aspects of touch behavior (Brzozowska et al., 2021). Some focus on specific low-level descriptors of touch actions, such as holding, tapping, or patting. Examples of this approach include instruments developed by Polan & Ward (1994) and Stack et al. (1996). In contrast, other methods aim to evaluate higher-level characteristics of parental touch behavior, by coding the functional role of each touch pattern during interactions, such as identifying touch as "affectionate/nurturing," "playful," or "instrumental" (Brzozowska et al., 2021). Instruments such as the ones developed by Goldyn & Moreno (2002) and Jean & Stack (2009) fall into this category.

Other instruments combine both low and high levels of abstraction, providing a comprehensive assessment of touch behavior. These tools, exemplified by the Tactile Interaction Index, TII (Weiss, 1992; Weiss & Niemann, 2011) and Mother Touch Scale, MTS (Stepakoff, 1999; Stepakoff et al., 2000; Beebe et al., 2010). In these tools, the directly observable touch behaviors applied by a caregiver to the infant are first collected (e.g., action

– such as caress, tickle, tap, pat, hold; intensity; velocity; location of the touch), and later clustered into global categories. This approach captures the diversity of purposes that touch can occur in the natural flow of a caregiver-infant social interaction, including affectionate touch - or nurturing touch; playful touch - or stimulating touch; harsh negative touch - or intrusive touch; caregiving touch - or utilitarian, instrumental, matter of fact touch (Beebe et al., 2010; Jean & Stack, 2009; Mantis et al., 2019; Polan & Ward, 1994; Weiss, 1992). Thus, these instruments measure the tactile actions performed by the mother but also the functional role associated with them.

Overall, observational instruments allow researchers to capture caregiver touch behavior considering their actions and/or their functional role in the interaction. In the following section we will review some pivotal research that examines how specific touch categories impacts infant's behavior and development.

In studies of infant development, touch is widely recognized as a crucial factor, as shown in the earlier summary of touch-related interventions within this chapter. It remains, nevertheless, a sensory system that is often neglected and not thoroughly explored (Botero, 2016; Botero et al., 2020; Hertenstein, 2002; Stack, 2010). This apparent when contrasted with other distal means of communication, such as visual and auditory systems (Thesen et al., 2004). Most touch-related studies conducted during the first six months of life have primarily focused on assessing whether maternal touch is present or absent, and its potential influence on infant development.

Research conducted within caregiver-infant interactions, focusing on maternal touch patterns, has provided insights into the diverse functions of different touch types during social exchanges and their connections to developmental outcomes (Stack & Muir, 1992; Stack et al., 1996; Beebe et al., 2010; Keren et al., 2003). For example, nurturing touch, characterized by actions such as stroking and caressing, has been associated to soothing distressed infants and fostering dyadic reciprocity (Moreno et al., 2006; Peláez-Nogueras et al., 1996; Jean & Stack, 2012; Jean et al., 2014; Ferber et al., 2008). Additionally, nurturing touch can elicit positive emotions in infants, as observed through increased smiling and vocalization (Peláez-Nogueras et al., 1997). Maternal nurturing touch is also associated with attachment security and reduced internalizing problems in infants (Weiss et al., 2000, 2001).

Findings illustrating the links between touch and developmental outcomes extend beyond the domain of nurturing touch. For instance, playful or stimulating touch, such as tickling, lifting, or moving a baby's arms or legs, has been demonstrated to enhance the infant's social behavior including increased positive emotions, greater eye contact, and higher levels of activity (Egmose et al., 2018; Lowe et al., 2016; Moreno et al., 2006). Furthermore, this type of touch has been associated with improved visual-motor and fine-motor skills in low-birth-weight infants (Weiss et al., 2004).

Another crucial aspect of touch is the caregiving/instrumental touch category. This type of touch includes actions that provide comfort and care for infants, such as adjusting their position or cleaning their mouth (e.g., Beebe et al., 2010; Mantis & Stack, 2018; Stepakoff, 2000). Caregiving touch has been linked to maternal sensitivity and is particularly important in contexts such as post-partum depression (Cordes et al., 2017; Egmose et al., 2018). Conversely, intrusive touch, which includes actions such as poking and scratching, has been associated with insecure attachment styles and negative infant affect (Beebe et al., 2010; Peláez-Nogueras et al., 1996; Weiss et al., 2001). These findings collectively highlight how different touch patterns convey specific information to infants (Tronick, 1995; Hertenstein, 2002) and serve distinct functions in caregiver-infant interactions (Beebe et al., 2010; Crucianelli et al., 2019; Hertenstein, 2002; Jean & Stack, 2009; Koester, 2000; Mantis et al., 2014; Paradis & Koester, 2015; Provenzi et al., 2020; Serra et al., 2020).

Touch frequency, and the touch types used by the mother, change significantly during an infant's first year of life, aligning with the infant's age and interaction needs (Ferber et al., 2008; Jean et al., 2009; Mercuri et al., 2023). Typically, as infants grow, maternal touch decreases during non-object-oriented activities such as face-to-face interactions (Ferber et al., 2008; Jean et al., 2009). For instance, Jean et al., (2009) observed infants in two settings (lap and floor) at 1 month, 3 months, and 5½ months of age. They found that mothers used more patting and tapping touch when holding infants in their laps at 1 month compared to 5½ months. In contrast, mothers increased their use of tickling as infants grew, particularly at 5½ months. Moreover, in the lap condition, mothers touched infants more frequently at 1 month than at 3 months. In the floor setting, mothers employed lifting movements more often at 1 month compared to older infants, indicating how maternal touch patterns adapt to infants' developmental needs in different contexts (Jean et al., 2009). These findings suggest that mothers adapt their touch patterns to their infants' developmental stages and specific interaction contexts indicating distinct functional and developmental roles for touch.

CHAPTER 1

The majority of research on maternal touch behavior has primarily focused on infants under six months old (e.g., Beebe et al., 2008; Cordes et al., 2017; Ferber, 2004; Hardin et al., 2021; Jean & Stack, 2012; Provenzi et al., 2020; Stefana & Lavelli, 2017; Weiss et al., 2000), particularly in the context of still-face procedures or face-to-face interactions. In contrast, less is known about how parental touch adapts to other interactional contexts, especially object-oriented play tasks that become significant during the second semester of the infant's life. Play interactions. in fact, serve as vital mode of active engagement during infancy, offering valuable prospects for early learning and the practice of responsive caregiving, as emphasized by the WHO et al. (2018). This becomes especially pertinent when considering critical cognitive developmental milestones at this age, particularly in the context of object-oriented play. These milestones include the gradual increase in the amount of time infants allocate to playing with toys during social interactions (Bakeman et al., 1990; Toyama, 2020; Williams, 2003) and the onset of active exploration of objects (Needham, 2009). In addition, at 12 months Infants occupy more than half of their time interacting with objects at home (Schatz, Suarez-Rivera, Kaplan, Linn, & Tamis-LeMonda, 2020; Herzberg et al., 2020) and develop the ability to engage in joint attention during triadic interactions that involve themselves, an object, and another partner (Bertenthal & Boyer, 2015). At this stage, research also suggests that parents adjust their touch behavior based on the infant's age and task requirements; for instance, parents tend to use more tactile stimulation, such as tickling, in play with younger infants, gradually transitioning to other forms of play such as object-oriented play as infants grow (Crawley & Sherrod, 1984; Williams, 2003). Additionally, studies highlight the important role of social touch in infant's object exploration. Tanaka et al., (2021) found that more physical contact from mothers facilitated infants' interaction with objects, reducing the time to first touch and prolonging object touch. Similarly, Della Longa et al., (2019) showed that affective touch from a caregiver enhanced infants' attention to and learning from new social information. Studies conducted with non-human primates have yielded similar results. When newborns received more physical contact compared to a control group raised under standard conditions, they displayed increased exploration of novel environments, objects, and social interactions at just 3 months old (Simpson et al., 2019). Additionally, these primates exhibited enhanced abilities for joint attention and cooperation by the time they reached their first year of life (Bard et al., 2014).

While previous studies have emphasized the importance of social touch in infant cognitive development, a significant research gap exists in understanding how caregivers incorporate touch during object-oriented play (a core aspect of cognitive development in the first years). Leiba (2000) notably, stands as an exception; this study explored the maternal touch patterns in the context of an object-oriented play task and found that mothers engage in more extended episodes of active affectionate touch, such as kissing, hugging, and rubbing, when interacting with their infants at 5 months compared to when the infants are 12 months old. Interestingly, this study also indicated an increase in the frequency of both active and passive affectionate events as infants age in the object-oriented context. However, a lack of data remains regarding how mothers employ touch to facilitate interactions between infants and novel objects and how this process evolves throughout infant development.

1.4 Maternal Touch Behavior and Neural Responses to Affective Touch in Infancy

Collectively, the body of behavioral research previously described underscores a positive link between the quality of caregiver-infant touch interactions and developmental outcomes across multiple domains. However, the neural mechanisms underpinning this connection remain poorly understood. Studies with adults have indicated that the frequency of exposure to tactile experiences can significantly influence touch perception and processing. Particularly, adults who report infrequent tactile contact in their daily lives tend to exhibit reduced abilities to distinguish between different stroking speeds and often rate touch applied at a speed optimal for C-tactile fibers as less pleasant compared to those with more frequent tactile exposure (Sailer & Ackerley, 2019). Although this study did not measure neural responses, it hinted at the idea that an individual's perception of tactile experiences may change depending on their exposure to tactile stimulation. Such variations in perception could potentially impact neural responses, particularly during infancy and childhood, when exposure to tactile stimuli is more frequent and neural patterns are being established.

Indeed, Brauer et al., (2016) using fMRI found that 5-year-old children who were exposed to higher levels of maternal touch, observed during a play task, also exhibited increased resting-state activity and connectivity in brain areas that are part of the so called “social brain network”, specifically in the rpSTS (right posterior superior temporal sulcus). Furthermore, research has revealed connections between caregiver-initiated tactile stimulation, behavioral markers, and infant neural activity. For example, 12-month-old infants who exhibit fewer negative behavioral responses to tactile stimuli demonstrate heightened neural activity in the superior temporal sulcus (Miguel et al., 2020). Additionally, findings by Mateus et al. (2021) suggest that infants who experience fewer sensitive interactions with their mothers may also have limited exposure to maternal touch, which subsequently impacts the neural processing of both affective and discriminative touch in infants. These findings further corroborate the link between social touch exchanges, early human socio-emotional development and add novel evidence regarding developing neural systems involved for early-life tactile processing.

1.5 The Present Dissertation

Altogether, the previous findings suggest that maternal touch behavior may have an important role in structuring infant object and non-object Interactions, as well as, in the development of infant's brain responses to tactile stimuli (affective and discriminative touch). As such, this thesis aims to analyze brain and behavioral correlates of social touch within mother-infant interactions, with the goal of addressing some of the research gaps highlighted in the introduction. Four studies were conducted, and in the following section, we provide a concise overview of the rationale behind each one and their primary objectives.

1.5.1 Study 1 – Observational Measures of Caregiver's Touch Behavior in Infancy: A Systematic Review

In recent years, there has been a notable shift in research focus from merely investigating the presence or absence of touch in parent-infant interactions to a more nuanced examination of the various types of touch used, their functional roles, and their impacts on both infants and parents in terms of behavior, development, and well-being. This growing interest in understanding how caregivers engage in tactile interactions with their infants is reflected in the increased number of observational instruments developed over the past three decades. However, a challenge within the field lies in the dispersion of these observational tools across different research teams, each assessing touch using different instruments and in specific contexts and situations (Field, 2019). This fragmentation complicates direct comparisons among studies employing different observational tools. Therefore, we conducted a systematic review of the literature, encompassing the first 24 months of an infant's life, following the PRISMA principles (Page et al., 2021). This first study, detailed in **Chapter 2**, was the following goals: 1) identify available observational tools for assessing touch in the context of caregiver-infant interactions; 2) create a categorization scheme grouping these instruments based on their approaches to measuring tactile interactions; 3) investigate the inherent the key characteristics, advantages and disadvantages associated with each category of instruments, ultimately providing valuable recommendations for the future development of observational tools; and 4) provide an overview of their utilization within existing research. This systematic review highlights the gap in the existing literature concerning maternal touch patterns, which have predominantly focused on the first 6 months of an infant's life and have been limited to a few specific interactional contexts. This finding provided empirical support for the subsequent studies (2 and 3).

1.5.2 Study 2 – The Effect of Play Task on Maternal Touch Patterns when Interacting with their 12 Months-old Infants: An Exploratory Study

As previously discussed in this chapter and showed in the preceding study, a significant knowledge gap remains regarding how mothers employ touch to structure infant play activities, Including both object-oriented and non-object-focused tasks, particularly during the latter half of an infant's first year. This developmental stage includes essential milestones like object exploration and joint attention. Therefore, both the second and third studies were conducted to investigate how mothers incorporated touch into their interactions with their infants during structured social activities, encompassing three distinct tasks: (1) free play with toys, (2) free play without toys, and (3) object play with a challenging toy. More specifically, our aim was to compare maternal touch patterns in object-oriented versus non-object-oriented play activities. In the second study, detailed in **Chapter 3**, our focus was on how mothers organized play interactions with their 12-month-old infants, taking into account the demands of the play task, with a particular emphasis on maternal touch behaviors. We found that mothers modulated their touch patterns to the demands of the task considering their 12 months old developmental needs, then a longitudinal study was designed to explore this effect across time.

1.5.3 Study 3 – Maternal Touch in Object and Non-Object-Oriented Play Interactions: a Longitudinal Study at 7 and 12 Months

In the third study, detailed in **Chapter 4**, we delved into the trajectory of maternal touch during interactions with their infants at two different age points: 7 and 12 months. This study also used a Bayesian zero inflated beta mixed model. Our objectives were to investigate potential differences in how mothers employed touch to structure play interactions, considering infant age and the complexity of the play task. Additionally, we sought to explore whether similar to prior research, there was a decline in maternal touch frequency across age points.

1.5.4 Study 4 – Maternal Touch and Infant's Brain Responses to Affective and Discriminative Touch: An fNIRS Study

Despite the advancements achieved in the field of developmental neuroscience, there is scarce data on how contextual factors, such as the frequency of caregiver-infant tactile interactions relate to the neural processing of tactile stimuli in infancy. Consequently, in the fourth study, presented in **Chapter 5**, we aimed to investigate whether early caregiving experiences, specifically maternal touch behavior at 7 and 12 months of age, are associated with infants' cortical responses to affective and discriminative touch, as measured by functional Near-Infrared Spectroscopy (fNIRS).

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CHAPTER 2

Observational measures of caregiver’s touch behavior in infancy: A systematic review

CHAPTER 2

A version of Chapter 2 was published in the Elsevier peer-reviewed journal *Neuroscience & Biobehavioral Reviews*.

Reference:

Serra, J. F., Lisboa, I. C., Sampaio, A., & Pereira, A. F. (2023). Observational measures of caregiver's touch behavior in infancy: A systematic review. *Neuroscience & Biobehavioral Reviews, 150,* 105-160. https://doi.org/10.1016/j.neubiorev.2023.105160

CHAPTER 2

2.1 Abstract

The caregiver's touch behavior during early infancy is linked to multiple developmental outcomes. However, social touch remains a challenging construct to operationalize, and although observational tools have been a gold standard for measuring touch in caregiver-infant interactions, no systematic review has been conducted before. We followed the PRISMA guidelines and reviewed the literature to describe and classify the main characteristics of the available observational instruments.

Of the 3042 publications found, we selected 45 that included an observational measure, and from those we identified 12 instruments. Most of the studies were of infants younger than six months of age and assessed touch in two laboratory tasks: face-to-face interaction and still-face procedure. We identified three approaches for evaluating the caregiver's touch behavior: strictly observational (the observable touch behavior), functional (the functional role of the touch behavior), or mixed (a combination of the previous two). Half of the instruments were classified as functional, 25% as strictly observational, and 25% as mixed. The lack of conceptual and operational uniformity and consistency between instruments is discussed.

Keywords: Touch behavior; Parent-infant interaction; Observational instruments; Measurement; Systematic review

2.2 Introduction

Touch is the primordial sense, the first sensory system to develop prenatally, and a bridge between the prenatal and the post-natal world (Hepper, 2015). By the 8th week of gestation, the fetus responds to touch around the lips, and by 14 weeks in all other areas of the body save the back of the head (Hooker, 1952; Humphrey & Hooker, 1959; Hepper, 2008). In the third trimester, fetuses respond to human touch on their mother's abdomen by moving or touching the wall of the uterus (Marx & Nagy, 2015, 2017). Born altricial into a highly social species, the human infant, like other mammals, requires touch to thrive (Field, 2010, 2019; Ardiel & Rankin, 2010) – in the words of Montagu (1986), touch is "a basic behavioral need as much as breathing" (page 46).

After birth and during early infancy, frequent tactile stimulation is almost inevitable, as the baby depends on others for the regulation of basic physiological functions (Moore et al., 2016), and for all everyday activities and routines, such as feeding, sleeping, hygiene, and soothing (Faust et al., 2020). A particular aspect of touch that sets it apart from other distal modalities, such as vision or audition, is that touch involves a partner in close proximity which touches but is also touched. An infant's tactile experience of others is therefore inherently relational and always occurs in a social context (Montagu, 1986; Hertenstein, 2002), whether or not partners have communicative intentions (or, indeed, are aware of them).

Touch behavior interacts with multiple developmental domains, as a consequence of the caregiver's use of multiple types of touch, in the service of a variety of purposes. There are the immediate utilitarian demands of caregiving, where the adult uses touch to carry, cradle the infant, or adjust an infant's body posture in space (Beebe et al., 2010; Mercuri et al., 2019). But there are other important functions beyond these: soothing, comforting or demonstrating love and affection, for instance, when the adult uses affectionate/nurturing touch to help the infant down-regulate high-intensity emotional states and/or with negative valence (e.g., Beebe et al., 2010; Jean & Stack, 2009; Moreno et al., 2006; Peláez-Nogueras et al., 1996; Weiss, 1992); promoting emotional states with positive valence, as when using playful or stimulating touch:behaviors such as tickling, lifting, moving the arms or legs (e.g., Beebe et al., 2010; Provenzi et al., 2020; Moreno, Posada, & Goldyn, 2006; Egmose et al., 2018; Jean & Stack, 2009); creating, sustaining or recapturing attentional states (Jean et al., 2009; Mantis & Stack, 2018; Paradis & Koester, 2015); offering the infant support and physical contact, using static or passive touch, the strongest safety signal for the attachment-behavioral system (Beebe et al., 2010; Crucianelli et al., 2019; Mercuri et al., 2019; Stack et al., 1996).

Despite major advances in touch research – see Field, 2010, 2019; Cascio et al., 2019 for a review – and in contrast to the importance of touch in early infant development, the study of touch continues to be relatively neglected when compared with other domains of perception, such as the distal senses of vision or audition, an omission repeatedly highlighted by touch researchers (Botero et al., 2020; Hertenstein, 2002; Hertenstein, Verkamp, et al., 2006; Montagu, 1983; Herring, 1949). For example, studies of caregiver-infant interactions typically focus on the examination of distal behavioral indices, such as gaze and affect, while disregarding the specific contribution of proximity behaviors, including touch (Mantis et al., 2014; Stack, 2001).

A confluence of historical, cultural, and methodological reasons has been offered as the explanation for the overlooking of touch in infancy research (Hertenstein, 2002; Hertenstein, Keltner, et al., 2006; Andersen, 2011). Some factors are evident, such as the long tradition in Western philosophy of favoring the study of vision over other sensorial modalities (Hertenstein, 2002; Hertenstein et al., 2006). Others, such as cultural assumptions regarding touch and the prioritization of touch as a research question are more nuanced and, to the best knowledge, less examined. Together, these have likely delayed the focus on touch as an object of research. A revealing comparison can be made with olfaction, where the hypothesis of poor sense of smell in humans, developed in the 19th century, does not match with empirical data, such as anatomical measurements across mammalian species (McGann, 2017).

Touch may be a primary sense in early human interactions, but the frequency, duration, types of touch, and nature of tactile exchanges differ significantly across cultures (Andersen, 2011; Sorokowska et al., 2021), shaping how parents use touch to communicate with their infants (e.g., Lowe et al., 2016; Stepakoff, 2000). Although challenging to conduct, descriptive studies on tactile contact in various contexts are crucial for identifying similarities and differences between cultures and determining how well the currently available instruments can accurately measure touch in specific cultural contexts (Hertenstein, 2002).

Another significant reason for ignoring these behaviors in infancy was methodological considerations regarding how touch-related behavior in early interactions should be analyzed. Therefore, developing methods that accurately measure touch in parent-infant interactions can be demanding since touch is a multidimensional construct which encompasses several actions, i.e., it may potentially be applied at different intensities, velocities, body locations, durations, and frequencies. These multiple actions also serve multiple purposes in the interaction flow (Geldard, 1960; Weiss, 1992; Jean & Stack, 2009). Some of these specificities and parameters of touch are also difficult to measure, for instance, velocity or intensity of touch, considering that the most widely used method for assessing tactile stimulation is the video recording of mother-infant interactions (Hertenstein, 2002).

In parallel, there is a growing interest in detailed studies of caregiver's touch patterns, and their association with developmental outcomes (e.g., Crucianelli et al., 2019; Ferber et al., 2008; Jean & Stack, 2009; Mantis et al., 2019; Polan & Ward, 1994; Weiss et al., 2000, 2004; Beebe et al., 2010, 2016; Koester, 2000; Paradis & Koester, 2015). Observational tools have played an important part in advancing our knowledge of caregiver's touch in adult-infant interactions, with several instruments developed in the last three decades. These tools were explicitly designed to capture the detailed patterns of caregiver touch behaviors. When compared with self-report instruments, e.g., questionnaires or diaries, observational instruments allow for a more detailed and objective assessment of the features of touch that occur in the flow of the interaction, e.g., action, location, duration, and function (Beebe et al., 2010; Brzozowska et al., 2021). In addition to this, the interactions are typically video recorded, thus, behavioral coding can use slow motion playback and/or repeated observations to allow measurement of touch dimensions that are challenging to measure in real-time, for example, the function of a specific touch behavior, its duration or how often it is used in the interaction (Weiss & Niemann, 2011).

Nevertheless, the different observational instruments are fragmented across different research teams, each independently assessing touch in specific contexts and tasks, making direct comparisons difficult. Additionally, the last detailed review of observational instruments was by Weiss and Niemann, (2011) but this study did not use a systematic review methodology. The present work has aimed to identify observational coding systems of caregiver touch behavior (following PRISMA guidelines), describe each instrument's main characteristics, and summarize how they have been used in the literature. We have also divided the extracted instruments into three groups based on commonalities, and we highlighted each category's key strengths and limitations, outlining possible directions for future research.

CHAPTER 2

Before systematically reviewing the available observational instruments for measuring caregiver touch patterns, we first present a summary background context, drawn from a selection of relevant touch studies in infancy. This overview revisits some important therapeutic interventions that are touch-based (such as massage and kangaroo care), as well as seminal work in touch research and its contribution to the development of instruments for assessing touch behaviors in caregiver-infant interactions.

2.2.1 A Historical Overview of Touch Research on Infants

The association between the infant's healthy development, and social proximity and contact offered by a caregiver, has been consistently demonstrated by touch research (Cascio et al., 2019; Dunbar, 2010; Field, 2010, 2014, 2019; Jablonski, 2021). An important part of the evidence comes from work with non-human primates that has reported the effects of severe caregiver separation and provided valuable insights for human research about the importance of touch in the baby's physical, emotional, and social development (for detailed information regarding animal studies see the following reviews: Barnett et al., 2022; Botero, 2018; Erica & Carol, 2018; Hertenstein, Verkamp, et al., 2006; Harlow & Suomi, 1970). We then briefly review some key research conducted on humans that has enhanced our understanding of the relation between a caregiver's touch behavior and the development and well-being of the infant.

2.2.1.1 Seminal Research on Touch in Pediatric Care. The work of Klaus, Kennell, and colleagues in the 1970s is a significant historical reference for studying tactile contact in early mother-infant interactions (e.g., Kennell & Klaus, 1976; Kennell et al., 1975; Kennell et al., 1974; Klaus et al., 1972). They performed a longitudinal study with 28 mother-infant dyads split into two groups: those who had extra contact with their newborns in the first three days after giving birth (experimental group) and mothers who only had routine contact with their babies in the days right after birth (control group). The authors found that mothers in the experimental group exhibited more "bonding" or affectionate behaviors towards their babies (such as strokes, and eye contact) when the infant was one month of age. When infants turned one, in addition to these affectionate behaviors, mothers in the experimental group reported missing their babies more when they left for work, and infants in this group also scored higher in the Bayley development test (Kennell et al., 1974; Klaus et al., 1972). In light of these findings, the authors argued that a sensitive period, which is in the first few minutes and hours after birth, was essential for mother-infant bonding – for a more detailed summary of Klaus and Kennell's studies see Hertenstein, Verkamp, et al., (2006) and Kostandy and Ludington-Hoe, (2019). Although the validity of the original studies by Klaus and Kennell was later brought into question (Myers, 1984), this work played an important role in changing obstetric care practices, making skin-to-skin contact a common practice. They also helped establish the importance of researching tactile contact immediately after birth to foster mother-infant bonding and, ultimately, how this affected later child development (Kostandy & Ludington-Hoe, 2019).

2.2.1.2 Kangaroo Care and Massage Therapy. In parallel with Klaus and Kennell's investigations, two neonatologists, Rey and Martinez, began researching a similar form of care with preterm infants, so-called "Kangaroo Care" (Kostandy & Ludington-Hoe, 2019). In kangaroo care interventions, parents (typically the mother) are encouraged to hold their neonates continuously against their naked chest during a period of the day. Numerous studies have been conducted since its inception to examine its advantages and safety, for both parents and infants (e.g., Campbell-Yeo et al., 2015; Charpak et al., 2005; Conde-Agudelo & Díaz-Rossello, 2016; Feldman & Eidelman, 2003; Feldman et al., 2014; Furman, 2017). It is currently commonly acknowledged that this touch-based procedure promotes physiological and neuroprotective advantages for low birth weight and preterm infants, including an improvement in sleep quality, pain control, support for neurodevelopment, increased physical growth, and promotion of parental bonding and breastfeeding exclusivity and duration (Campbell-Yeo et al., 2015; Moore et al., 2016; Conde-Agudelo & Díaz-Rossello, 2016; Johnston et al., 2017). The practice of skin-to-skin contact is also beneficial for full-term infants and their parents. Benefits include enhancing parent-infant positive interaction, attachment and well-being, lowering the levels of anxiety, stress, and pain in both parents and infants, as well as stimulating the mother's milk production and the newborn's growth, weight gain, and development (Moberg et al., 2020; Norholt, 2020; World Health Organization, 2022).

Another comprehensively documented touch-based intervention is that of infant massage therapy. Massage therapy is the targeted application of tactile stimulation to the skin, muscles, tendons, ligaments, and fascia utilizing manual and structured techniques (Esfahani et al., 2013). Recent literature reviews conducted over the past 10 years have shown that massage therapy has several positive benefits for both preterm infants and their caregivers, including increased weight and reduced hospitalization time; increased bone density; better neurodevelopment scores; decreased risk of neonatal sepsis; pain relief for infants; and less stress, anxiety, and depression for parents (e.g., Field, 2018; Field, 2019; Field et al., 2010; Mrljak et al., 2022; Chen et al., 2021; Li-Chin et al., 2020, Álvarez et al., 2017; Pados & McGlothen-Bell, 2019). Similarly, studies with full-term newborns, although less common, also found several benefits, including lowering bilirubin levels, reducing crying, colic, and sleep difficulties, promoting infant development, enhancing parent-infant interactions, and lowering parental stress; for a detailed review see Field, 2016, 2018, 2021; Norholt, 2020). Altogether, research on the effects of skin-to-skin contact has improved our knowledge of parent-infant interactions, showing the unique contribution of proximity behaviors, such as tactile contact and stimulation (Mantis et al., 2014; Stack, 2001; Botero, 2016; Botero et al., 2020).

2.2.1.3 The Adapted Still-Face Paradigm. Another seminal line of research is composed of experimental studies that used an adapted version of the still-face paradigm (Tronick et al., 1978). In its original form, the still-face procedure consists of three brief parent-infant interactions: normal interaction, still-face, and reunion periods (Tronick et al., 1978). The classic still-face effect (measured in the second moment of the procedure) is categorized by a decrease in gaze and smiling at mothers, and an increase in neutral to negative affect and vocalizations, compared with normal face-to-face interaction (e.g., Ellsworth et al., 1993; Gusella et al., 1988; Lamb & Malkin, 1986; Stack & Muir, 1990; Mesman et al., 2009). The still-face episode is more stressful for 4-month-old infants than a brief separation from the mother (Field et al., 1986). Infants demonstrate more motor activity, gaze aversion, furrowed brow, crying, and less smiling during the still-face episode compared with the brief separation period. Of relevance to understanding touch, mothers also use more tactile-kinesthetic behavior after the still-face period (Field et al., 1986). These findings highlighted the importance of touch in the interaction by suggesting that mothers adapt their touch behavior to the infant's soothing and comforting needs.

In their adapted version, Stack and colleagues allowed mothers to touch the infant in the still-face period. Stack and Muir, (1990) tested 3-, 6-, and 9-month-old infants and compared the standard still-face period (where touch is not allowed) with the still-face period where mothers could touch the infant. They found that, across the age range, infants who received touch smiled more, grimaced less, and were more content than when exposed to the standard still-face procedure. In the absence of other modalities of communication, the presence of touch (operationalized as the total amount of touch provided by the caregiver to their infant during the interaction) can elicit positive affect and attention from infants and can decrease the negative effects of the still-face episode (Stack & Muir, 1990). In a follow-up study, the same authors also demonstrated that the increase in the infant's positive affect during the still-face period was uniquely related to the tactile stimulation and could not be explained by the visual stimulation of the adult's hands (Stack & Muir, 1992).

These results suggest that infants are sensitive to touch and that maternal touch can support the infant's emotional regulation and attentional state. However, these studies provided only limited information on infant sensitivity to more subtle changes in maternal touch, and if mothers could use touch to achieve specific responses from their infants. To address these questions, Stack and LePage, (1996) designed a study where they observed mothers interacting with their 5.5-month-old infants in an adapted still-face design composed of four periods: (1) normal face-to-face interaction; (2) still-face while touching (i.e., mothers could touch their infants without restrictions); (3) still-face where mothers were asked to touch and encourage the most smiles from the infant; and (4) still-face while touching only one chosen part of the infant's body. The authors found that mothers modified their touching behavior according to the instructions per condition, and, of relevance, that those changes were reflected in the infant's affect and attention across different periods. For example, infants smiled more in the still-face period in which mothers were instructed to elicit smiling from the infant, than in both other still-face conditions (Stack & LePage, 1996). In a similar study Stack and Arnold, (1998) observed how the mother's touch behaviors and gestures impact the infant's specific responses. These authors showed that infants smiled more in the still-face period when mothers were allowed to touch, compared with the normal still-face period. Maternal touch and gestures in the still-face period could draw the infant's visual attention to the mother's face. Together, these findings suggested that (1) infants are sensitive to the specificities of different maternal touch and hand gestures; (2) mothers use touch and hand gestures to elicit specific infant responses, (3) touch-only interactions had a positive effect on infants, in periods of maternal unavailability; (4) when mothers were asked to touch only specific areas of their infant's bodies, they use the same touch types consistently (Stack et al., 1996; Stack, 2004; Stack & Arnold, 1998; Stack & Muir, 1992; Stack & Muir, 1990). This work provided empirical support to the general hypothesis that mothers adapt their touch patterns to communicate different messages to their infants (Góis-Eanes et al., 2012; Hertenstein, 2002). This research, which employed the adapted still-face approach, was critical in demonstrating the influence of diverse touch types on infant behavior, revealing that social touch may serve multiple purposes (Hertenstein, 2002; Jean & Stack, 2009).

In sum, touch-based interventions (like massage and kangaroo care) were critical to expanding our understanding of the link between social touch and the infant's early physical, emotional, and social development. Meanwhile, research using the modified still-face procedure was key to revealing how distinct touch behaviors performed by the parents elicited different affects in the infant, which prompted methodological advances in how social touch was measured in infancy and led to the development of instruments for assessing touch behaviors in caregiver-infant interactions.

2.2.2 Measuring Social Touch in Caregiver-Infant Interactions

Throughout this review, we consider a broad definition of "social touch" as any type of touch performed by a partner in a social context. This enabled us to accommodate different uses of the term "social touch", namely, from two distinct fields of study (Cascio et al., 2019; Gliga et al., 2019; Saarinen et al., 2021): (1) an older one, that consists of behavioral studies, concerned with examining the interpersonal and interactional features of touch behavior, such as "who" is delivering the touch, the types of touch used or the function of the touch behavior (e.g., Field, 2019; Hertenstein, 2002; Stack & Jean, 2011; Stack, 2004); and (2) a more recent, neurophysiology-oriented field, concerned with affective touch and focused on the sensory characteristics of touch. In this second more recent account, touch is defined as social when it activates a particular class of skin mechanoreceptors – the C tactile fibers (CTs) that are activated by light pressure, slow, and caress-like stroking, which is experienced as gentle touch (Ackerley et al., 2014; Fairhurst et al., 2022; McGlone & Spence, 2010; W. Olausson et al., 2008).

2.2.3 Conceptual Frameworks of Touch Behavior

To our knowledge, very few conceptual frameworks have sought to operationalize the properties of infant-oriented touch behavior. In this context, we highlight three major conceptual frameworks. First, Hertenstein (2002, as cited in Weiss & Campos, 1999) considered four dimensions of touch qualities: duration, location, action, and intensity.

Second, the Weiss & Campos, (1999) model was extended by Hertenstein, (2002) to provide a broader understanding of how specific types of touch communicate different messages to the infant – this framework proposed the distinction between qualities and parameters of touch. For simplicity, we will use the terminology 'properties' or 'features' to refer to both. In Hertenstein, (2002), qualities of touch include features of the actual tactile stimulus that is administered to the infant: action (i.e., what are the specific touch behaviors used to interact with the partner: e.g., stroking, rubbing, holding, or squeezing), intensity (i.e., level of pressure applied to the social partner's skin), velocity (i.e., the speed of the touch movement used by the caregiver to touch the infant's skin), abruptness (i.e., the level of acceleration used in the act of touching the other) and temperature. Parameters of touch refer to where and how much touch is administered: location, frequency, duration, and extent of the surface area touched. The author notes that this systematization is only useful for conceptual purposes because, in the flow of the interaction, all of these touch dimensions act together. Finally, and in addition to this structural operationalization highlighting the role of the features of touch (Hertenstein, 2002), a third and functional approach appeared, focused on exploring the purposes and consequences of touch within dyadic interactions (Hertenstein, Verkamp, et al., 2006, as cited in Burgoon et al., 1996). Specific touch actions provided by caregivers can elicit unique infant responses; as such, touch may serve a variety of purposes within caregiver-infant exchanges, such as nurturing/affectionate, playful, and caregiving/instrumental touches (Jean & Stack, 2009; Stack, LePage, Hains & Muir, 1996).

2.2.3.1 The Challenge of Measuring Touch. Accurately studying the caregiver's behavior within naturalistic interactions is a demanding task (Beebe, 2006, 2017; Lourenço et al., 2021). For touch behaviors, designing an instrument that captures the phenomenon to its fullest extent is still a challenge (Hertenstein, 2002; Hertenstein, Verkamp, et al., 2006). There are numerous parental touch behaviors of interest: holding the infant in the lap, tickling, caressing, kissing, etc. Indeed, the Maternal Touch Scale (MTS; Beebe et al., 2010; Stepakoff, 2000) defines 21 individual touch behaviors and the Caregiver Infant Touch Scale (CITS; Stack et al., 1996) defines 8 touch behaviors. Touch also varies across a set of dimensions such as intensity, velocity, abruptness, temperature, location, frequency, duration, and he extent of the surface area touched (Hertenstein, 2002; Weiss, 1992). Hence, there is a wide range of degrees of freedom to consider when measuring a single touch action where specific combinations of touch action with particular values in each dimension can convey different messages to the infant or serve different functions (Hertenstein, 2002; Jean & Stack, 2009; Tronick, 1995). For instance, infants can experience a caressing touch as affectionate or intrusive, depending on the intensity of the parent's touch (Beebe et al., 2010; Stepakoff, 2000). As in other domains of perception, the meaning of touch is context-dependent, underscoring the importance of observing a specific dyad at a particular moment in order to measure touch. As such, beyond identifying the act of touching itself, collecting accurate information about the touch behavior also requires examining how it is delivered to the infant in the context of where it occurred. Consider the example of an abrupt holding touch: if it is performed when the infant is frightened, it may be perceived as affectionate for both mother and infant. In parallel, it is also important to consider who touches and who is touched, the parent's intentionality when using touch, and the infant's response to it. Caressing a baby can be used to convey affection, but if it stops the baby from playing with an object, it may be intrusive. Finally, there are also large cross-cultural variations regarding parenting practices that range from almost constant proximity between infants and other group members to frequent physical separation, an important dimension if we consider that most of the empirical data comes from WEIRD nations - Western, Educated, Industrialized, Rich, and Democratic (Henrich et al., 2010; Montagu, 1986; Rad et al., 2018; Tronick, 1995).

To address the challenges in measuring the touch behavior of the caregiver during parent-child interactions, a variety of methods to assess the quantity and types of contact have been developed, including self-report instruments and observational instruments, which will be addressed in more detail.Using self-report instruments, which include parent-report questionnaires and diaries, the parents provide the measurement. Parent-report questionnaires can be used to rate, often using a Likert scale, how frequently parents engaged in specific touch-related actions (such as rocking, kissing, and holding) with their infants - e.g., the Parent-Infant Caregiving Touch Scale – PICTS, Koukounari et al., 2015). These measurements are important for collecting data about the parents' self-perception of how they touch their infants. There are also self-report questionnaires that do not specifically address the caregiver's touch behavior toward the infant but are instead intended to assess the parent's social touch attitudes and experiences (e.g., the Social Touch Questionnaire – STQ, Wilhelm et al., 2001; the Touch Experiences and Attitudes Questionnaire – TEAQ, Trotter et al., 2018) - For a more extensive review of self-report methods see Brown et al., 2011 and Weiss & Niemann, 2011.

In self-report diaries, parents are asked to complete a paper or electronic diary recalling their recent touch behavior and/or the infant's behavior, once or more per day and during a fixed time period (e.g., Barr et al., 1988; Lam et al., 2010). Diaries can be used to record the behavior of interest over extended periods of time and in different contexts (Brzozowska et al., 2021).

One shortcoming of self-report instruments is the possibility of participants "faking good" or performing for the researcher (Field, 2019). In contrast, observational measures of touch allow for a more objective measurement of the caregiver's touch behavior. Typically, parent-infant interactions are recorded, and touch behavior events coded using a microanalytic scheme, wherein the granular unit of analysis is the individual touch action (Brzozowska et al., 2021; Weiss & Niemann, 2011). Coding is done by first segmenting each behavior (by coding the onset and offset of every touch) or alternatively observing the interaction for a fixed time interval (e.g., one second). Then, depending on the measure, each event or time window can also be categorized using the specific criteria defined by the observational tool. Examples of these measures include the Maternal Touch Scale (Beebe et al., 2010; Stepakoff, 2000) or the Touch-Scoring Instrument (Polan & Ward, 1994). Microanalytic observational tools have a higher coding cost but enable the measurement of social interactions on their natural time scale (Beebe, 2006, 2017; Lourenço et al., 2021), and allow the study of the fine-grained details of touch (e.g., intensity, type of touch) that occur during dyadic interaction (Weiss & Niemann, 2011).

2.2.3.2 Observational Instruments of Caregivers Touch Behavior. Several observational instruments have been designed to capture different levels of abstraction of touch behavior (Brzozowska et al., 2021): some are more focused on low-level, descriptive touch features, such as touch actions (e.g., hold, tap, pat) – e.g., Polan and Ward, (1994) and Stack et al., (1996) – while others measure the higher level touch characteristics of parental touching behavior by coding the functional role of each touch pattern in the flow of the interaction, such as "affectionate/nurturing touch", "playful touch", or "instrumental touch" – e.g., Goldyn & Moreno, (2002) and Jean & Stack, (2009). Other authors combine both and include both lower and higher levels of abstraction in the instrument (e.g., Beebe et al., 2010; Stepakoff, 2000; Weiss, 2000).

2.2.3.3 Observable Touch Behaviors and Functional Roles of Touch. We propose a three-category classification for observational instruments measuring social touch, designed to describe and aggregate current observational tools according to their similarities: (1) strictly behavioral instruments; (2) functional instruments; (3) mixed tools. This categorization into three groups was used to structure the information in the article. The instruments are either strictly behavioral in the sense that only the observable touch behavior is coded – e.g., a tap or a hold behavior is coded as such – or they are functional in that what is coded is the functional purpose of the observable touch behavior – e.g., what is coded across many events of the tap or hold behavior is the functional purpose of the behavior in the context of the interaction. This categorization is also consistent with existing conceptual frameworks for touch (Hertenstein, 2002; Hertenstein, Verkamp, et al., 2006, as cited in Burgoon et al., 1996; Hertenstein, 2002, as cited in Weiss & Campos, 1999). Some instruments use both approaches, and we have labelled them as mixed.

Next, we define each category by presenting examples of instruments that fall within each category and review major findings associated with each category/instrument.

2.2.3.3.1 Strictly Behavioral Instruments. These instruments consider the characteristics of touch behavior that can be directly observed in the context of the interaction: how do parents touch their infants? The constructs are designed to capture surface-level features of touch behavior, such as whether the parent touches the infant passively or actively, what type of touch is used (e.g., tickle, caress), how intensely it is applied, or where on the body it is applied. Studies using strictly behavioral tools, such as CITS (Stack et al., 1996) have revealed that the mother's use of touch adapts to the instructions in the adapted still-face paradigm with touch: when asked to maximize their infant's smiling, mothers used more active types of touch (lifting, tickling), larger surface areas, and greater intensity and speed, but when told to touch only one area of the infant's body, mothers used more stroking, less shaking, and the touching was slower and less intense (Stack & Jean, 2011). Moreover, mothers also adapt the frequency and diversity of their touch behavior depending on the infant's age and the interactional context (Ferber et al., 2008; Jean et al., 2009). For instance, Ferber et al., (2008) observed that the amount of maternal touch decreased during the first year of life. Additionally, Jean et al. (2009) found that mothers touch their infants more in the lap context than in the floor context when they are requested to play with them.

Mercuri et al. (2019), using an adapted form of CITS, compared how much touch each parent applied to the infant during the first interaction after birth, noting disparities in the quantity, but not in the types of touch used: mothers were more likely than fathers to employ kissing, stroking/caressing, utilitarian/instrumental, holding, massage/rubbing, palmar grasp reflex, and other types of touch. These measures were also used to describe dyads in clinical groups. For instance, Koester, (2000) observed both deaf and hearing mothers during a still-face procedure with their 6-and 9-month-old infants (deaf or hearing) and observed that dyads with the same hearing status (both deaf or both hearing partners) increased their tactile contact when the interaction resumed to normal, following the still-face episode, and exhibited a similar touch profile. Likewise, Mantis et al., (2019) examined the effect of maternal depressive symptomatology on maternal touch behavior towards their infants instill-face (maternal emotional unavailability) and separation (maternal physical unavailability). This study found that mothers with higher levels of depressive symptoms touch less and use considerably fewer stimulating types of touch during the reunion period of the still-face procedure, and both the normal and reunion-normal periods of the separation procedure.

***2.2.3.3.2* Functional and Mixed Instruments.** On the other hand, functional measures were designed to assess the functional role of each touch behavior performed by the adult towards the infant. Examples of scales that fill this category are the FTS (Jean & Stack, 2009) and the Functions of Mother-infant Mutual Touch Scale (FMTS; Mantis et al., 2013; Mantis & Stack, 2018). When using mixed instruments, such as the Maternal Touch Scale (MTS; Beebe et al., 2010), the directly observable touch behaviors are first collected, and in a second step are aggregated into categories according to their functional role. For example, the touch actions caress, kiss, stroke, nuzzle and pat, when applied to the extremities of the infant's body, with light or moderate intensity, are classified as affectionate touch by the MTS instrument. As studies using mixed instruments typically only report functional categories and not directly observable touch behaviors (for example, types of touch: stroke, kiss, hold), we did not make a distinction between functional and mixed measures in the brief literature review of studies on the functional role of touch presented next – finer differences will be addressed later in the methods and discussion sections.

Concerning the quality of tactile stimulation within caregiver-infant interactions, the purpose/function of touch in infancy has also been addressed in touch research. In a number of studies, observational measures were employed to examine how caregivers use touch for specific functional purposes. For instance, Jean and Stack, (2009) measured the infant's distress levels considering behavioral markers (e.g., duration and intensity of the infant's fretting and motor agitation) in a still-face procedure. They found that after the still-face period, mothers used nurturing touch (e.g., stroking, caring) more frequently when the infant was displaying high levels of distress. This is consistent with other studies that reported the mother's use of affectionate/nurturing touch to relax and soothe the infant and reduce the level of distress (Moreno et al., 2006; Peláez-Nogueras et al., 1996). In addition to this role in modulating the infant's negative emotions, maternal affectionate touch can also elicit positive emotions. Peláez-Nogueras et al. (1997) compared the effects of systematic affectionate touch (e.g., stroking) versus stimulating touch (e.g., tickling and poking) on 2- to 4.5-month-old infants, while the infants maintained eye contact with the experimenter. This study found that infants who were stroked expressed themselves more vocally, smiled more and cried less than those who received tickles/pokes. Furthermore, it has been shown that playful or stimulating touch (e.g., tickling, lifting, moving arms or legs) is significant for the infant's social interactions, reinforcing the infant's social behavior while also increasing positive affect, eye contact, and activity level (Lowe et al., 2016; Moreno et al., 2006; Egmose et al., 2018). Maternal touching behaviors that are intended to promote the infant's comfort, including repositioning the infant on the carpet or wiping the infant's mouth, have been labeled as caregiving/instrumental touch. Recent research on touch behavior of mothers with and without post-partum depression during a prolonged mother-infant interaction at 4 months found that the infant's negative affect was more likely to stop during periods that included caregiving touch (Egmose et al., 2018). In addition, in both clinical and non-clinical samples, caregiving touch – but not affectionate and static touch – was linked to higher maternal sensitivity (Cordes et al., 2017). Moreover, maternal touch has been shown to be effective at attracting, maintaining, and recapturing the infant's attention (Gusella et al., 1988; Jean & Stack, 2009). In contrast, infants that experience intrusive touch (such as poking, pulling, and scratching) are more likely to display negative affect and behavior (Peláez-Nogueras et al., 1996) and have insecure attachment styles (Beebe et al., 2010).

Along with the effect that particular touch behaviors have on the infant, the infant's and mother's health conditions also have an impact on how parents apply touch behaviors. For instance, compared to a control group, mothers of failure-to-thrive infants delivered less physical touch, including less matter-of-fact, unintentional, and proprioceptive touch (Polan & Ward, 1994). Using the still-face procedure, Jean and Stack (2012) examined mothers and their 5.5-month-old infant in two groups: full-term infants and very-low-birth-weight preterm. They found that mothers touched their infants very frequently (82% of the interaction time), more frequently utilizing attention-getting touch during the normal period and nurturing and playful touches in the reunion normal period. Moreover, mothers of very-low-birth-weight preterm infants employed playful and utilitarian touch types more often than mothers of full-term infants. In addition, mothers of insecure infants, assessed at 12 months, used less affectionate touch to engage with their infants at 4 months (Beebe et al., 2010).

On the other hand, the state of maternal health has also been shown to impact tactile exchanges in mother-infant interactions. A study by Ferber (2004) showed that the number of previous pregnancies (parity) and instances of maternity blues (defined as a transitional depressive state that initiates soon after childbirth and can present a range of symptoms such as crying, anxiety, tension, restlessness and, exhaustion) affected maternal touching behavior towards the infants. Multiparous mothers used more frequent and varied modes of physical contact, whereas mothers with maternity blues provided less touch stimulation to their infants, independently of their parity status. In line with these results, Stepakoff (1999) found that depressed mothers, when compared with non-depressed mothers, engaged in less affectionate touch and more object-mediated touch. Infants of depressed mothers (who tend to touch less often or use more negative types of touch, such as rough tickling or poking), also exhibit more self-touch behaviors when compared with infants of non-depressed mothers (Beebe et al., 2008; Herrera et al., 2004).

Altogether, these studies highlight the importance of studying parental touch behavior considering not only the amount of touch but also the different types of touch and the functional role these have in early parent-infant interactions. These findings showed that touch is not only a causal force for an infant's emotional, social, and physiological development (Field, 2010, 2019) and well-being but it is also sensitive to multiple variables, such as the infant's age, cultural context, or the dyads' mental health status (Stack & Jean, 2011; Stack, 2001, 2004). This increased interest in and recognition of touch in infancy is certainly responsible for a diversity of novel findings, but it has also resulted in a wide-ranging heterogeneity in the assessment of touch behavior.

2.2.4 The Present Study

Observational measures offer several advantages over other options to assess touch behaviors: they are generally more detailed, objective, and can be used in naturalistic interactions. As such, several observational coding systems have been developed over the past three decades, focusing on different dimensions of touch behavior. There has been a considerable effort to develop observational measures that assess the complexity of parental touching behaviors in the context of dyadic interactions. However, discussions about the variety of ways in which the touch phenomenon has been conceptualized and operationalized are still scarce. The current study addresses these gaps by providing an updated overview that can be used to compare the findings of research conducted using different instruments and to promote the development of new tools that aim to clarify, standardize, and uniformize touch assessment.

Moreover, the selection of one particular observational instrument over another is challenging when designing an observational study, since it depends on several practical and psychometric arguments. It is critical to consider factors such as the availability of the measure, its psychometric qualities, the construct measured, the target population, the interaction context, and/or the popularity of the measure. Collecting and organizing this information may assist researchers in making an informed selection of a particular observational measure, which is one of the contributions of this systematic review. We reviewed available observational instruments and how they were used in the literature. To the best of our knowledge, this is the first systematic review of observational measures of caregiver's touch behavior in parent-infant interactions. Weiss and Niemann, (2011) performed a detailed review of different methods of measurement of touch behavior, including observational instruments of caregiver's touch patterns. However, Weiss and Niemann, (2011) did not report the eligibility criteria, search strategy, study selection process, or data extraction strategy from the included observation instruments. Besides, several new observational instruments have been designed to measure the caregiver's touch within parent-infant interactions over the past decade—and these are not included in Weiss and Niemann, (2011) review.

In summary, the present work has aimed to extend the field by providing an up-to-date overview of existing observational instruments. The study had three main goals: (1) systematically identify available observational instruments, describing and characterizing their main attributes (following PRISMA guidelines); (2) examine how these instruments are used in the literature (namely regarding their target population and experimental settings); and (3) discuss the main strengths and limitations of each category of instruments, and provide tentative guidelines for the design of future observational studies.

2.3 Methods

This systematic review report has followed the guidelines published in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Page et al., 2021). At least two of the authors were involved in each phase of the systematic review process with the objective of minimizing the risk of bias. All the authors of the present study participated in defining the study inclusion criteria and the study search strategy to ensure that they were precise, appropriate, and focused on the study's primary objectives.

2.3.1 Eligibility Criteria

We included instruments that were: (1) designed for microanalytic observation of caregiver-infant touch interactions; (2) rated by an external observer; (3) specifically developed to assess qualitative (e.g., types of touch) and quantitative (e.g., frequency or duration) features of caregiver’s touch behavior; (4) applicable before the infant is 24 months of age; (5) published in Portuguese, Spanish or English. The exclusion criteria were: (1) instruments primarily designed for multimodal assessment of caregiver-infant interactions but that only include touch as a sub-scale; (2) self-response measures, such as diaries or questionnaires; (3) tools only used with infants older than 24 months of age; (4) instruments that only assessed the total amount of caregiver touching behavior; (5) publications in a language other than Portuguese, Spanish, or English.

2.3.2 Search Strategy

The search strategy was conducted on the following databases: APA PsycInfo, Medline, Scopus, APA PsycArticles, and Web of Science. Queries included, per database, the first allowable search date through July 2022. No publication date or publication status restrictions were enforced. The search was limited to title, abstract, and keywords. For searches conducted on the APA PsycInfo, Medline, Scopus, and Web of Science databases we used the following query: *(mother OR father OR caregiver OR parent* OR maternal) AND (touch OR tactile) AND (assessment OR scale OR instrument OR tool OR scoring OR coding OR measure* OR index) AND (infancy OR Infant)*. Since we obtained a very limited number of results using the above query in the APA PsycArticles database, a broader search using the following query was made: *(mother OR father OR caregiver OR parent* OR maternal) AND (touch OR tactile) OR (assessment OR scale OR instrument OR tool OR scoring OR coding OR measure* OR index) AND (infancy OR Infant)*.

2.3.3 Selection Process

All the collected references were uploaded to a database of citations using the EndNote reference manager (The EndNote Team, 2013) and duplicates were automatically removed. The titles and abstracts of the remaining publications were then screened using the Rayyan tool (Ouzzani et al., 2016). The screening process was divided into the following steps: (1) duplicates not found by EndNote were manually removed; (2) the first author conducted a preliminary phase of screening to remove articles that were irrelevant to the subject or that did not use a coding system for assessing caregiver touch behavior; (3) titles and abstracts of the remaining publications were analyzed to determine their eligibility in light of the established inclusion and exclusion criteria; (4) full texts of the selected publications were, whenever available, obtained and read to decide whether to include or exclude them; (5) in order to gather more relevant literature that may have been overlooked during the original search, a manual search of reference sections, full titles, and acronyms of relevant tools was performed using Google Scholar. In the event of relevant citations, the article was selected and screened based on the aforementioned inclusion and exclusion criteria.

Two reviewers (JS and IS) independently conducted the selection process and disagreements were resolved during face-to-face discussions. When consensus was not reached a third review author was involved (AP).

2.3.4 Data Extraction

We extracted three types of data from the included publications: (1) characteristics of studies (i.e., type of article, publication year, country); (2) characteristics of the observational instruments (e.g., constructs measured by the instrument, availability) and their psychometric properties (reliability and validity); (3) information about the use of the extracted instruments in the included publications (e.g., target population, location of the observation, type of task). The strategy of data extraction was created based on Bai et al. (2018), Lotzin et al. (2015), and Weiss and Niemann (2011)'s reviews (the form including this information can be obtained from the authors on request). The first (JS) and the second author (IS) separately performed the data extraction achieving a 93.18% interrater agreement, whereupon the two reviewers consulted the full text again to correct any observed inconsistencies.

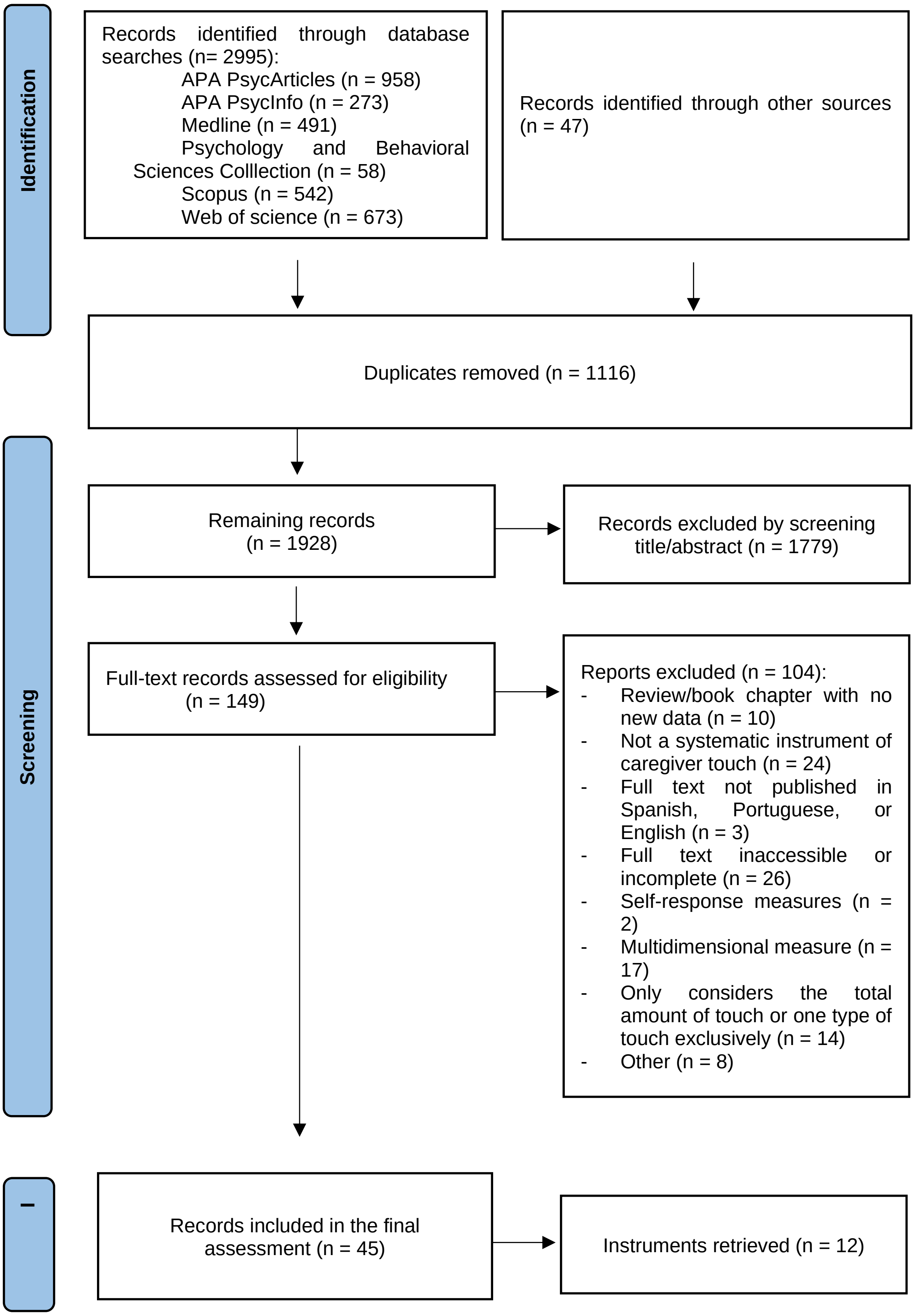
2.4 Results

2.4.1 Review Process

Figure 1 summarizes the flow of information in this study as required by PRISMA guidelines. The search queries returned 3042 potentially eligible publications, including 2995 records from the selected databases, and 47 from other sources (Google Scholar and articles reference sections). Duplicates were subsequently removed, resulting in 1928 publications. After screening the titles and abstracts, a total of 149 publications were retrieved for full-text review. 45 publications that included microanalytic observational instruments for measuring the caregiver's touch behavior were retrieved. From these, 12 instruments were extracted.

Figure 1

PRISMA Systematic Review Flow Diagram



2.4.2 Characteristics of the Included Publications

Publication dates for the records ranged from 1990 to 2021 with the majority (60%) published between 2010-2022 – see Figure 2. Peer-reviewed journal articles comprised 82% of the included publications. The publications included samples from 10 countries distributed on four continents. The majority of the studies were conducted with North American samples (51% from the USA and 22% from Canada) followed by samples from Europe (20%), Asia (4%), Africa (2%), and South America (2%). Table 1 provides more thorough information on the characteristics of the publications included in the review.

Figure 2

Number of Publications Distributed Over Time

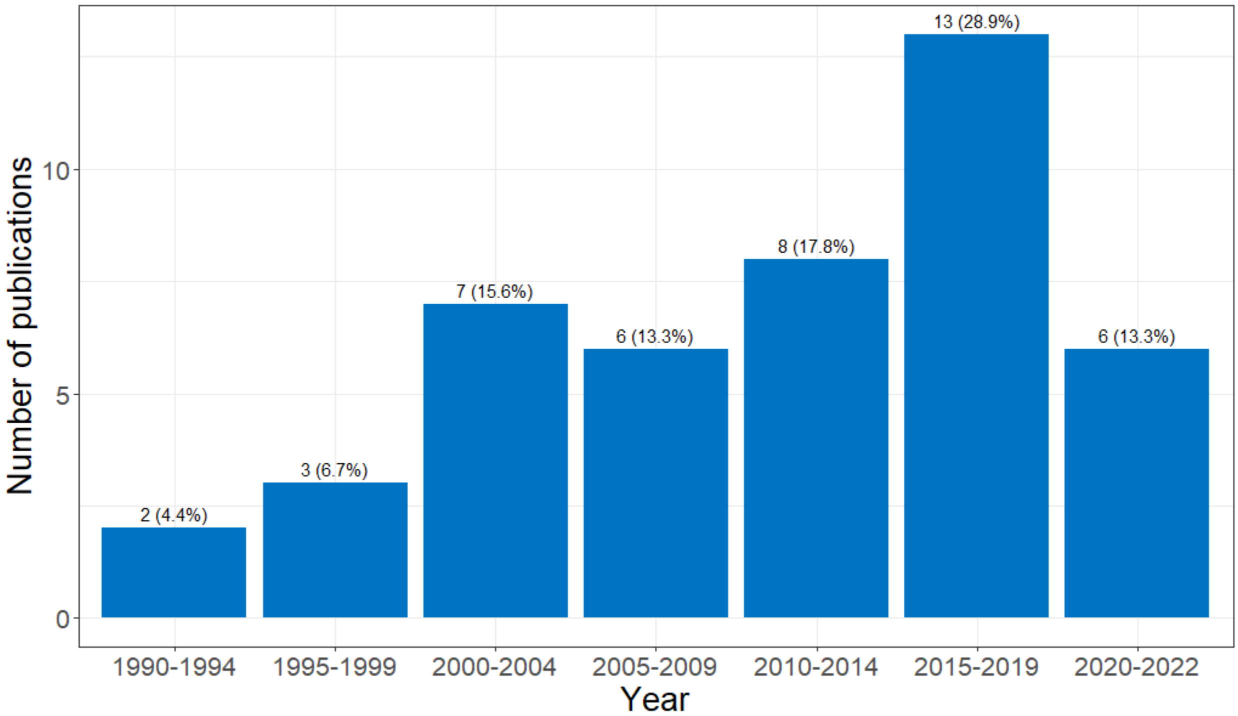


Table 1

Characteristics of the 45 Publications Including Observational Instruments for Measuring Caregiver's Touch Behavior in Parent-Infant Interactions

Characteristics		n	%
Type of article	Peer-reviewed article	37	82.2
	Dissertations and conference abstracts	8	17.8
Continent (Country [a])	America:		
	Canada	10	22.2
	USA	23	51.1
	Ecuador	1	2.2
	Europe:		
	Denmark	2	4.4
	Italy	4	8.9
	Germany	1	2.2
	Portugal	1	2.2
	UK	1	2.2
	Africa:		
	South Africa	1	2.2
	Asia:		
	Israel	2	4.4

[a] Total percentage is over 100 because 2 studies included a population of more than one country.

2.4.3 Characteristics of the Observational Instruments

Table 2 and Table 3 summarize the characteristics of each instrument included, and how they have been used in the literature, regarding target population and experimental settings. From the 45 publications included, we extracted 12 observational instruments. Three different approaches to assessing the touch phenomenon were identified: (1) strictly behavioral measures; (2) functional measures; (3) mixed measures. We found three strictly behavioral measures: Caregiver Infant Touch Scale (CITS; Stack et al., 1996; Stack et al., 2001), Caregiver-Infant Touch Scale - Adapted (CITS-Adapted; Mercuri et al., 2019), and Face-to-face Touch Coding System (FFTCS; Koester et al., 2000); six functional instruments: Quality of Parent-to-Infant Touch Protocol (QPTP; Moreno et al., 2006), Functions of Touch Scale (FTS; Jean et al., 2005; Jean et al., 2007; Jean & Stack, 2009), Caregiver Touch Coding System (CTCS; Koester & Paradis, 2010; Paradis & Koester, 2015), The Functions of Mother-Infant Mutual Touch Scale (FMTS; Mantis et al., 2013; Mantis & Stack, 2018), The Mother-Infant Touch Scale (TMITS; Crucianelli et al., 2019) and Maternal Touch Coding System (MTCS; Provenzi et al., 2020). Finally, the three remaining instruments included both observable and functional constructs in their coding systems: Tactile Interaction Index (TII; Weiss, 1992; Weiss, 2000), Touch-Scoring Instrument (TSI; Polan & Ward, 1994), and Maternal Touch Scale

(MTS; Stepakoff, 1999; Stepakoff et al., 2000; Beebe et al., 2010). Regarding the dimensions of touch codes, the majority of the tools considered the functional role (75%) and the frequency of touch (92%). Other dimensions such as action (25%), duration (67%), location (25%), and intensity (25%) of touch were also coded. All the extracted instruments included reliability studies, however only one of them reported validity studies: the Tactile Interaction Index (Weiss, 1992; Weiss, 2000) . Eight of the extracted instruments are available in published articles and book chapters (67%); the remaining are available on request from the authors of the unpublished manual. Most of the extracted publications included at least one clinical population (60%), while the remaining 40% only included non-clinical populations. This review included research with infants whose ages ranged from 0 to 24 months old, with a sample of infants aged 0 to 6 months of age in 84% of the included studies. We also examined the contexts where the instruments were used, of the 12 instruments: 42% were used in more than one context; 25% only in a laboratory context; 25% in a home context, and 17% were utilized in hospital settings. However, when we analyzed the 45 included publications, we found that 53% of the studies had occurred in a laboratory context, followed by a home context (31%), while the remaining 16% were conducted in a hospital or more than one context in the same study (or it was unspecified). The two most frequent tasks used in the studies were face-to-face interaction and the still-face procedure. Typically, the interaction duration ranged from 2.5 to 12 minutes. Except for one study which was conducted on newborns following delivery and lasted 45 minutes. Considering the frequency of use (in our sample of publications), the most commonly used was MTS (27%) followed by the CITS (18%), and then FTS and TII (13%).

Table 2

Characteristics of Observational Instruments for Measuring Caregiver's Touch Behavior in Parent-Infant Interactions Extracted from Literature Review

Instrument name (reference)	Strictly behavioral or functional measures?	Properties of touch [a]	Touch constructs measured	Availability	Reliability studies	Validity studies
Tactile Interaction Index (TII; Weiss, 1992; Weiss, 2000)	Mixed	Intensity Location Action Frequency Duration Functional role	5 Qualities of touch: Location, Action, Intensity, Frequency, Duration 8 Types of touch: Touch high innervated body areas; Extent of the contact; Nurturing touch, Harsh touch; Cutaneous touch; Proprioceptive touch; Vestibular touch; Diverse 4 Patterns of touch: Stimulating touch; Complexity of touch; Affective nature of touch; The overall amount of touch	Published article Unpublished manual	Inter-observer and retest reliability	Construct, Content and concurrent validity
Touch-Scoring Instrument (TSI; Polan & Ward, 1994)	Mixed	Action Frequency Functional role	3 Physical characteristics: Firm touch; Proprioceptive stimulation; Vestibular stimulation. 3 Affective communicative qualities: Light active touch; Holding; Awkward touch; Rough touch. 2 Non-specific touch: Matter-of-fact; Passive or accidental touch.	Published article	Inter-observer	Not available
Caregiver Infant Touch Scale (CITS; Stack et al., 1996; Stack et al., 2001)	Strictly behavioral	Action Frequency Duration	8 Types of touch: Static touch; Stroke/rub/caress /massage, Pat/tap, Grab/squeeze/pinch; Tickle/finger-walk/prod/poke/ push;	Published conference abstract Unpublished manuscript Published book section	Inter-observer	Not available

			Shake/wiggle; Pull/lift/flexion/ clap; Other types of touch			
Caregiver-Infant Touch Scale - Adapted (CITS-Adapted; Mercuri et al., 2019)	Strictly behavioral	Action Frequency Duration	9 Categories of touch: Static touch; Stroke/caress; Massage/rub; Holding; Palmar grasp reflex; Rocking; Utilitarian/instrumental; Other; Kissing.	Published article	Inter-observer	Not available
Maternal touch scale (MTS; Stepakoff, 1999; Beebe et al., 2010; Stepakoff, 2000)	Mixed	Intensity, location, Action, Frequency, Duration. Functional role	21 Types of touch (e.g., tap, pat, rub/massage, kiss/nuzzle, tickle) 11 Categories of touch: Affectionate Touch, Static Touch, Playful touch, No touch, Centripetal Touch, Rough Touch, and High-Intensity Touch.	Published article Published thesis	Inter-observer	Not available
Face-to-face Touch Coding (FFTCS; Koester et al., 2000)	Strictly behavioral	Active vs passive actions Intensity Location Frequency Duration	4 Types of contact: Passive; Active/moving; Active/passive; Moving; 2 Intensities: Low-moderate or Moderate-high; 4 Locations: Head/face; Torso; Arms/hands; Feet/legs 3 Durations: Low, Medium, or High	Published article	Inter-observer	Discriminant validity
Quality of Parent-to-infant Touch Protocol (QPTP; Goldyn & Moreno, 2002)	Functional	Functional role Frequency	5 Categories: Affectionate touch; Stimulating touch; Instrumental touch; No touch; Cannot code	Unpublished manuscript	Inter-observer	Not available
Functions of Touch Scale (FTS; Jean et al., 2005; Jean et al., 2007; Jean & Stack, 2009)	Functional	Frequency, Duration. Functional role	9 Functions of touch: Passive accompaniment; Active accompaniment; Nurturing; Playful; Attention-getting; Accidental; Utilitarian; Harsh or negative;	Unpublished manuscript	Inter-observer	Not available

			Unspecified function.			
Caregiver Touch Coding System (CTCS; Koester & Paradis, 2010; Paradis & Koester, 2015)	Functional	Frequency Functional role	7 Categories: Affection; Play-directed; Attentional; Instructive; Prohibitive; Reposition; Incidental	Unpublished manuscript	Not available	Not available
The functions of mother-infant mutual touch scale (FMTS; Mantis et al., 2013; Mantis & Stack, 2018)	Functional	Duration Functional role	6 Functions of touch: Playful; Regulatory; Passive; Attention-centered; Guided; Unbalanced.	Unpublished document	Inter-observer	Not available
The mother-Infant touch scale (TMITS; Crucianelli et al., 2019)	Functional	Functional role Frequency Duration	Incidental touch 3 Categories of intentional touch: Instrumental touch; Static; Affectionate touch (Contingent-Excitatory or Non-Contingent-Down-regulatory).	Published article	Inter-observer	Not available
Maternal Touch Coding System (MTCS; Provenzi et al., 2020)	Functional	Frequency Functional role	5 Touch types: Affectionate touch; Playful touch; Facilitating touch; Holding touch; Harsh touch;	Published article	Inter-observer	Not available

[a] We set the dimensions of touch-based on Hertenstein, 2002, Hertenstein, Verkamp, et al., (2006, as cited in Burgoon et al., 1996) and Hertenstein (2002, as cited in Weiss & Campos, 1999)

Table 3

Use of extracted instruments in included publications

Instrument name (reference)	Target population	Age of the infant/ child (months)	Location of observation	Type of task	Interaction duration (minutes)	Relevant publications	%[a, b] (n = 45)
Tactile Interaction Index (TII; Weiss, 1992; Weiss, 2000)	Parents of LBW/preterm infants	3	Home	Feeding	5	Weiss (1992) Weiss et al.(2000) Weiss et al. (2001) Weiss & Goebel, (2003) Weiss et al.(2004)	13.3 (n = 6)
Touch-Scoring Instrument (TSI; Polan & Ward, 1994)	Mothers of failure thrive infants, Mothers of typically developed infants Mothers with maternity blues/ depressive symptomology	2 days - 19	Lab Home Hospital	Feeding Free play with toys Caregiving session	5 or 10	Polan & Ward (1994) Ferber (2004) Ferber et al. (2008) Hardin et al.(2021)	8.9 (n = 4)
Caregiver Infant Touch Scale (CITS; Stack et al., 1996; Stack et al., 2001)	Caregivers of typically developed infants Mothers with high vs. low depressive symptoms Mothers of preterm infants	1-13	Home Lab Hospital	Still face procedure (original and adapted) Free play without toys	2 per task (SF procedure), 5 or 10	Stack et al. (1996) Jean et al.(2009) Mantis et al. (2019) Mercuri et al. (2019)	17.8 (n = 8)
Caregiver-Infant Touch Scale - Adapted (CITS-Adapted; Mercuri et al., 2019)	Parents of typically developed infants	0	Hospital	Free flow triadic interaction	45	Mercuri et al. (2019)	2.2 (n = 1)
Maternal touch scale (MTS; Stepakoff, 1999; Stepakoff et al., 2000; Beebe et al., 2010)	Mothers with PPD Mothers with high vs. low depressive symptoms Mothers with high vs. low anxiety symptoms Preterm infant's mothers Caregivers of typically developed infants	4 -12	Lab	Face-to-face interaction Structured play session	2.5, 3, 5, 10 or 12	Beebe et al. (2008) Beebe et al. (2010, 2016) Beebe et al. (2011) Beebe et al. (2018) Cordes et al.(2017) Egmose et al. (2018);	26.7 (n = 12)

						Serra et al. (2020) Stefana & Lavelli (2017)	
Face-to-face Touch Coding (FFTCS; Koester et al., 2000)	Hearing and deaf mothers of hearing or deaf infants Mothers of typically developed infants	6/8 weeks -9 months	Lab Hospital	Still-face procedure Face-to-face interaction	2 min per task	Koester et al. (2000) Potgieter & Adams (2019)	4.4 (n = 2)
Quality of Parent-to-infant Touch Protocol (QPTP; Goldyn & Moreno, 2006)	Mothers of typically developed infants	3.5	Lab	Face-to-face interaction	3	Moreno et al. (2006)	2.2 (n = 1)
Functions of Touch Scale (FTS; Jean et al., 2005; Jean et al., 2007; Jean & Stack, 2009)	Mothers of typically developed infants Mothers of VLBW preterm infants	4- 5.5	Lab Home	Still-face procedure Modified SF with touch	2 min per task	Jean & Stack (2009, 2012) Jean et al. (2014) Lowe et al.(2016)	13.3 (n = 6)
Caregiver Touch Coding System (CTCS; Koester & Paradis, 2010; Paradis & Koester, 2015)	Hearing and deaf mothers of hearing or deaf infants	6-18	Lab	Free play with toys	10	Paradis & Koester (2015) Silvia (2011)	4.4 (n = 2)
The functions of mother-infant mutual touch scale (FMTS; Mantis et al., 2013; Mantis & Stack, 2018)	Mothers of VLBW preterm infants Mothers of full-term infants	5.5	Home	Still-face procedure	2 min per task	(I. Mantis & Stack, 2018)	2.2 (n = 1)
The mother-Infant touch scale (TMITS; Crucianelli et al., 2019)	Mothers of typically developed infants	12	Home	Book sharing activity	10	Crucianelli et al., (2018)	2.2 (n = 1)

Maternal Touch Coding System (MTCS; Provenzi et al., 2020)	Mothers of infants with neurodevelopmental disability Mothers of VLBW preterm infants Mothers of typically developed infants	3-24	Lab home	Free play with toys Face-to-Face Still-face paradigm	5 2 min per task	Provenzi et al. (2020) Wigley et al.(2021)	4.4 (n = 2)

Note. In this systematic review, we only considered studies including at least one sample of infants up to 24 months of age. For more detailed information about these measures see the following section: “Description of included instruments”.

LBW = Low birth weight. VLBW = Very low birth weight. PPD = Post-partum depression.

[a] Percentage of the included studies that used each instrument.

[b] Total percentage is superior to 100 because 2 studies used more than one instrument.

2.4.4. Description of Included Instruments

This section describes the 12 observational instruments for measuring social touch that resulted from our review. Instruments are presented in chronological order. The information presented here was based on the methods section of the publications reporting the instruments and in supplementary information materials (when made available by the authors) — see Table 2 for a summary of the constructs measured by each tool, and Table 3 for information on how the instrument was used in the included publications. Next, we summarize, for each observational instrument: the research contexts where it was used, the constructs measured, the control variables typically used (i.e., the measures used to control the quality and standardization of the touch measures, such as blind coding or percentage of double coded videotapes for reliability), psychometric metrics (when available), and a summary of how the tools were used in the selected studies.

2.4.4.1 Tactile Interaction Index (TII; Weiss, 1992; Weiss, 2000). The Tactile Interaction Index (TII) was designed to objectively describe the features of touch in dyadic interactions and applies to a range of age groups and relationships (Weiss & Niemann, 2011), including parent-infant interactions. It has been used in a diversity of contexts, such as infant feeding, structured play with children, health care procedures in the intensive care unit, and interactions at home or in a laboratory setting (Weiss et al., 2000, 2001, 2004; Weiss & Niemann, 2011). Touch patterns measured by TII were also used to analyze the association between parental touch in secure attachment (Weiss et al., 2000), social adaptation and emotional/behavior problems (Weiss et al., 2001), the neurodevelopmental level in low-birth-weight infants (Weiss et al., 2004), and the relationship between parental touch of preterm infants and their parent's state of mind regarding touch (Weiss & Goebel, 2003).

TII was specifically conceived for the microanalysis of parent-infant videotaped interactions (Weiss et al., 2001) and measures five indexes of touch (that Weiss and colleagues labeled as qualities of touch): intensity, location, action, frequency, and duration of touch events (Weiss, 1992). In the intensity index, touch is coded as deep, strong, moderate, or light, depending on the level of pressure on the skin. The location index considers nineteen areas of the body that can be touched. The action index identifies twenty-eight gestures or movements that can be used in touch behavior: contact, grab, hit, hold, hug, kiss, lift, massage, pat, pick, pinch, poke, press, pull, push, rub, scratch, shake, slap, squeeze, stroke, bite, kick, lick, suck, tap, tickle, and vibrate. The duration index measures the total time of touch throughout an observation period, while the frequency index considers the number of touches (Weiss, 1992). These five qualities of touch can also be aggregated into two different modalities of tactile behavior: types of touch and patterns of touch (Weiss, 1992; Weiss & Niemann, 2011). Weiss and Niemann, (2011) described the eight types of touch assessed by TII; two of these types of touch are determined by the location index: (1) frequency of "highly innervated body areas" (p. 254) touched by the social partner, such as face and hands; (2) extent of the contact (i.e., the quantity of body' locations touched by a social partner, from the previous nineteen coded locations). The remaining six types of touch are calculated from the action index: (3) nurturing or comforting touch (e.g., kiss, stroke); (4) harsh or painful touch (e.g., slap, pinch, pull); (5) cutaneous touch (e.g., contact); (6) proprioceptive touch (e.g., rub, hug); (7) vestibular touch (e.g., lifting); (8) diverse or varied touch, i.e., how many different actions the caregiver carried out among the 28 actions tracked by the scale (Weiss & Niemann, 2011).

Finally, the qualities and types of touch can also be combined into four patterns of touch: (1) stimulating touch, which refers to touch in very innervated body areas, high-intensity tactile stimulus, and proprioceptive touch; (2) complexity of touch, which considers the extent of body locations touched and the diversity of actions used in touching; (3) affective touch refers to the ratio between nurturing/comforting sensations and harsh or intrusive actions; (4) the overall amount of touch can be measured in terms of frequency or duration, these scores were obtained directly from the corresponding aforementioned indexes (Weiss & Niemann, 2011).

The interaction videos were examined twice or four times by a trained research assistant for each index: the control variable most frequently employed in the studies included (Weiss et al., 2000, 2001; Weiss & Goebel, 2003). Regarding inter-rater reliability, Weiss, (1992) reported the Cronbach alpha coefficients by: location (0.33 for the breast and the remaining values ranged from 0.70 for the torso and 0.98 for the head); action (0.32 for grab, with remaining values ranging from 0.51 for tickle to 0.96 for kiss); intensity (ranging from 0.76 to 0.92) and duration (ranging from 0.84 to 0.99). Concurrent validity values between the coding observers and those who had been observed using touch were reported by Weiss (1992) as follows: location (r = 0.18-.99), intensity (0.51-0.89), action (r = 0.11-0.88), and duration (r = 0.78-0.93). Studies were also conducted to determine the construct validity between the TII and a self-report questionnaire on touch experiences in daily life (r=0.46-0.66), as well as the validity of content – 100% agreement across five experts in defining the four qualities of touch (Weiss, 1992). The use of the TII requires training, which includes the use of videotape examples of different touch qualities as well as a coding manual (Weiss & Niemann, 2011). Furthermore, in the context of this review, we found that TII has been primarily used to encode parental touch in brief 5-minute feeding interactions with 3 months-old infants at home.

2.4.4.2 Touch-Scoring Instrument (TSI; Polan & Ward, 1994). The Touch-Scoring Instrument (TSI) was designed to capture and systematically classify the richness and diversity of the caregiver's touch repertoire. It was first created to measure the role of maternal touch behavior when interacting with typical and failure-to-thrive infants (Polan & Ward, 1994). However, more recently, TSI has been used to measure touch patterns in both clinical and normative samples and a diversity of contexts and tasks. For instance, Ferber, (2004) analyzed the association between tactile stimulation, parity (number of pregnancies), and maternity blues in newborns. This instrument was also applied to capture the developmental trajectories of maternal touch behavior when interacting with their typically developed infants (Ferber et al., 2008).

TSI considers nine categories of touch, that were typically micro-coded into 30-second frames: three categories defined by their physical characteristics, four by their affective nature, and two general touch categories to describe other events that did not suit the previous categories. The three physical touch categories include:

> (1) firm touch, defined as firm patting, stroking, or massaging with the whole hand; (2) proprioceptive stimulation, defined as flexion-extension of the child's limbs by the mother …; and (3) vestibular stimulation, defined as movements that change the infant's body orientation in space. (Polan & Ward, 1994, p.1100)

The four categories of touch's affective nature comprise:

> (4) light touch, defined as affectionate kissing, or caressing, stroking, or tickling with the fingertips: (5) holding, defined as affectionately or comfortingly holding, leaning against, or hugging, in ventral-ventral, ventral-dorsal, or other positions; (6) awkward holding, defined as holding the child in an uncomfortable or precarious manner with an uninterested or neglectful quality; (7) rough handling, defined as exercising forceful or abrupt restraint or physical control of the child with an angry or punitive quality. (Polan & Ward, 1994, p.1100)

Lastly, the authors included two general touch categories:

> (8) matter-of-fact touch, defined as purposeful utilitarian contacts such as wiping the child's mouth, guiding the child's hand to a toy, etc.; and (9) unintentional touch, defined as brushing, bumping, or other types of fortuitous physical contact. (Polan & Ward, 1994, p.1100)

Recently, Hardin et al., (2021)developed a modified version of the Touch Scoring-Instrument to examine the effects of maternal depression and breastfeeding on mother-infant affectionate touch. This adapted version includes seven touch categories: (1) rough handling; (2) awkward holding; (3) no touch; (4) not affectionate/passive/reactive, i.e., any maternal touch that does not fit into the affectionate, passive, or reactive touch categories; (5) passive touch; (6) light active; and (7) firm touch.

The control variables most frequently used in the included studies are the following: blind coding for the study groups (Ferber, 2004; Ferber et al., 2008; Polan & Ward, 1994) and selecting a percentage of videos to be coded by two or more coders for reliability (Ferber, 2004; Ferber et al., 2008; Hardin et al., 2021; Polan & Ward, 1994). Regarding the interrater reliability of TSI, Polan and Ward (1994) reported the following intraclass correlation coefficients: 0.87 for light touch, 0.57 for firm touch, 0.79 for proprioceptive touch, 0.96 for vestibular touch, 0.94 for unintentional touch, 0.96 for the matter of fact, and 0.91 holding. Cohen kappa scores for the reliability of the TSI adapted version ranged from 0.85 to 0.95 (Hardin et al., 2021). In addition, to our knowledge, no validity studies were performed. The included studies reported that the observers were trained to use the coding system, but we were not able to find further details about that training process. In the context of this review, we also found that TSI was used to capture caregiver's touch when interacting with their infants (aged 2 days to 19-month-old) during a diversity of tasks (e.g., feeding, free play with toys, caregiving moments) and experimental contexts (home, hospital, and lab).

2.4.4.3 Caregiver Infant Touch Scale (CITS; Stack et al., 1996; Stack et al., 2001) and Caregiver Infant Touch Scale – Adapted (CITS – Adapted; Mercuri et al. 2019). The Caregiver Infant Touch Scale (CITS) was developed to identify in detail the different caregiver touch types from videotapes of caregiver-infant interactions. This scale has been applied with 1- to 13-month-old infants in both clinical, e.g., mothers with depressive symptomatology, and non-clinical contexts and populations, and across different interactional contexts, e.g. home, hospital, and lab, and tasks, e.g. still-face procedure and free-play (e.g., (Jean et al., 2009; Mantis et al., 2019; Mercuri et al., 2019; Stack et al., 1996) **.**

This instrument considers eight different types of touch assessed on a second-by-second basis: (1) *static touch*; (2) *stroke/rub/caress/massage*; (3) *pat/tap*; (4) *grab/squeeze/pinch*; (5) *tickle/finger-walk/prod/poke/push*; (6) *shake/wiggle*; (7) *pull/lift/flexion/ clap*; and (8) *other types of touch*, such as, adjusting clothing, rocking or bouncing. Any physical contact between the mother's hands and the infant that lasts more than 0.5 second is coded. Later on, some studies aggregated these touch types into more general touch categories, such as: *nurturing/affectionate touch* (i.e., static, stroke, and pat types of touch) and *playful/stimulating* (i.e., pull, squeeze, shake, and tickle types of touch) (e.g., Mantis et al., 2019). This aggregation of categories was conducted not only with CITS but also with CITS-adapted (M. Mercuri et al., 2019). Thus, the CITS has an adapted version, the Caregiver Infant Touch Scale - Adapted (CITS-Adapted).

The CITS-Adapted was created to measure caregiver's touch behavior specifically when interacting with their newborn (i.e., during the immediate postpartum period). To our knowledge, this instrument was only used by Mercuri et al., (2019) to study how mothers and fathers use touch to interact with their newborn infant during their first naturalistic interaction.

The CITS-adapted includes nine categories of touch that were measured on a second-by-second basis: (1) *static touch*; (2) *stroke/caress*; (3) *massage/rub*; (4) *holding*; (5) *palmar grasp reflex*; (6) *rocking*; (7) *utilitarian/instrumental*; (8) *other*; and (9) *kissing*. When compared with the original scale, the CITS-adapted excludes the following touch behaviors: pat/tap, squeeze/pinch/grasp, tickle/finger-walk/prod/poke/push, shake/wiggle, and pull/lift/extension/clap. The authors justified the removal of these touch behaviors by citing the low likelihood of them occurring immediately after birth. Instead, more typically touch patterns for this period were added to the scale: *holding*, *rocking* (i.e., cradling), and *utilitarian/instrumental* behaviors (M. Mercuri et al., 2019).

For both CITS and CITS-Adapted, the following control variables were most frequently employed in the included studies: the coders were blind to the study's hypotheses, a percentage of a random position of the video recordings were double coded, and percentage durations were used to control for duration of time across interactions (Jean et al., 2009; Mantis et al., 2019; Mercuri et al., 2019). Inter-rater reliability was frequently observed in the included studies using Cohen's Kappa, with the overall touch ranged from 0.88 (Jean et al., 2009) to 0.90 (I. Mantis et al., 2019) for CITS. To our knowledge, no validity studies were performed for both CITS and CITS-Adapted. The majority of studies included reported that the observers were trained to use the coding system, but we were unable to find further details regarding that training process. Mercuri et al. (2019) reported, as an exception, that the training procedure included identifying discrepancies between the coders, evaluating the corresponding portion of the video second-by-second, then discussing and finally choosing what type of touch should be coded in that segment.

2.4.4.4 Maternal touch scale (MTS; Stepakoff, 1999; Stepakoff et al., 2000; Beebe et al., 2010).

The Maternal Touch Scale (MTS) was designed to examine parental touch behavior in the context of mother-infant interactions. MTS has mainly been used by Beebe and colleagues to study self- and interactive contingency during early mother-infant interactions at 4 months, in both clinical and non-clinical populations, and laboratory settings (Beebe et al., 2007, 2008, 2010, 2011, 2016, 2018; Beebe & Lachmann, 2017). MTS has also been used to examine the effect of the infant’s gender, and the mother’s ethnicity and depressive symptomatology on her touch behavior (Stepakoff, 2000). More recent studies applied MTS to understand the association between maternal touch behavior, post-partum depression, sensitive and overriding caregiving behavior (Cordes et al., 2017), and infant’s affect (Egmose et al., 2018).

Finally, this scale was adopted to study the effect of object vs. non-object-oriented play tasks on maternal touch behavior (Serra et al., 2020).

This instrument is very complete as it considers not only different touch types (e.g., stroking, kissing, tapping) but also a variety of meanings and implications that touch can bring to the social exchanges (e.g., affectionate touch, caregiving touch). MTS is coded with second by second windows and in each second interval a code for one of the 21 touch types included in the scale is assigned: no touch, hold, provide hand or fingers, stroke/caress, jiggle/large movements with arms or legs, caregiving, tap, pat, rub/massage, kiss/nuzzle, tickle, pull/push, pinch, poke, scratch, object-mediated touch, self-directed oral touch, infant-directed oral touch, other, un-codable. The location where the touch is applied (face, body, head/neck, hands/arms, feet/legs) and the intensity of the touch type (mild/moderate, high intense, n.a.) are also coded. All these 21 types of touch can also be aggregated into 11 categories, ordinalized from more affectionate to more intrusive: affectionate touch, static touch, playful touch, no touch, caregiving touch, jiggle/bounce touch, oral touch, object-mediated touch, centripetal touch, rough touch and high-intensity touch (Beebe et al., 2010; Stepakoff, 2000).

Studies using MTS most frequently used the following control variables: coding carried out by observers who were blind to the study's group status, along with double coding of a random percentage of the dyads (e.g., Beebe et al., 2008, 2010, 2011) or/and a randomly selected position of the video recordings for reliability (Cordes et al., 2017; Egmose et al., 2018; J. Serra et al., 2020). Cohen's Kappa score was used in the included studies to assess inter-rater reliability, with the overall touch ranging from 0.60 (Cordes et al., 2017) to 0.90 (Beebe et al., 2018). To our knowledge, no validity studies were performed for MTS. Most of studies included reported that the observers were trained to use the coding system, but we were unable to find further details about that training process - see Stepakoff (2000) for one exception. In the context of this review, we found that MTS has primarily been used in studies conducted in a laboratory setting with infants from 4 to -12 months.

2.4.4.5 Face-to-face Touch Coding System (FFTCS; Koester et al., 2000). The Face-to-Face Touch Coding System (FFTCS) was designed to assess touch behavior performed by hearing vs. deaf mothers when engaged in the still-face procedure with their hearing or deaf infants. Touch was measured during the normal and reunion periods (Koester, 2000).

However, FFTCS was also used in non-clinical contexts: Potgieter and Adams (2019) examined the effect of early skin-to-skin contact on maternal touch behavior at 7-8 weeks postpartum.

The four types of tactile contact considered in FFTCS were coded using the event-sampling approach: (1) passive, touch without movement, e.g., resting the hand on the infant's leg; (2) active, touch that implies movement, e.g., tapping or stroking; (3) active and passive touch combined, e.g., one hand rests on the leg while the other strokes the infant's head; (4) movement of the infant's body or limbs. The location, intensity and duration of the touch behavior are also coded. In this sense, four locations (arms/hands, feet/legs, torso, head/face, or any combination of these), and two intensities ("gentle/mild," or "vigorous/strong") are considered (Koester, 2000).

A random percentage of the video recordings double coded for reliability were utilized as a control variable in studies using FFTCS (Koester, 2000; Potgieter & Adams, 2019). Inter-rater reliability of this scale is 84.7% for the type of contact, 97.8% for location, and 77% for the intensity of touch (Koester, 2000). Weiss and Niemann (2011) found evidence of discriminant validity on the constructs assessed by this instrument. The included studies sugested that the observers were trained to use the coding system, but we were unable to find additional details regarding the training process. We found that FFTCS has been used in studies conducted in hospital and laboratory settings with infants from 6–8 weeks post-partum to 9 months.

2.4.4.6 Quality of Parent-to-infant Touch Protocol (QPTP; Goldyn & Moreno, 2002; Moreno et al., 2006). The Quality of Parent-to-infant Touch Protocol (QPTP) was developed for measuring individual differences both in the quality and type of parental touch. This instrument has been applied to typically developing populations in mother-infant face-to-face interactions, e.g to 3.5-month-old infants to analyze the effect of touch on mother-infant coregulation (Moreno et al., 2006).

The QPTP consists of 5 mutually exclusive categories, measured in 5-second segments: (1) affectionate touch; (2) stimulating touch; (3) instrumental touch; (4) no touch; and (5) cannot code. The level of affection and stimulation conveyed through touch is rated on a 4-point scale. In the case of two types of touch occurring simultaneously only the most salient one is coded. The mother's actual actions with her hands and fingers, the infant's reaction, and the duration of the contact are all considered by coders to determine the salience of one touch type over another in a 5-second segment (Moreno et al., 2006).

Control variables in QPTP research included coding performed by observers who were unaware of the study's hypothesis and double coding of a random percentage of the video recordings. Regarding the inter-rater reliability of this scale, Moreno et al., (2006) reported the following intraclass correlation coefficients per touch category: 0.81 for affectionate touch, and 0.79 for stimulating touch. To our knowledge, no validity studies are available. QPTP requires training to be used, including the use of a coding manual and the achievement of a satisfactory degree of inter-rater reliability between coders, i.e., higher than .80 on 10 dyads (Moreno et al., 2006).

2.4.4.7 Functions of Touch Scale (FTS; Jean et al., 2005; Jean et al., 2007; Jean & Stack, 2009). The Functions of Touch Scale (FTS) is a systematic observational instrument designed to assess the functions of touch used by mothers to interact with their infants. This coding system measures the qualitative and quantitative aspects of maternal touch as well as contextual information such as verbal and non-verbal modalities of communication, maternal affect, verbalizations, or the infant's affect and attention (Jean & Stack, 2009).

In this scale, for each second of the interaction, one of nine functions of touch are coded: (1) passive accompaniment, i.e., touch that does not imply movement (e.g., a resting hand on the infant's leg) and complements other communication modalities, such as speaking; here, touch is not the primary means of communication in the interaction; (2) active accompaniment, that is, touch with movement without playful goals (e.g., lifting and moving the infant) that accompanies another communication modality; again, touch is not the primary means of communication in the interaction; (3) nurturing touch, affectionate touch behaviors aimed to transmit affection or regulate infant's affect (e.g., kissing, stroking); (4) playful touch, active touch usually to make the infant smile and laugh (e.g., tickle, extend, or flex the infant's limbs); (5) attention-getting touch (e.g., patting or squeezing the infant); (6) accidental touch; (7) utilitarian touch that is used to perform instrumental tasks (e.g., fixing the infant's clothes); (8) harsh or negative touch, which typically involves controlling the infant's behavior by touching in an intrusive and negative way; and (9) unspecified function, i.e., touch without an apparent function (Jean et al., 2007; Jean et al., 2005; Jean & Stack, 2009).

The following control variables are the most frequently employed in the included studies: the coders were blind to the study's hypotheses; a percentage of a random position of the video recordings were double coded; and percentage durations were used to control for duration of time across interactions (Jean et al., 2014; Jean & Stack, 2009, 2012). The included studies evaluated inter-rater reliability using the Cohen's Kappa score, with an overall range of 0.86 (Lowe et al., 2016) to 0.90 (Jean et al., 2014). All the included studies reported that the observers were trained to use the coding system, but we were not able to find further details about that training process. No formal validity testing has been described for this instrument (Weiss & Niemann, 2011). In the context of this study, we found that FTS has been applied mainly with infants (5.5-month-old), both normative and clinical populations, during the still-face procedure.

2.4.4.8 Caregiver Touch Coding System (CTCS; Koester & Paradis, 2010; Paradis & Koester, 2015). The Caregiver Touch Coding System (CTCS) was created to capture the functional role of maternal touch behaviors. Similarly to the Face-to-face Touch Coding System (FFTCS), CTCS has been used in longitudinal projects studying the impact of early deafness on an infant's cognitive, social, and communicative development (Paradis & Koester, 2015; Silvia, 2011).

CTCS measures the frequency of touch and categorizes each type of touch considering its function. Thus, this instrument considers even mutually exclusive categories: (1) affection touch, tactile behavior is gentle and/or has nurturing nature; although it can include more abrupt movements as in the case of playfulness or tickling (2) play-directed touch, touching the infant in a playing interaction, without the intention of helping the infant interact with the toy; (3) attentional touch (e.g., tapping on the infant's hand to get his attention); (4) instructive touch, guiding the infant interaction with a toy; (5) prohibitive touch, applied to control or redirect infant behavior; and (6) incidental: touch without an apparent purpose; (7) reposition touch, applied to adjust the infant's position in space. Each touch behavior initiated by the mother is counted, resulting in frequencies for each category (Paradis & Koester, 2015).

The CTCS requires training before it can be used, which involves instruction on a set of "master recordings" that have been coded by the system's creators and reaching a satisfactory level of inter-rater agreement of at least 80% on all categories of touch prior to coding the actual study tapes (Paradis & Koester, 2015; Silvia, 2011). Apart from the training information, no details about interrater reliability between coders or validity metrics was provided, in the studies that were included. In the context of this review, we found that CTCS has been applied to mothers interacting with their 6- to 18-month-old infants, generally in face-to-face or free play with toy interactions.

2.4.4.9 The Functions of Mother-Infant Mutual Touch Scale (FMTS; Mantis et al., 2013; Mantis & Stack, 2018). The Functions of Mother-Infant Mutual Touch Scale (FMTS) was designed to analyze the functions of mutual touch within early mother-infant social interactions. Functions of mutual touch are defined as a continuous and dynamic tactile exchange between the elements of a dyad (I. Mantis & Stack, 2018). This instrument was based on two previous coding systems, the Functions of Touch Scale (FTS, and the Functions of Infant Touch Scale (FITS; Moszkowski et al., 2009). Specifically, the coding method and the mutual touch definitions in this scale were based on a previously unpublished scale (Mantis et al., 2013).

FMTS includes six categories of mutual touch coded on a second by second basis: (1) playful touch, mutual touch transmitting enthusiasm to the dyad; (2) regulatory touch, mutual touch that conveys calmness to the dyad with the potential aim of regulating emotions; (3) passive touch, when both elements of a dyad hold their resting hands; (4) attention-centered touch, when one element of the dyad gets the other's attention, for instance, by tapping the other; (5) guided touch, that occurs when one element of the dyad helps the exploratory touch of the other; (6) unbalanced touch, occuring when there is not enough synchrony between the elements of the dyad to engage in mutual touch (I. Mantis et al., 2013; I. Mantis & Stack, 2018).

Research using FMTS presents the following control variables: percentage durations were used to control for duration of time across interactions, Cohen's kappa was corrected for chance, and a percentage of the videos were randomly selected to be coded by two coders for reliability (I. Mantis & Stack, 2018). Inter-rater reliability in FMTS for the total amount of mutual touch was $\kappa = 0.87$, while reliability coefficients by function were: $\kappa = 0.89$ for playful mutual touch; $\kappa = 1.00$ for regulatory mutual touch; and $\kappa = 0.78$ for passive, guided, and attention-centered mutual touch (I. Mantis & Stack, 2018). No information about validity metrics was mentioned. The authors reported that the observers were trained to use the coding system, but we were unable to find additional details considering that training process.

In the course of this review, we found that FMTS has been utilized to code maternal touch interaction with full-term or very low birth weight infants who were 5.5 months old during still-face procedures.

2.4.4.10 The Mother-Infant Touch Scale (TMITS; Crucianelli et al., 2019). The Mother-Infant Touch Scale (TMITS) is based on previous observational tools (Ferber et al., 2008; Polan & Ward, 1994; Reece et al., 2016; Stack et al., 1996; Stack et al., 2001) and was developed to code both maternal and infant touch, considering the contingency, valence, functionality, and purpose of touch behaviors. This scale, to our knowledge, was used once to examine whether the contingency of maternal mind-mindedness (i.e., a mother's social cognitive ability to understand their infant's mental state, needs and desires) was related to the maternal touch behavior when they read a book to their 12-month-old (Crucianelli et al., 2019).

In this scale, maternal touch is classified as incidental, when touch is directed at an object instead of the child, or intentional, when touch is directed at the child (Reece et al., 2016). Intentional touch is then coded second by second in one of three touch categories: instrumental, static, or affectionate touch. Affectionate touch can be divided into two subtypes, considering the touch valence: (1) contingent-excitatory when touch provides positive affect and is congruent with the infant's experience, e.g., gentle, tickling, kissing; (2) non-contingent-down-regulatory, when touch is not congruent with the infant's experience, e.g., restrictive firm touch and rough tickling. The decision as to which sub-type best describes the touch depends on the infant's mental state before and after the maternal touch, considering the infant's facial expression, e.g., happy vs. sad, sounds/calls/utterances, e.g., laugh vs. cry, and the infant's body movement, e.g., rapid vs. slow, approaching, retreating (Crucianelli et al., 2019).

The study using TMITS presents the following control variables: coders were blind to any demographic information of the infant and mother; a percentage of the videos were randomly selected to be coded by two coders for reliability and each touch category's total touch occurrences (measured as frequencies) were weighted according to the precise length of each videorecording to account for differences in duration (Crucianelli et al., 2019). An inter-observer agreement in this instrument was computed for all touch categories using Cohen's kappa of 0.56, 95% CI 0.30–0.82 (Crucianelli et al., 2019). No information about validity metrics was mentioned. TMITS requires training to be used, which entails two observers coding six tapes randomly selected from the study database for reliability, with parallel discussions about their agreements and disagreements, until a level of agreement equal to 80% of all tactile behaviors is reached (Crucianelli et al., 2019).

2.4.4.11 Maternal Touch Coding System (MTCS; Provenzi et al., 2020). The Maternal Touch Coding System (MTCS) results from the merging and adaptation of previous coding systems (Crucianelli et al., 2019; Jean & Stack, 2009; Polan & Ward, 1994; Reece et al., 2016). This instrument was developed to measure and compare the functions of maternal touch in play interactions of 12- to 24- month-old toddlers with neurodevelopmental disabilities and toddlers with typical development (Provenzi et al., 2020).

MTCS is focused on the functional role of touch behavior and it includes seven touch categories measured on a 2 seconds basis: (1) affectionate touch (e.g., slow pace/ gentle stroking, caressing, or massaging); (2) playful touch (e.g., tickle, shake or lift); (3) facilitating touch, divided into two subcategories: (3.1) instrumental touch (e.g., fixing child's position or facilitating infant's physical equilibrium by holding) and (3.2) attention-getting (helping the infant to pay attention to the mother by tapping or patting the infant's arm, for instance); (4) holding touch, including two subcategories: (4.1) containment (i.e., touch that may regulate the infant's negative emotional state, aimed at controlling infant's posture and movements); (4.2) static (e.g., when the mother is resting her hand on the infant's leg); (5) harsh touch (e.g., intrusive, awkward or overwhelming touch behavior); (6) no touch; and (7) unspecified touch. For every two-second segment, coders have to select only one type of touch. If two types of touch occur simultaneously, the authors prioritize the one with greater duration during the segment.

The studies using MTCS present the following control variables: coders were blind to the study's aims and hypothesis; a percentage of the videos were randomly selected to be coded by two coders for reliability and percentage of time in touch were used to control for duration of time across interactions (Wigley et al., 2021; Provenzi et al., 2020). The included studies evaluated inter-rater reliability using Cohen's Kappa score, for the overall touch range of 0.80 (Wigley et al., 2021) to 0.81 (Provenzi et al., 2020). No information about validity metrics was mentioned. MTCS requires training to be used, which entails identifying discrepancies between the coders, evaluating the corresponding portion of the video, then discussing and finally choosing what type of touch should be coded in that segment. For the purposes of this study, we found that MTCS was used to measure and compare the functions of maternal touch on full-term, very low birth weight infants and infants with neurodevelopmental disability aged 3 to 24 months old in play interactions and still-face procedures.

2.5 Discussion

Touch is a foundational part of the infant's early experience of the world, marked by proximity with social partners who use touch in multiple forms and for multiple purposes (Hertenstein, 2002; Jean & Stack, 2009; Stack, 2001), from the practicalities of caregiving to the regulation of physiology or emotion, or for play. The complexity of social touch is more frequently studied using observational methods where touch events are segmented from video recordings of social interactions and categorized according to a well-defined instrument (Brzozowska et al., 2021; Weiss & Niemann, 2011).

We conducted a systematic review of the literature on observational instruments designed specifically to measure the caregiver's touch behavior in parent-infant interactions. This approach offers several advantages when compared with other alternatives, based, for example, on parental retrospective evaluation or self-report (Brzozowska et al., 2021), and we conjecture that these benefits have motivated renewed interest in observational methods for touch research. As such, our main goals were to identify available instruments, describe their main features, and summarize how these instruments were used in the literature. We also propose categorizing the different tools into three groups based on how they measure the touch phenomenon, discussing the core strengths and limitations of each group of instruments, and providing guidelines for the design of future observational instruments.

From the 45 publications that met the inclusion criteria, we extracted 12 observational tools for measuring caregiver touch behavior. Ten different countries produced these studies, with the USA producing the majority. The number of observational studies of caregiver touching patterns has grown considerably over the past decade, with 60% of the included papers published between 2010 and 2022. Our analysis found different instruments designed to capture distinct perspectives of the touch phenomenon (strictly behavioral, functional, or mixed). Although some observational tools were developed using previous tools, and thus share similar features or organizational structures, there is, nonetheless, a great conceptual and operational variability, as well as a lack of consistency across observational measures of touch. Half of the instruments in question measure the functional role of the caregiver's touch behavior. In addition to this, publications that include observational instruments are mostly concerned with the first 6 months of life, measuring touch in two laboratory tasks: (1) structured social interaction (e.g., face-to-face interactions); and (2) the still-face procedure. MTS (Mother Touch Scale) is the most widely employed instrument included in the selected publications.

2.5.1 Characteristics of the Observational Instruments

We organized the 12 selected observational instruments using three main categories: strictly behavioral, functional, and mixed (i.e., tools that include both strictly behavioral and functional constructs). This classification system was developed to help structure the information in the article and was based on conceptual frameworks for touch already used in the literature (Burgoon et al., 1996 cited in Hertenstein et al., 2006; Brzozowska et al., 2021; Hertenstein, 2002), as well as on the major similarities that we identified between the instruments in our post-hoc analysis (after extraction).

Half of the instruments included in this review were focused on the functional role of touch, i.e., the particular function that each touch event has in the flow of the caregiver-infant interaction, for example, if a mother squeezes the infant's arm to get his/her attention. Our study also revealed that 75% of the included instruments provided a measure of the functional role of touch. Furthermore, all the functional tools included in this review have been developed over the last 20 years. We advance two possible explanations to account for this rise in levels of research into the functional character of touch. Firstly, there is growing evidence that certain types of touch elicit specific responses in the infant (Stack & Arnold, 1998; Stack & LePage, 1996), suggesting that different touches play distinct functional roles in caregiver-infant interactions. Secondly, studies in this area have also found that specific touch patterns are associated with positive developmental outcomes in the infant. For instance, nurturing/affectionate touch can relax and soothe the infant after a distressing event (Jean & Stack, 2009; Moreno et al., 2006; Peláez-Nogueras et al., 1996). When compared with highly vulnerable preterm infants, higher levels of nurturing touch promote more secure attachment in less vulnerable preterm infants (Weiss et al., 2000).

Furthermore, infants that receive more nurturing/affectionate touch at 3 months old exhibit fewer behavioral and emotional problems at the age of 2 years (Weiss et al., 2001, 2004). Another example is caregiving touch: this type of touch can help lower the infant's negative affect (Egmose et al., 2018) and is associated with a higher level of maternal sensitivity (Cordes et al., 2017). The growing corpus of studies indicating that the different types of touch serve various functions in social interactions and have an impact on the infant's development and behavior may have also served as a catalyst for the creation of new methods to evaluate touch constructs.

Our findings also show that most instruments are accessible, and can be used and consulted in published articles, theses, and book sections (67%). Despite this, we argue that the practical replication of the coding systems included in these observational tools is demanding. The descriptions of the methods available are often vague and poorly detailed, making it difficult to accurately replicate the coding systems in new studies. Additionally, proper training of coders involves several hours of supervised coding, followed by a highly time-consuming coding process. Besides that, it is crucial to create and publish more specific guidelines per instrument (with examples on how to apply and score the caregiver's touch behavior) and/or to develop open-access training programs for the coding systems. This would support the overall research community in applying these instruments/coding systems and would make them more replicable.

The availability of studies on the psychometric proprieties of the instruments is another salient point to consider. In general, reliability studies are included but formal validity studies of the instruments are practically non-existent — see Weiss, (1992) for an important exception. As a result, more thorough psychometric studies, which include validity comparisons of various observational touch instruments paired with self-response measures, are crucial for improving the accuracy and reliability of the observational tools available for measuring touch.

Detailed information on the use of the instruments in research was also provided in this review. We systematically reviewed the observational instruments used to measure the caregiver's touch behavior on infants between the ages of 0 to 24 months old and found that most studies focused on infants younger than 6 months. Observational tools were used to assess both non-clinical and clinical populations (e.g., failure to thrive, preterm or deaf infant's caregivers, and mothers with post-partum depression) and were primarily used in the context of two tasks, face-to-face interactions, and the still-face procedure. Finally, the majority of the instruments were applied in three settings: hospital, family home, or laboratory, with most of the studies occurring in the laboratory context. The higher frequency of the laboratory setting can be explained by the fact that MTS is commonly applied in that context (Beebe et al., 2010; Stepakoff, 2000).

2.5.2 Measuring Caregiver Touch Behavior: Strictly Behavioral vs Functional Instruments

Before discussing the advantages and disadvantages of utilizing the instruments included in each category of observational touch measure (strictly behavioral, functional, and mixed), we will first look at some similarities and differences between them. Some instruments were designed to capture specific behavioral traits, such as the parent's touch action (stroke, pat, tap), the touch's intensity, and whether or not the hand was moving – we referred to them as strictly behavior instruments, because they were focused on the surface-level observable aspects of touch behavior. Other methods, in turn, were more focused on assessing what parents meant to convey to their infants through these specific behavioral features – we called them functional (Hertenstein, Verkamp, et al., 2006, as cited in Burgoon et al., 1996) because the emphasis is not on the touch behavior per se but on the role it has in the interaction. Then, we identified that some instruments measured specific behavioral features and then aggregated them in functional categories – because these instruments measured both construct types alluded to in the two previous categories, we referred to them as mixed instruments. Despite these operationalization differences among the categories, there are also some overlapping similarities. These similarities appear to be mostly accounted for by the fact that some recent observational measures were based on earlier observational measures and as such, they measured similar or slightly modified constructs. For instance, when comparing the functional tools, FTS and FMTS, we found that FTS presents more constructs (e.g., active accompaniment, accidental, harsh, and negative) than FMTS; however, the common constructs between the two tools either have the same name (playful) or have a different name but measure very similar behaviors (e.g., attention-getting vs attention-centered). Attributing different designations to the same touch behaviors is a common occurrence in observational measures of touch, a point that will be covered in more detail later in this review. Another commonality can be found between the strictly behavioral and mixed instruments categories since they both measured directly observable characteristics of the touch behavior. However, while in mixed instruments the directly observable touch behavior is aggregated based on the function touch has on the interaction (e.g., kiss and stroke transmit affection to the infant, thus, these actions are included in the affectionate category in MTS), strictly behavioral tools code these observable touch patterns per se (e.g., kiss, tap, tickle, hold) and are not focused on their function. Although we did not focus on similarities between categories in the following sections, it is crucial to bear in mind that they do exist and could be helpful when comparing the findings of research that employs different observational measurements. The benefits and drawbacks of using the instruments contained in each category of observational touch measure will be discussed in the sections that follow.

2.5.2.1 Strictly Behavioral Instruments. Strictly behavioral instruments (e.g., CITS and FFTCS) allow researchers to capture and describe touch in a great level of detail. They provide information about how specific touch types and their dimensions vary across time, contexts, caregiver/infant's health, and even between caregivers. For instance, Jean et al., (2009) used CITS to examine the mother's touch behavior when interacting with their infants at 1, 3, and 5.5 months of age, in two interactional contexts (lap and floor). They found that mothers touch their infants more at 1 month of age than at 3 months, but also used different types of touch depending on the infant's age and context. Specifically, while in the lap, mothers used more patting and tapping touch when their infants were one month of age compared with when they were 5.5 months old; mothers stroked their infants more often at 1 month than at 3 months and applied more tickling at 5.5 months than at 1 month. In the floor context, mothers used lifting touch more often at 1 month than when interacting with their older infants. The auditory status of mothers also impacts the use of touch: hearing mothers use touch with longer duration and are more active compared with deaf mothers (Koester, 2000). These findings underscore the importance of touch in its most basic observable behavioral element. They also suggest that parents adapt the use of touch to a diversity of circumstances, such as infant age, interactional context, and touch is altered in clinical dyads. The description of touch behavior at this level of detail could be beneficial for several practical reasons. For example, for the development of parenting intervention programs that stimulate certain touch types considering specific interactional contexts and clinical conditions, or for early detection of clinical indicators that may impact an infant's healthy development.

However, it is important to note that some of these studies, particularly the more recent ones, grouped specific touch patterns into more functional categories (e.g., nurturing, stimulating, and instrumental categories), after collecting them using a strictly behavioral instrument – for example see Mantis et al. (2019) and Mercuri et al. (2019). Parental touching exchanges go beyond their simple actions and have different roles and communicate different messages within the interaction, a fact which is ignored by methodologies that only focus on the observable touch behavior. However, the grouping of specific touching behaviors into more functional ones may reflect to some extent the research field's recognition of this. This assertion is further supported by the fact that over the past 20 years, researchers have focused on developing more functional tools.

2.5.2.2 Functional Instruments. Functional instruments code for the functional purpose of a touch behavior in the context of the interaction (not necessarily the same as the exact type of touch). According to our systematic review, there has been an increased interest in this component of touch, as evidenced by the rise in studies using functional tools available in the recent literature - 75% of the tools presented in this review included a measure of the functional role of touch. Functional measures (such as FTS, FMTS, and TMITS) consider the function that each touch event plays in the interaction flow. For example, a mother’s kissing and slow stroking in response to the infant’s fussiness may be coded as nurturing touch, according to the FTS. Indeed, such tools have been essential for deepening our understanding of the functional significance of parental touch behavior in early parent-infant interactions as well as the relationship between these touch behaviors and the infant's emotional, social, and physical development (e.g., Crucianelli et al., 2019; Jean & Stack, 2009; Moreno et al., 2006). However, there is a lot of variation in how the functional role of touch has been operationalized across instruments. Some tools are more detailed than others, with a range of 3 to 9 functions of touch (e.g., QPPTP vs FTS). There are different research teams categorizing comparable touch functions using different terms (in the following section, this specific point is covered in more detail). Additionally, distinct instruments operationalize similar functional constructs of touch differently. A caregiver´s gentle and slow touch behavior intended to soothe, relax, and calm the infant, for instance, is assessed differently depending on the tool employed. The CTCS characterized this action as affection touch and this category includes both touch with a gentle and nurturing quality but also playful movements such as patting and tickling. TMITS categorizes this type of touch as contingent-excitatory affectionate touch, and in addition to considering the gentle quality of touch (much like CTCS), it also assesses whether touch is contingent on the baby's emotional state. Playful and nurturing touch behaviors fall under separate categories in FTS and FMTS, while gentle contact is designated as nurturing touch and regulatory touch in each scale, respectively.

Moreover, the behavioral variables that different instruments take into account can vary. For example, some instruments (such as FTS, CTCS, and QPPTP) only assess the caregiver's tactile behavior, while others (such as FTS) consider other interaction modalities when coding, such as vocalizations; others still evaluate the infant response to the caregiver when operationalizing the functional role of parent's touch behavior (e.g., TMITS and FMTS). Overall, this variability in how the functions of touch were evaluated via the lens of various observational metrics makes systematic comparisons between studies and instruments difficult at best.

Another limitation associated with functional instruments is that they only measure the purpose of a specific touch behavior in a given situation, and do not account for the observable behaviors associated with each function (i.e., the opposite problem of when the same touch behavior is used for multiple functions). For instance, when various touch actions (e.g., caress, stroke, tap) are classified as affectionate touch category, we lose access to information about how many caresses the mother provides to their infant at a given context or age; instead, we only have access to the composite that included it, affectionate touch in this particular example. In fact, some studies have shown that there is an association between the developmental trajectory of different touch types and infant development (e.g., Stack & Jean, 2011; Jean et al., 2009; Mantis et al., 2019). Do parents use the same touch behaviors to communicate the same message? How do these changes relate to the infant's well-being, behavior, and developmental level? Responding to these questions in future studies may help researchers to explore the relation between certain socio-emotional and cognitive skills, and specific touch types provided by the caregiver.

Despite these limitations, when compared with strictly behavioral tools, functional instruments go beyond the mere description of tactile behavior since they collect information on the purpose of tactile stimulation in each moment of the interaction flow, for instance, if a mother is slowly caressing her infant on the head, she probably aims to relax, show affection, or regulate her baby's affect.

2.5.2.3 Mixed Instruments We found three instruments measuring both the strictly observable touch behavior and the functional role of touch: TII, MTS, and TSI. These instruments, in a first step, code for the type of touch and their additional dimensions (e.g., intensity and location). In a second step, this detailed information is aggregated into more general categories/patterns of touch, reflecting the functional role of the touch in the interaction. When compared with functional tools, mixed measures provide a more accurate description of the precise relationship between the type of touch and the dimensions that underlie each function of touch. This is particularly important because different touch types may have different functions in the interaction depending on factors such as the location of the body touched or the intensity of the touch. For instance, in the MTS instrument, the “tap” type of touch can be used to play with the infant when caregivers touch their infant’s hands, arms, feet, or legs with moderate intensity. Yet, if the same “tap” behavior was applied to the face, body, head, or neck, it may be regarded as more stimulating (i.e., centripetal touch), or as intrusive, if applied with great intensity. Thus, these instruments can describe in detail how parents use touch at different levels of abstraction. However, important information could be missed when using mixed measures, since the functional role is not coded from the interaction but rather comes from the combination of other elements (e.g., types of touch, intensity). For example, pulling the baby by the arm with moderate intensity may reflect two different functions if we consider what is happening in the interaction: it may be intrusive to restrict the infant’s access to the desired toy (rough touch) or a protective behavior from the parent to protect the baby from approaching danger, for example, an electrical plug (caregiving touch). This disadvantage can be mitigated by simultaneously encoding the observable behavior (e.g., actions, intensity, location of the touch behavior) and the function associated with it.

2.5.3 Towards More Uniform and Consistent Social Touch Constructs

Touch researchers have noted that designing an observational instrument that accurately measures the complexity of caregiver’s touch exchanges in parent-infant interactions is a challenging task (Hertenstein, 2002; Hertenstein, Verkamp, et al., 2006). This stems from the caregiver’s use of diverse touch behaviors, and how these behaviors vary in several important dimensions (e.g., action, location, velocity, intensity, frequency, and duration). The combination of these dimensions defines the purpose or function of each specific touch behavior performed by a caregiver. In addition, parents and infants have their unique social context and bring particular characteristics to everyday interactions that naturally affect the quality and quantity of touch exchanges. As such, designing a measure that captures the phenomenon of touch to its fullest extent is a difficult task for researchers (Hertenstein, 2002; Hertenstein, Verkamp, et al., 2006), which may have contributed (in part) to the diversity of instruments found in this review. Thus, there is considerable heterogeneity in the way each instrument is organized, both in the dimensions of touch that are used, and in which constructs of touch are included for measurement. This is evident when comparing terminology associated with the same or very similar touch behavioral cues. At the strictly behavioral level, which includes the different behaviors that parents use to interact with their infants through touch (e.g., hold, tap, stroke, tickle), we observe several terminological variations. For instance, in TII these behaviors are called actions, in MTS and CITS they are named touch-types, while in TSI they are designed as categories of touch. This terminological inconsistency also applies to the higher-level touch dimensions. The functional role of touch in interpersonal interaction has, in touch research, been labelled touch categories (e.g., QPPTP, CTCS, and TMITS), functions of touch (e.g., FTS and FMTS), or types of touch (e.g., MTCS). Distinct scales also use different categorizations for the same touch, for example, purposeful/utilitarian contacts, such as wiping an infant's nose are categorized as matter-of-fact touch in the TSI, as utilitarian touch in FTS, as instrumental touch in QPPTP or as caregiving touch in MTS. The opposite is also true: similar functions have different definitions per instrument. For instance, considering affectionate/nurturing/affection touch: CTCS included playful movements such as tickling in the affectionate construct; FTS considered other interaction modalities, such as vocalizations, in their measurement of nurturing touch; in TMITS, the contingency of parental touch to the infant experience is considered as part of the affectionate touch definition. A greater effort to clarify, standardize and seek a more uniform use of terms and definitions in the literature is an important next step.

In summary, the great variety of measurement strategies and the lack of consistency in definition and operationalization hinder direct comparisons between similar concepts measured by different instruments. We argue for an increase in uniformity and consistency of the assessed constructs, with the future goal of supporting more standardized measures of tactile behavior, and for the importance of including both the observable and functional features of caregiver's touch behavior in the design of new observational measures.

2.5.4 Strengths and Limitations of this Review

To the best of our knowledge, this is the first systematic review of observational tools to measure parental touching behavior during infancy; a previous review was done in 2011 but was not systematic in the methodology (Weiss & Niemann, 2011). A broad search with no year limitations in several relevant datasets was conducted. We included a detailed description of the constructs, the main characteristics of the instruments, and how they are used in the literature. The information collected in this review can assist researchers in the process of selecting an instrument for designing an observational study. However, in our review, we have only included structured observational instruments specifically oriented to measuring the quality and quantity of the parent's touch behavior in interaction with their infants up to 24 months, and multimodal instruments were not included – these code for several modalities in the interaction and include touch, but do not propose a separate instrument for touch. In addition, we only added observational measures, although recent work indicates that self-report and observational measures should be used together to enhance the understanding of touch behavior in parent-child interactions (Brzozowska et al., 2021).

Finally, only a limited number of gray literature publications, including conference papers and dissertations, were considered in our analysis (we only included conference papers and dissertations that were published on the commercial platforms that we had access to or were available in Google Scholar); recent evidence has shown the importance of considering more gray literature in systematic reviews (see Paez, 2017). A broader review of all the available measures, including self-report measures and other methods of evaluating touch behavior described in the literature, such as neurophysiological measures, should be addressed in further research.

2.5.5 Future Directions

We will now address some potential directions that might be taken in further research. Although some more recent tools (e.g., TMITS, FMTS) measure the role of parental touch in the interaction by considering both the parent's intention when touching, and whether it is congruent or not with the infant's experience in a particular moment, the majority of these tools were designed to capture only the caregiver's behavior (and primarily the mother's), independently of the infant's response to it[2]. However, we know that caregivers and infants interact in a bidirectional manner, and, in the flow of the interaction, infants will actively respond to their parent's touch, or initiate touching by touching their parents or by touching themselves. There also moments of discoordination, in which the intention of the parent when initiating the touch will not be adequate. All these moments are an important part of parent-infant natural interactions, however, save for some exceptions, infant and caregiver touch is measured separately – see Beebe et al., 2010, 2016, 2018; Crucianelli et al., 2019 and Mantis & Stack, 2018 for studies that measure both. Future research should therefore consider the development of instruments that more extensively and consistently account for both infant touch behavior and how it ties into adult touch behavior. More attention should also be paid to how the contact is initiated, i.e., if parental touch behavior is congruent with the infant's experience, and how these aspects affect the infant's development, behavior, and emotional state.

The validity of observational touch measures is another crucial factor that needs to be evaluated in subsequent studies. Although some of the instruments included in this review mentioned validity studies (e.g., TII), this is not the rule. The fact that many observational measures were developed to evaluate touch for a single study or a few related research projects, rather than creating standardized touch assessment tools appears to account in part for the lack of these investigations. As a result, further empirical studies on an instrument's validity are required to increase the level of confidence in the findings and conclusions of observational studies of touch. To uniformly describe and clarify the variability that has been utilized to assess and touch on observational instruments, studies on the content and construct validity would be greatly beneficial. This is of particular importance for functional tools because of conceptual discrepancies. There has already been some research on evaluating the criterion validity of an observational instrument in comparison to a self-report measure (Brzozowska et al., 2021). To our knowledge, however, the criteria validity between two or more distinct observational tools has not yet been carried out, even though it would be important in order to comprehend the degree of correlation that exists between the instruments used to measure related constructs. Finally, cross-cultural validity studies on

[2] For more information on instruments to measure infant's touch behavior see Moszkowski, Stack, & Chiarella, 2009; Moszkowski, Stack, Girouard, et al., 2009 and Moszkowski & Stack, 2007

tactile contact are essential for identifying cultural similarities and differences, as well as for determining how well the existing instruments can accurately measure touch in different cultural contexts.

While the relation between the caregiver's touch behavior and the infant´s social and emotional development has been widely explored (e.g., Ferber et al., 2008; Weiss, 2000; Weiss et al., 2001, 2004; Beebe et al., 2010; Cordes et al., 2017; Mantis et al., 2014; Mercuri et al., 2019; Polan & Ward, 1994), comparatively less is known about how parental touch, which is a permanent presence in the infant's everyday routines, impacts the infant's early cognitive development, particularly object exploration. Social touch and the development of object exploration in infancy have been studied separately in the literature: social touch studies typically study the dyad in non-object interactions, while studies of object exploration, in mother-infant play interactions with objects, are typically more interested in understanding how object manipulation and exploration is associated with developmental outcomes, especially high-order social cognition abilities, such as sustained attention and joint attention skills (e.g., Barbaro et al., 2016; Yu & Smith, 2013, 2017; Suarez-Rivera, Smith, & Yu, 2019; Schatz, Suarez-Rivera, Kaplan, Linn, & Tamis-LeMonda, 2020). The object-oriented behaviors may or may not include contact, such as the difference between a mother who holds the infant's hand with a mother that rings the bell for the infant. There are a few studies that suggest that parents adapt their tactile behavior to the infant's developmental needs and interests, in different play contexts (Leiba, 2000; J. Serra et al., 2020) and that parent's physical contact is associated with infant's object exploration (Tanaka et al. 2021). As such, the possible association between the caregiver's touch and the infant´s cognitive development raises some important questions: does parental touch affect the infant's cognitive development? If it does, is this effect direct (i.e., the parent's touch behavior scaffolds the infant when exploring objects)? or indirect (i.e., the parent's touch behavior touch behavior provides suitable circumstances that favor the exploration of an object)? Or is it a result of both direct and indirect pathways? To answer the aforementioned questions, and expand our understanding of the association between social touch and the development of the infant's ability to explore objects, it is necessary to develop instruments that combine the knowledge of these two research fields, i.e., including in future research not only the measurement of the quality of touch in the interactional context but also the detailed description of parental touch behaviors geared towards facilitating the infant's manipulation and exploration of objects.

Another relevant issue is the implicit assumption of intentionality. In functional instruments, the category for each touch type can be interpreted as stating some level of parental intentionality: a mother's gentle caress in a baby's arm can be categorized as affectionate touch, but this also suggests that she is acting with the intention of showing affection. Unless the method is explicit, there is an implicit assumption here that parental touch behavior always entails a communicative intention towards the infant (Hertenstein, 2002; Hertenstein, Verkamp, et al., 2006). However, and across instruments, the strategy for coding of the functional role of a touch event is heterogeneous and any intentionality is inferred. While some instruments code the functional role of touch in the interaction by only considering parental touch behavior (e.g., CTCS and QPTP), others also include contextual variables, such as the infant's response to parental touch or the presence of other modalities (e.g., FTS and FMTS). As a result, we argue that more work can be done in future research to clarify the construct of the functional role and whether the assumption of intentionality is required.

Finally, future research should also make efforts to organize and summarize the terms used to define the touch construct, in order to clarify them, and move toward greater conceptual uniformity and consistency, with the goal of creating more standardized measures. There is also a lack of studies measuring the caregiver's touch behaviors when engaging with infants over 6 months of age, particularly in more naturalistic tasks and contexts. In addition, although measuring touch behavior is important, there is a critical need to measure its association with other sensory modalities and how it impacts infant global development.

2.6 Conclusion

Our systematic review provides a detailed description and synthesis of the available observational instruments to assess a parent's touch behavior in the context of caregiver-infant interactions. We identified three categories of observational measures, examined the strengths and limitations of each category for assessing touch behaviors in parent-infant interactions, and proposed possible future directions for research. Twelve instruments were identified from 45 publications. Our review collected a set of instruments designed to capture distinct perspectives of the touch phenomenon. We found a lack of conceptual and operational uniformity and consistency among them, and most of these instruments assess the functional role of caregiver touch behavior. In addition, most of the studies included in this review are with infants below six months of age, measuring touch in face-to-face interactions and the still-face procedure in a laboratory setting.

The current work provides an updated review of the available observational instruments for measuring caregiving touch behaviors, taking into account how they have been used in the literature, which can serve as a guide for future researchers to select the more suitable measurement for their future studies. Furthermore, we reviewed the primary strengths and limits of each of the three identified categories of instruments, as well as the conceptual challenges that the field of touch is facing, particularly when it comes to measurement. Such observations may help to increase the quality of future developed observational instruments of caregiver touch behavior, taking another step toward standardizing touch measurements. Finally, we summarize some of the key challenges in the field of touch and explore potential approaches to addressing them in future research.

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CHAPTER 3

The effect of play task on maternal touch patterns when interacting with their 12 months-old infants: An exploratory study

CHAPTER 3

A version of Chapter 3 was published in the Elsevier peer-reviewed journal *Infant Behavior and Development.*

Reference:

Serra, J., Miguel, H., Moura, A. A., Sampaio, A., & Pereira, A. F. (2020). The effect of play task on maternal touch patterns when interacting with their 12 months-old infants: An exploratory study. *Infant Behavior and Development, 59*. https://doi.org/10.1016/j.infbeh.2020.101438

Errata list

Title: The effect of play task on maternal touch patterns when interacting with their 12 months-old infants: An exploratory study

Page	Lines	Original text	Corrected text
100	11	"…mother's use touch is highly frequent (M = 71%)…"	"…mother's use touch is highly frequent (M = 56%)…"
100	13	"..in the challenging play task as in the free play with toys (M = 26% vs. M = 14%)…"	"..in the challenging play task as in the free play with toys (M = 21% vs. M = 12%)…"
108	24-25	"…the average *total* proportion of time touching was 71% for *Free Play Without Objects* vs. 14% and 26% for *Free Play With Objects* and *Challenging Object Play* respectively.."	"…the average *total* proportion of time touching was 56% for *Free Play Without Objects* vs. 12% and 21% for *Free Play With Objects* and *Challenging Object Play* respectively
111	10	"…touched considerably less in both triadic object play tasks (on average 14% and 26% of the interaction time, for free play with objects and challenging object play, respectively)…"	"…touched considerably less in both triadic object play tasks (on average 12% and 21% of the interaction time, for free play with objects and challenging object play, respectively)…"
111	12	"…compared with the dyadic interaction in the free play without toys task (i.e. on average 71%)..."	"…compared with the dyadic interaction in the free play without toys task (i.e. on average 56%)..."

CHAPTER 3

3.1 Abstract

Multiple studies have demonstrated the critical role of touch in human development and the impact of mother's tactile input for infant's well-being. However, the literature lacks a detailed description of maternal touch behavior during play tasks. Our study examined maternal touch patterns during mother-infant interactions. We analyzed the touch behavior of 41 mothers while they interacted with their 12-month-old infants, in a structured social interaction, composed of three tasks: (1) free play with toys, (2) free play without toys, and (3) object play with a challenging toy. Every touch performed by the mother was segmented and categorized using the Ordinalized Mother Touch Scale (OMTS Category). In a 3 (Play Task) x 8 (OMTS Category) ANOVA, all effects were significant. We found that in the free play without toys task, mother's use touch is highly frequent (M = 71%), when compared to object-oriented tasks. Mothers also adjusted to object-oriented task difficulty: they touched almost twice as much in the challenging play task as in the free play with toys (M = 26% vs. M = 14%). In addition, the different play tasks influenced the proportion of time mothers used particular categories of touch. In summary, our study found that mothers' touch behavior depends on the play task demands (non-object oriented vs. object oriented) changing in terms of frequency but also in the mother's use of different categories of touch.

Keywords: Social touch; Mother-infant interaction; Maternal touch

3.2 Introduction

Touch is an essential element of caregiver-infant interactions and has a vital role in infant's early physiological, cognitive, and social development (Field, 2010), as well as in the maintenance of social relationships (Field, Diego, & Hernandez-Reif, 2010). Studies in this area have made important strides in our understanding of the benefits associated with touch and massage for human infants (Field, 2019; Field, 2010) , as well as the mechanisms and functions associated to touch stimulation, in adults and in infants (Stack & Jean, 2011).

Our knowledge about social touch has increased in significant ways in the past decades. However, because disciplines and research groups focus in various forms of touch, methods, measures, and clinical vs. normative samples, without an integrated perspective (Field, 2019), there is still a lack of understanding and definition of the social touch construct (Gliga, Farroni, & Cascio, 2018). One broad division can be made between behavioral studies, concerned with examining the characteristics and functional role of a dyad's behavioral stream of touch, and neurophysiological studies, concerned with affective touch and a particular class of skin mechanoreceptors, the C-tactile-fibers (CTs).

CT fibers are present in hairy skin and are tuned preferentially to light pressure, slow and caress-like stroking, and to the human skin temperature (Olausson, Wessberg, Morrison, McGlone, & Vallbo, 2010; Ackerley et al., 2014). These aspects of touch tend to be present in affiliative interactions or affective touch exchange between individuals (Gallace & Spence, 2010), including mother and infant, and are linked with stimulus ("pleasantness"/"unpleasantness") valence encoding which have an important role in social interactions (Morrison et al., 2010). While the CT system has been tied to the neurophysiological substrate underlying affective touch, higher-order factors, such as the relationship between the dyad members, social context (Cascio et al., 2019) and the diversity of stimulus types and modes of delivery have also been found to play a role in the definition of touch as social (Gallace & Spence, 2010).

Behavioral work has paid more attention to the contextual factors contributing to social touch, in particular two questions: (1) the agent - i.e. "who" is delivering the touch and (2) the function - i.e. the tactile stimulation's intention (Cascio et al., 2019).

In the first topic, authors are interested in how humans respond to social touch delivered by different social partners. For example, Lew-Williams, Ferguson, Abu-Zhaya &

Seidl (2017) measured 7-month-old infants' ability to learn auditory tone sequences using a head-turn preference procedure. The condition where infants demonstrated sequence learning was when the experimenter provided redundant touch information, aligned with the auditory sequence (by tapping the infant on the elbows and knee using the same timing of the auditory sequence).

The second line of research on social touch concerns the functional role of a variety of interpersonal touch patterns and examines how the agent of touch (e.g. mother) uses tactile stimulation with different intentions (Cascio et al., 2019). Typically, mother's touch behavior is measured second-by-second using pre-defined inventories of different touch patterns; two representative systems are the Caregiver-Infant Touch Scale, CITS (Stack et al., 1996), and the Mother Touch Scale, MTS (Stepakoff, 1999; Stepakoff, Beebe, & Jaffe, 2000). These inventories are later clustered in global aggregate constructs, such as affectionate touch (or nurturing touch), playful touch (or stimulating touch), harsh negative touch (or intrusive touch) or caregiving touch (or utilitarian/instrumental touch), e.g. (Mantis, Mercuri, Stack, & Field, 2019; Reece, Ebstein, Cheng, Ng, & Schirmer, 2016; Ferber, Feldman, & Makhoul, 2008; Stepakoff et al., 2000). Behavioral work, in summary, points to social touch as a multi-dimensional phenomenon that includes various sub-types of touch and to the importance of context – i.e., frequency and type of mother's touch behaviors are influenced by the task at hand.

In contrast to the well-demonstrated importance of touch in infant development, the contribution of touch in context of mothers-infants interaction during early infancy remains relatively neglected and understudied (Field, 2010; Hertenstein, 2002; Stack, 2010), when compared to other distal forms of communication, such as gaze and facial affect (Mantis et al., 2012, Mantis et al., 2014). The majority of touch studies to date, in the first months of life, measured presence or absence of maternal touch and its impact on infant development (e.g. Underdown, Barlow, & Stewart-Brown, 2006; Hertenstein, Verkamp, Kerestes, & Holmes, 2006; Field, 1998; Field et al., 2010; Dieter, Field, Hernandez-Reif, Emory, & Redzepi, 2003); comparatively, less is known about interaction through touch within the context of caregiver-infant relationship, and consequently, about the qualitative aspects of touch or how often specific touch behaviors occur (Field, 2010). Several studies have shown that the type of touch matters, and different touch types are connected to distinct outcomes in the caregiver and in the infant (Stack & Muir, 1992; Keren, Feldman, Eidelman, Sirota & Lester, 2003, Beebe et al.

2010). For instance, Stack & Muir (1992) found that when mothers use affectionate touch (e.g. stroking, caring, tickling) more often than static touch (e.g. holding) this elicited more smiling and vocalizations from the infant. In another study, with mothers of premature infants, Keren et al. (2003) analysed the relation between mother-infant interaction quality and mother's narratives concerning the infant, the premature birth, and herself as a parent – measured by Clinical Interview for high-risk Parents of premature babies (CLIP). They found that maternal positive touch was predicted by positive representations of the maternal role, measured by a *Readiness for Motherhood* factor in CLIP, and was also associated with mother's abilitiy to adapt to her infant's needs. Maternal affectionate contact also predicts positive outcomes in the infant, namely perceptual-cognitive and motor development (Feldman et al., 2002). On the other hand, playful touch (such as tickling, lifting, moving arms or legs), has been associated to infant's social behavior reinforcement, increasing positive affect, eye contact, and activity level (Lowe et al., 2016; Moreno, Posada, & Goldyn, 2006; Egmose et al., (2018). In contrast, intrusive touch (such as poking, pulling, and scratching) has been associated with insecure attachment styles (Beebe et al., 2010) and with the infants exhibiting more negative affect and behavior (Peláez-Nogueras et al.,1996). Infants of depressed mothers (mothers who tend to touch less often or use more negative types of touch, e.g. rough tickling and poking), show more self-touch behaviors compared to infants of non-depressed mothers (Beebe et al., 2008; Herrera, Reissland, & Shepherd, 2004). Moreover, the use of different forms of touch by mothers is modulated by the infant's cues – touch, vocal, and level of engagement (Beebe et al., 2016) – and temperamental dispositions (Weiss et al., 2000). The quality and quantity of maternal touch patterns undergoes considerable changes during development; for example, Ferber et al. (2008) measured mother touch patterns in mother-infant interactions and found that the amount of maternal touch decreases during the first year of life. Jean, Stack, & Fogel (2009) replicated this finding; in a longitudinal study, the frequency and types of touch used by mothers changed with the infant's age and interaction context, suggesting that mothers adjust their touch patterns to the infant's social and physical developmental level. These findings point to mother's tactile patterns as an important factor in infant development and dyadic communication, with both mother and infant sensitive to the specificities of touch (Stack & Muir, 1992).

The number of studies that quantified mothers' use of different types of touch are, however, still limited (Stack, 2004; Field, 2010). Previous studies have mainly focused on early infancy, until 6 months of age (e.g. Jean, Stack, & Fogel, 2009; Peláez-Nogueras et al., 1996), or how different forms of touch change depending on the presence of a pathology in the mother or the infant (e.g. Beebe et al., 2008; Herrera, Reissland, & Shepherd, 2004; Polan & Ward, 1994; Feldman, Keren, Gross-Rozval, & Tyano, 2004).

Also, touch is typically measured in non-object-oriented play interactions (e.g. face-to-face) while, from 6 to 12 months of age, infants gradually increase the amount of time they spend playing with toys during social exchanges (Bakeman et al., 1990), becoming increasingly more object focused – the onset of active object exploration is a major developmental milestone in this period (Needham, 2009). Infants develop the ability to engage in joint attention during triadic interactions that involves them, an object, and another partner (Bertenthal & Boyer, 2015). Parents also follow infant development and shift in this period from the predominant use of tactile stimulation during play (e.g. tickling and rough-and-tumble) to other forms of play, such as object-mediated dyadic play (Crawley & Sherrod, 1984). The increase in parent-infant play repertoire (Williams, 2003) and the modulation of social touch by age (Crawley & Sherrod, 1984) suggests that parents adjust tactile behavior to a specific play task.

However, although current research has addressed the role of maternal touch patterns in non-object-oriented play interactions (e.g. face-to-face), less is known about mother's tactile behavior in context of object-oriented interactions. As such, our goal was to study maternal touch patterns in play tasks representative of mother-infant interactions at 12 months. We measured the detailed micro-level touch patterns of each mother during three mother-infant play interactions: free play with objects; free play without objects; and object play with a challenging object (above the infant's developmental level). Specifically, our study had three main objectives: 1) explore the effect of object vs. non-object oriented play tasks on the proportion of time mothers spent touching the infant; 2) explore how often each category of touch occurs depending on different play tasks; 3) analyze if maternal touch behavior is modulated by the demands of different play tasks, not only in terms of frequency of touch but also considering the types of touch used by the mother. We hypothesized that mothers will adjust the frequency of touch and the types of touch to the demands of the play task, touching more frequently and using a greater number and differentiated touch categories in the free play without objects task compared to the object exploration tasks.

3.3 Methods

3.3.1 Participants

The data reported here is part of a larger longitudinal research project studying affective touch processing that evaluated infants at three different stages: 7, 12, and 18 months (for a detailed description of the sample see Miguel, 2017). N = 59 mothers and their infants were initially recruited in parenting classes, social networks, and daycare centers in Braga, Portugal. In the present study we only examined data of infants at 12 months. All infants were typically developing infants with normal birth weight (> 2500g; two infants had slightly less birth weight: 2350g and 2440g) and no reported hearing problems or neurological conditions. For the analysis of the proportion of time mothers spent in touch events, n = 41 dyads were included (18 female infants, 23 male). Eighteen dyads were excluded due to not completing the task (n = 15) or having more than 25% of the video recording marked as uncodable and/or with an obstructed view of the mothers' hands (n = 3). The mother's mean age was 33.7 years (SE = 3.7); five were unemployed and thirty-three had attended college. The mean gestational period was 38.9 weeks (SE = 1.3) and in 23 dyads, the infant was the first child and in all the remaining 18, it was the second child. All mothers gave informed written consent before their participation in the study and agreement of the videotaping of the dyad structured social interaction, respecting their privacy and confidentiality for posterior use for research purposes i.e., coding of mother's touch patterns.

3.3.2 Procedure

Mother-infant dyads were videotaped for 15-min in a child-friendly room; a camera was placed in order to capture a side view of the dyad. Mother and infant sat on the floor on a soft carpet and mothers were asked to interact, as naturally as possible, with their infants in a structured social interaction, composed of three tasks, each lasting approximately 5 minutes, with a small pause in between.

The first task was (1) free play with objects – the dyad was requested to play freely using objects suitable to the infant's age, selected from Bayley-III and/or Griffiths 0-2; the second task was (2) free play without objects – the dyad was invited to play freely, as they usually do at home, without any objects; the last task was (3) challenging object play– mothers were asked to help their infant play with a difficult object, i.e. above the infant's developmental level (we used a shape sorter toy). In the free play without objects task the most frequent orientation was face-to-face, but sometimes the infant could be facing with his back towards the mother (e.g. when the mother placed the infants on her lap).

The experimenter provided only general instructions about the play tasks and never mentioned the use of touch; mothers were free to interact with their infants and with the objects without restrictions. In the first two tasks the instructions were simply to play as you would at home; in the third task, the experimenter directed the mother to help the infant play with the toy, using a short and generic instruction.

The toys used in the free play with objects task were selected to be age appropriate: bear, bell, doll, mirror, story book, blanket, cup, spoon, ball, ring, pegboard, ring with string, and squeeze toy. In the challenging toy task, a shape sorter was used. The objects were only visible to the infant in the respective task.

To ensure that the infant was in an alert state and more available to perform the tasks, the laboratory visit was scheduled to fit the infant's eating and sleeping patterns. Before every task, the experimenter entered the room, provided general instructions and placed or removed the objects from the floor according to the task; the period when the investigator was in the room was disregarded in the analysis of mothers' touch patterns. Finally, before the first task, the mother was informed that they could stop the interaction at any time if they considered the infant was uncomfortable or tired due to excessive fretting or crying.

3.3.3. Coding of Mother's Touch Behavior

Social touch in mother-child interactions was coded using an adapted version of Beebe and colleagues' Mother Touch Scale. The original Mother Touch Scale (Stepakoff, 1999; Stepakoff et al., 2000) is composed of twenty-one detailed types of touch behaviors coded in five locations in the infants' body and in two levels of intensity. Type, location, and intensity are further aggregated in an ordinalized scale composed of 11 categories, ordered from the most affectionate to the most intrusive as follows: 1) Affectionate Touch; 2) Static Touch; 3) Playful Touch; 4) No touch; 5) Caregiving; 6) Jiggle/Bounce; 7) Oral Touch; 8) Object Mediated; 9) Centripetal Touch; 10) Rough Touch and 11) High intensity Touch. This scale was designed to measure how mothers touch their infants using the face or the hands. The No touch category is included here for convenience, when calculating relative frequency, and also because No touch is included in the ordinalized scale; the level for No touch separates the less intrusive touches (affectionate, static, and playful) from the more intrusive ones.

Since the original Mother Touch Scale was developed to code maternal touch in early infancy, we slightly adapted the criteria for maternal touch coding to fit the behavioral repertoire of 12-month-old infants (see the full details of this adapted version in supplemental Tables 1 and 2). The original Mother Touch scale was developed for measuring maternal touch patterns in face-to-face interactions with 4-month-olds; during the interaction, infants sat in a baby chair. In this context, maternal touch in the central areas of infant's body (face, trunk, head, neck) was considered more stimulating than touch on the peripherical areas of the infant's body (hands, arms, feet, legs). However, this distinction between center and periphery touch is not adequate for 12-month-olds. They have a higher range of motor autonomy for exploring the environment through movement (e.g. crawling, climbing, cruising and/or walking) comparatively to 4 months-old infants. Thus, at 12 months the touch in the center of infant's body (centripetal touch) is generally not used for stimulating purposes; it is used instead for repositioning the infant in the rug, supporting the infant, etc. As a result, we did not include the centripetal touch category in our adapted version of Mother Touch Scale. On the other hand, since our study includes two play tasks with objects, we added to Object-Mediated touch code events in which mothers used their touch to assist the infant to performing a task (e.g. mother's pick up the infant's hand and demonstrates the infant how to ring a bell).

Maternal touch patterns were coded using the ELAN version 4.9.4 software (Sloetjes & Wittenburg, 2008). Every maternal touch given with mother's hand or face, was coded using a microanalytic coding approach system: each individual touch event was segmented by coding onset frame (beginning of touch) and offset frame (end of touch); this was done for the entire interaction. Because multiple touches can happen simultaneously, we segmented the maternal touch events in three separate tiers: one for hand touches, a second for touches made with the face (e.g. kissing), and a third for when the mother was touching the infant with both hands but performing different touch types with each one. After segmentation, each touch event was categorized into one of twenty-two types of touch (see Supplemental Tables 1 and 2). We also coded periods of the interaction that were considered *uncodable* due to camera errors or a position that obstructed the view of the mothers' hands. Our final dataset consisted of 4393 individual touch events.

Following the Mother Touch Scale, touch types were later clustered in nine touch categories: 1) Affectionate Touch; 2) Static Touch; 3) Playful Touch; 4) No touch; 5) Caregiving; 6) Jiggle/Bounce; 7) Oral Touch; 8) Object Mediated; 9) Rough Touch. High Intensity Touch was excluded due to low frequency (0% in total).

To establish inter-rater reliability, a second trained person coded in 50% of our sample 25% of each play task per dyad. Kappa was calculated using ELAN version 4.9.4 (Holle & Rein, 2013) and inter-rater reliability between coders was high (k = 0.82).

3.3.4. Analysis of the Proportion of Time Mothers Spent in Touch Events

The dependent variable was proportion of interaction time per touch category and this data was modeled by fitting proportion of time mothers spent touching the infant with a 3 *(Play Task*: *Free Play With Objects, Free Play Without Objects, Challenging Object Play*) x 8 (*OMTS Category*) general linear model, where *Play Task* and *OMTS Category* were within-subjects factors. The *OMTS Category* factor in the model did not include the proportion of No Touch. The degrees of freedom were Greenhouse-Geisser corrected due to violations of sphericity; post-hoc pairwise comparisons were adjusted for multiple comparisons using Sidak's method and all p's < .05 unless otherwise stated.

3.4 Results

3.4.1. Analysis of the Proportion of Time Mothers Spent in Touch Events

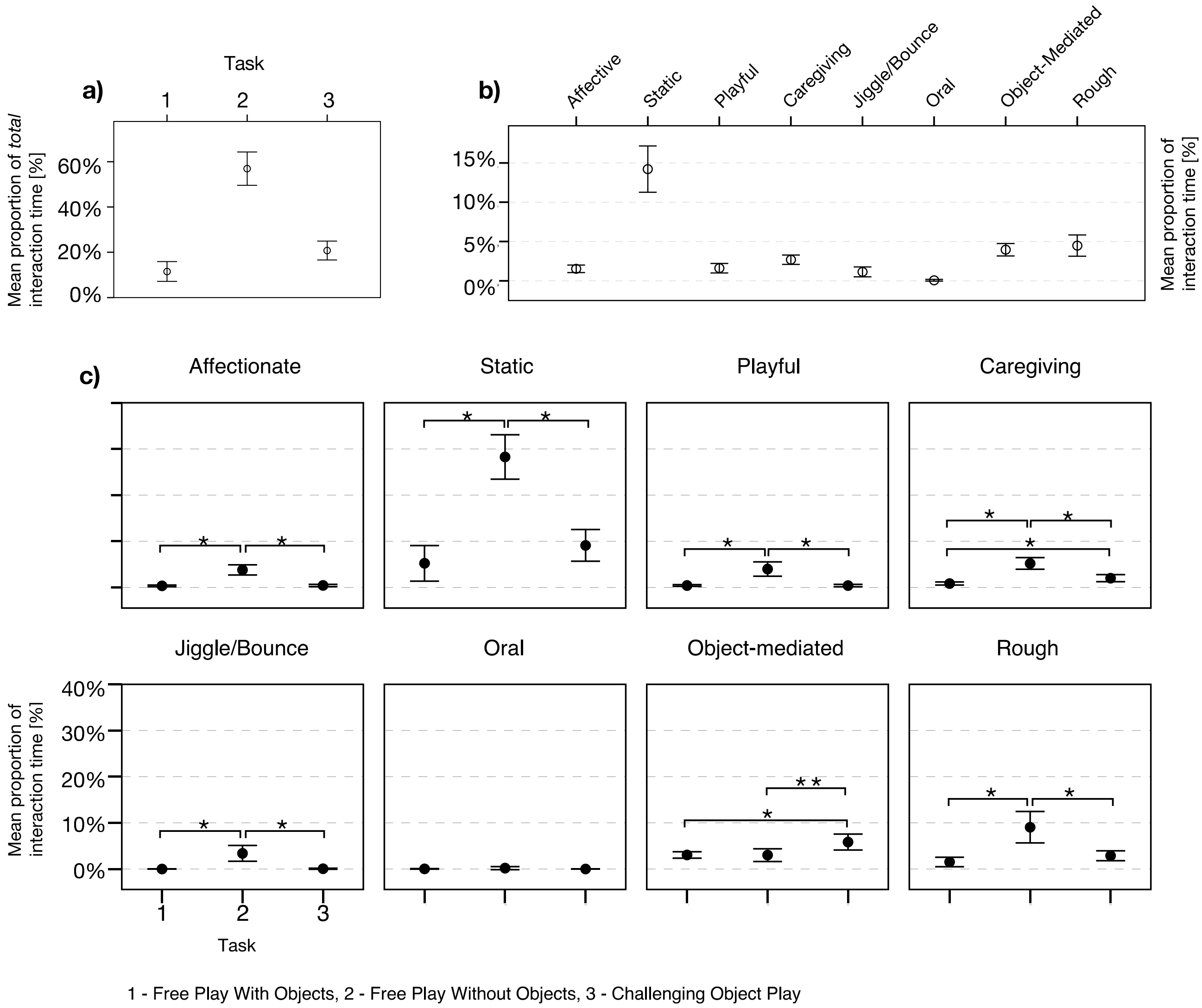
In the main analysis we examined if the type of play task had an effect on the mother's use of different touch categories, as measured by the Ordinalized Mother Touch Scale Category (OMTS).

Both main-effects and the two-way interaction were significant (p < .01); see Figure 3 b) and Figure 3 c). Regarding the significant main effect of *Play Task*, $F(2, 80)$ = 97.08, mothers used touch significantly more often in the non-object oriented task than in the object-oriented tasks; overall, the average *total* proportion of time touching was 71% for *Free Play Without Objects* vs. 14% and 26% for *Free Play With Objects* and *Challenging Object Play* respectively, see Figure 3 a). In addition, mothers also touched significantly more in the *Challenging Object Play* episode than in the *Free Play With Objects* episode. The effect of *Play Task*, and the variability of mother's behavior, are apparent in Supplemental Figures 1 and 2. Supplemental Figure 1 shows, by *individual* dyad, mother's touch events per level of the OMTS, expressed as proportion of total interaction time; Supplemental Figure 2 shows a micro-level view of the entire dataset of touch events.

Figure 3

Mean Proportion of Time Spent in Touch by Task and Touch Category

a*) Mean total proportion of time the mother was touching the infant, per task (± 2 SE).* ***b)*** *Mean proportion of time the mother was touching the infant, per touch category in the OMTS (± 2 SE).* ***c)*** *Mean proportion of interaction time where the mother was touching the infant, per OMTS Category and per task (1 - Free Play With Objects, 2 - Free Play Without Objects, 3 - Challenging Object Play). To assist visualization, the No Touch category is not shown. * p<.01, ** p<.05, post-hoc pairwise-comparisons corrected using Sidak method.*



Post-hoc analysis of the *OMTS Category* main effect, *F*(2.16, 86.26) = 53.20 revealed that mothers used different touch categories: mothers spent more time using *Static Touch* (M = 14.1%, SE = 1.4%), followed by *Rough Touch* (M = 4.5%, SE = 0.8%), *Object Mediated Touch* (M = 3.9%, SE = 0.4%), *Caregiving Touch* (M = 2.7%, SE = 0.3%), *Playful* (M = 1.6%, SE = 0.3%), *Affectionate Touch* (M = 1.5%, SE = 0.2%), *Oral Touch* (M = 0.1%, SE = 0.1%) and *Jiggle/Bounce Touch* (M = 1.1%, SE = 0.3%). Moreover, the *Static Touch* was used significantly more than the other types of touch, and *Oral touch* significantly less.

Finally, the 2-way interaction was significant, *F*(3.98, 159.16) = 26.53, $p < 0.01$ and post-hoc comparisons indicated that this interaction was explained in great part by the use of *Static Touch* category in the *Free Play Without Objects* task. Moreover, mothers spent significantly more time using *Affectionate*, *Static*, *Playful*, *Caregiving*, *Jiggle/Bounce* and *Rough* touches in *Free Play Without Objects* interaction than in the other two object-oriented tasks. In the *Challenging Object Play* task, mothers used significantly more *Object-Mediated* touch in comparison with the other tasks. Mothers also used significantly more *Caregiving* Touch in the *Challenging Object Play* task comparably to the *Free Play With Objects* episode. No significant differences across play task were observed for *Oral Touch.* These findings are illustrated in Figure 3 c), which shows the mean proportion of interaction time mothers spent touching their infants per category of OMTS.

3.5 Discussion

Touch is an important aspect of mother-infant interaction (Hertenstein, 2002), providing a unique context for healthy physiological, cognitive, and social development (Field, 2010; Stack, 2010). Touch also benefits mothers: promotes adaptation to their mothering role, increases mother's positive affect, and decreases mother's depression (Tessier et al., 1998; Feldman et al., 2002; Keren et al., 2003). Touch is a complex, dynamic and multidimensional system (Hertenstein, 2002), and the relevance of social touch in infancy goes well beyond its mere presence/absence (Stack, 2004). It is important that we expand our knowledge about the qualitative aspects of touching and how often – specific – touch behaviors occur (Field, 2010). Here, we measured mothers' use of touch, when interacting with their typically developing 12-month-olds, using a modified version of the Ordinalized Mother Touch Scale – this scale orders types of touch from more intrusive to more affective (Stepakoff, 2000); we also examined how mothers adapted touch behavior to the demands of three play tasks, representative of an infant's everyday life: free play with toys, free play without toys, and challenging object play. There were two main findings: (1) frequency of mother's touch varied greatly depending on the play task; and (2) mothers used different types of touch depending on the play task. We discussed each one next.

3.5.1 Mother's Touch is Prevalent in Dyadic Interactions and Lowered in Triadic Object Play but Mothers Adjust Touch to Task Difficulty

The play task was found to influence how often mothers use any type of touch during the interaction. This suggests that object presence or absence and play task complexity shaped the amount of touch provided by mothers in different play contexts. Specifically, mothers touched considerably less in both triadic object play tasks (on average 14% and 26% of the interaction time, for free play with objects and challenging object play, respectively) compared with the dyadic interaction in the free play without toys task (i.e. on average 71% of the interaction period). The high level of touch behavior in the free play without toys task is in the range of previously reported values, underscoring how touch is a prevalent mode of communication (Stack, 2004): in studies of mother-infant social exchanges, mother's touch relative frequency ranges from 33% to 81% of interaction time (Hertenstein, 2002; Stack & Muir, 1990; 1992; Jean et al., 2009).

A novel finding from our study concerns the comparison between the two triadic play tasks; we found that in the challenging toy task, mothers used touch almost twice as much when compared with the free play with objects task. In the more difficult task, mothers were asked to help the infant place pieces inside a shape sorter toy; this toy was purposely selected to be above the infant's developmental level, e.g. only 24-month-olds are capable of spatially orienting a shape for insertion into a slot (Smith et al., 2014; Street et al., 2011). Consequently, mothers may have used touch more frequently in the challenging play task, to help the infant successfully perform the task. Considering the difficulty of the shape sorter, infants could not succeed on their own; touch would thus keep the infant attentive and involved in the task, decreasing the likelihood of infant's disengagement from it. Some studies found that adult touch is able to elicit and maintain infant's visual attention in the still-face procedure (Stack & Muir, 1992), for example; however, little is known about the role of touch in the infant's attentional span in the context of mother-infants play interactions. In contrast, the free play with toys task was age-appropriate, which implied that infants had greater autonomy exploring objects visually and by active manipulation, requiring less support of mother's touch to fulfil the task.

In summary, our study adds novel evidence showing that mothers modulate touch behavior in a manner consistent with sustaining the level of infant engagement in a difficult task. Differences in touch frequency reflect mothers' attunement to the infant's developmental needs and the interaction context (Jean et al., 2009).

3.5.2 Mother's Use of Different Types of Touch Varies with Tasks Demands

Similar to previous studies (e.g. Ferber et al., 2008; Jean & Stack, 2009), we found that not only mothers' touch frequency but also diversity varies across interaction context, in our case, three different play tasks. Touch was more diverse – i.e. mothers used more categories of the Ordinalized Mother Touch Scale – during the free play without toys task compared with the two triadic object-oriented tasks. Again, this shows that mothers adjust touch behavior to the infant's needs and the interactional context demands (e.g. Jean & Stack, 2009, 2012; Moreno et al., 2006). Mothers touched the infant more often in the dyadic task using specific categories: static, playful, caregiving, affectionate, jiggle/bounce, and rough touch. We discuss next the potential functions of these different types of touch.

At 12-months, infants are able to explore the environment using a wide range of motor behaviors (e.g., crawling, standing, walking). Thus, the high levels of static touch in the free play without toys task may reflect the mother's need to provide physical support to the infant but also to impose boundaries on an increasingly mobile infant, with goal of maintaining the dyadic play interaction (e.g., by holding the infants on the arms or lap). The higher use of caregiving touch (typically for delivering care and repositioning the infant) also signals a sensitive maternal response that helps redirect and sustain the infant's attention to the play task; this is supported by studies of maternal sensitivity that found an association between caregiving touch and maternal sensitivity (Cordes et al., 2017). Rough touch is also used more frequently in the free play without toys task, indicative that mothers may use more intrusive types of touch (e.g., pull, push) for directly interrupting the infants' ongoing behavior and redirect attention to the play task.

In contrast with the dyadic task, in the triadic object-oriented play tasks, mothers have the objects themselves to stimulate and support infant engagement; this could decrease the need for tactile stimulation. Our analysis also revealed that mothers, in object-oriented play tasks, did not use affectionate and physical stimulating categories of touch (e.g., when compared to the free play without toys in particular, playful and jiggle/bounce touch categories had very low frequency). One possible explanation for this difference is, since mothers in the dyadic interaction were instructed to play with their infants without toys, as they did at home, they preferred touch behaviors that increased infant's positive affect. This hypothesis is congruent with several studies showing how affectionate and some types of stimulating touch are associated with infant's positive affect (e.g. Stack & Muir, 1992; Lowe et al., 2016; Egmose et al., 2018).

An additional novel finding of our study is the frequent use of object-mediated touch in the challenging object play task, when compared to other tasks; the object-mediated touch category includes all touch events where the mother assists the infant in performing an object-oriented behavior or uses an object to touch the infant. In effect, this is a more constrained version of the general finding that mothers adapt their tactile behavior to task complexity and infant's developmental level; mothers used more object-mediated touch in this task to help the infant succeed – e.g. by picking up infant's hand and helping infants fitting the pieces in the shape sorter toy – and, in this way, promoted the development of new skills, a clear example of scaffolding (Wood et al., 1976). As such, our study points to maternal touch behavior as not only essential for the quality of mother-infant relationship (Underdown, Barlow, & Stewart-Brown, 2004; Hertenstein, Verkamp, Kerestes, & Holmes, 2006), but also as a mechanism of parental scaffolding. We also found that mothers used more caregiving touch in the challenging object play when compared to free play with toys. These results may be explained by the discomfort, frustration and disengagement of the infant caused by the task's difficulty, i.e., the infant quickly lost interest and mothers repositioned them close to the toy, using caregiving touch, in order to keep the infant focused on the task. This is consistent with Egmose et al. (2018) findings: mothers were more likely to initiate caregiving touch then playful touch in response to infant's negative affect, suggesting that caregiving touch could be used as a way of decreasing infant's discomfort.

Further conclusions from the present study are, however, restricted by a few limitations: first, we reported data from a larger longitudinal social touch project, where task order was fixed (tasks increased from easiest to most stressful); second, we focused only on mother touch patterns without considering the reciprocal effect of infant's behavior in the different play situations; third, other maternal behaviors apart from the touch modality were not measured; fourth, in our study the diverse object-oriented touch behaviors were aggregated into the object-mediated touch category.

3.5.3 Conclusions

Taken together, our findings provide a number of important contributions to the literature focused on the role of social touch in development. To the best of our knowledge, the present study was the first to investigate how the amount of maternal touch stimulation was modulated by three naturalistic mother-infant play tasks. It was also the first to compare the impact of different play tasks in the use of different touch categories when mothers were interacting with their typically-developing 12-month-old infants.

Moreover, social touch is a fundamental element of caregiver-infant interactions and human development. Our findings contribute to expanding the knowledge about maternal tactile behavior, when interacting with one-year-olds, in contrast with the majority of studies that are focused in the first months of life (e.g. Jean, Stack, & Fogel, 2009; Stack & Muir, 1992; Lowe et al., 2016; Beebe et al., 2010). Additionally, our exploratory study added novel evidence regarding how mothers adjust their tactile behavior to different play contexts and use touch to support infant development – a motivation for studies that examine the moment-to-moment behavior of mother and infant, i.e. the occurrence of touch in context.

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3.7 Supplemental Materials

Supplemental Table 1

Coding criteria for the adapted Maternal Touch Scale (based from Stepakoff, 1999; Stepakoff et al., 2007)

Type of touch	Codes	Location
No touch	0	
Hold or gently squeezed, rest hand or palm on infant	01	Legs, feet, arms, hands
	22	Body, face, head, neck
Provide hand or finger for infant to hold	02	Legs, feet, arms, hands
		Body, face, head, neck
Stroke, caress	03	Legs, feet, arms, hands
	23	Body, face, head, neck
Tap (using one or more fingers), graze	04	Legs, feet, arms, hands
	24	Body, face, head, neck
Caregiving (e.g., reposition infant; wipe infant's mouth; adjust infant's clothing; etc.)	05	Legs, feet, arms, hands
	25	Body, face, head, neck
Kiss, nuzzle	06	Legs, feet, arms, hands
	26	Body, face, head, neck
Tickle	08	Legs, feet, arms, hands
	27	Body, face, head, neck
Rub (can be unidirectional or bidirectional, one finger or many)	9	Legs, feet, arms, hands
		Body, face, head, neck
Scratch	10	Legs, feet, arms, hands
		Body, face, head, neck
Flexion, extension, lift arms or legs, circling motions and similar large movements	11	Legs, feet, arms, hands
		Body, face, head, neck
Rock	12	Legs, feet, arms, hands
		Body, face, head, neck
Jiggle, bounce, shake, wiggle	13	Legs, feet, arms, hands
		Body, face, head, neck
Infant-directed oral touch (e.g., offer finger for infant to suck, put finger in infant's mouth, put infant's hand in infant's mouth, put infant's toes in infant's mouth)	14	Legs, feet, arms, hands
		Body, face, head, neck
Pull	15	Legs, feet, arms, hands
		Body, face, head, neck

Type of touch	Codes	Location
Push, inhibit/constrain movement, force or control infant's movement (e.g., force infant's foot into infant's face, force infant's hand down)	16	Legs, feet, arms, hands Body, face, head, neck
Pinch	17	Legs, feet, arms, hands Body, face, head, neck
Poke, jab	18	Legs, feet, arms, hands Body, face, head, neck
Object-mediated touch (e.g., waves cloth in infant's face, dangles toy on infant's chest, manipulates clothing non-caregiving purpose; mediates touch with a part of the infant's body, e.g. mother tap infant's hand against infant's face, mother help the infant playing with a toy)	19	Legs, feet, arms, hands Body, face, head, neck
Other (e.g., sniffs, chews, knocks with knuckles)	20	Legs, feet, arms, hands Body, face, head, neck
Pat (implies use of whole hand, if only with finger, code as "tap")	21 28	Legs, feet, arms, hands Body, face, head, neck
Uncodable (e.g., due to changes of position, camera errors, etc.)	99	

Note: These codes were used to construct an ordinalized mother's touch scale (see supplemental table 2)

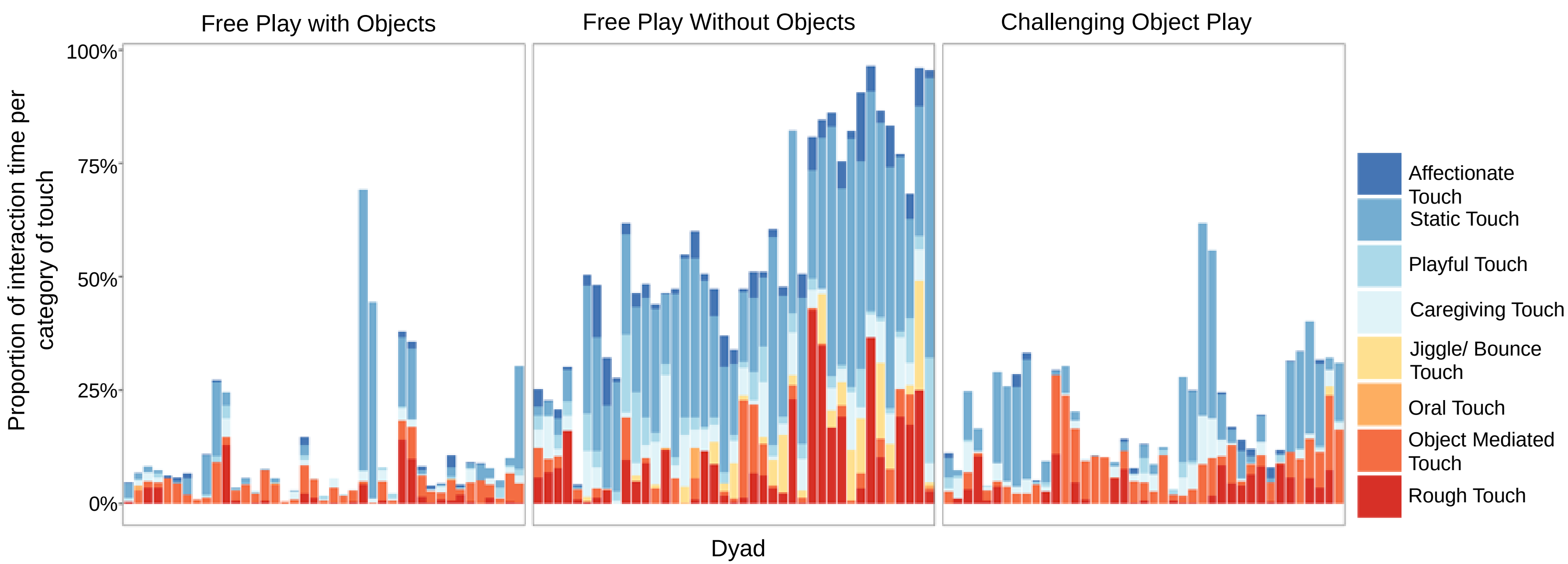
Supplemental Table 2

Coding criteria for Ordinalized Maternal Touch Scale: from affectionate to intrusive. Adapted from based from Stepakoff, 1999; Stepakoff et al., 2007.

Scale Category	Type of Touch
Affectionate Touch	(3 and 23) stroke, caress; (6 and 26) kiss, nuzzle; (21 and 28) pat
Static Touch	(1 and 22) hold; (2) provide hand or finger for infant to hold
Playful Touch	(4 and 24) tap; (8 and 27) tickle; (9) rub; (11) large movements with arms or legs
No Touch	(0) no touch
Caregiving	(5 and 25) caregiving
Jiggle / Bounce	(13) jiggle / bounce
Oral Touch	(14) infant-directed oral touch
Object Mediated	(19) object-mediated touch
Rough Touch	(10) scratch; (15) pull; (16) push; (17) pinch; (18) poke

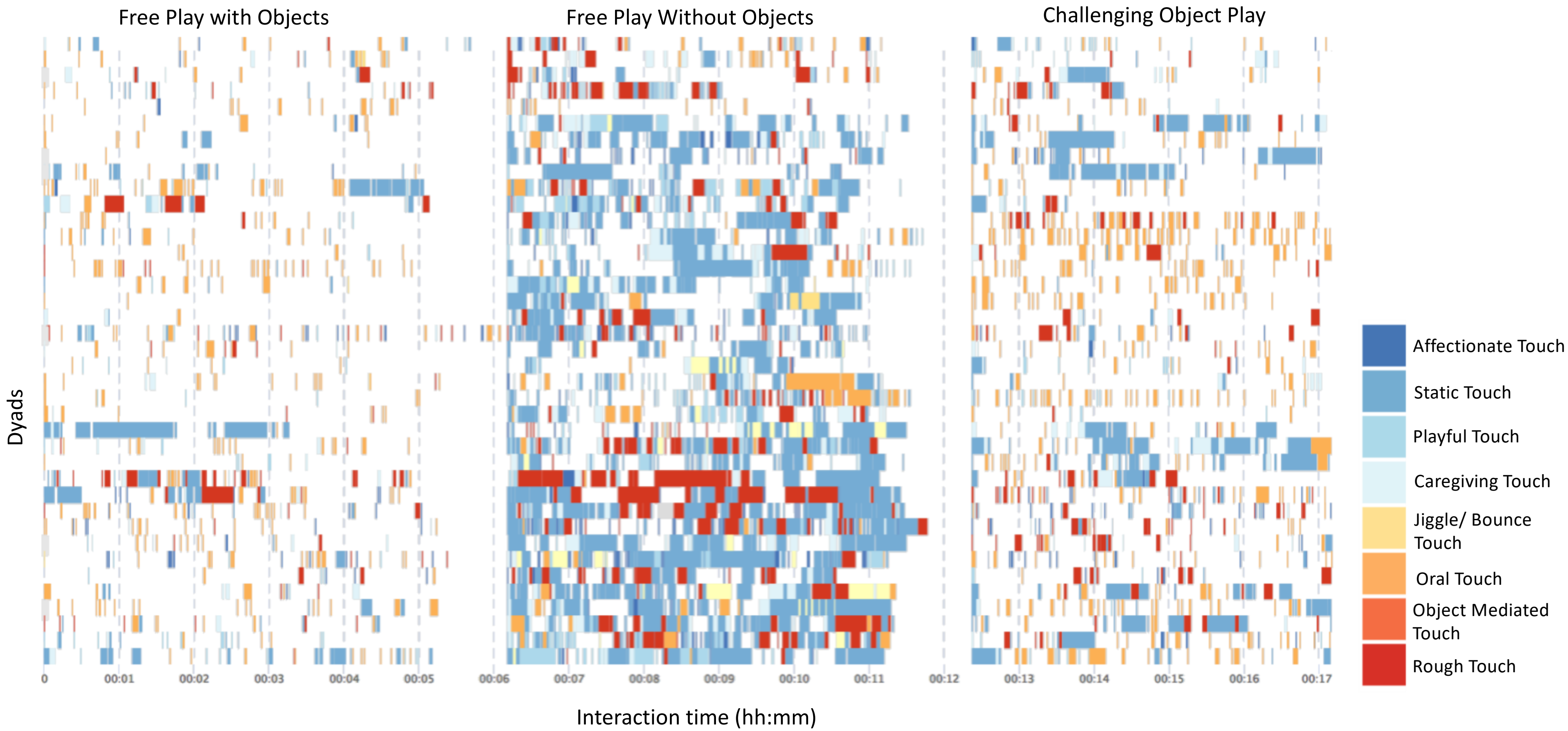
Supplemental Figure 1*:*

Proportion of interaction time where the mother was touching the infant, per dyad and per task (Free Play With Objects, Free Play Without Objects, Challenging Object Play). Touch was categorized using a modified version of the OMTS, Ordinalized Mother Touch Scale (see Stepakoff, 1999, Methods section, and supplemental Tables 1 and 2). Each vertical bar corresponds to one mother (across tasks, mothers maintain their ordinal position in the x-axis) and the horizontal ordering of mothers was calculated by applying hierarchical clustering (Ward's method) to the vector composed of proportion of interaction for OMTS category x Play Task. To assist visualization, the No Touch category is not shown.



Supplemental Figure 2

A visualization of the entire dataset of mother's touch events. Each horizontal line corresponds to one mother; each touch event's onset/offset and OMTS category is shown as a single block of color.



CHAPTER 4

Maternal touch in object and non-object-oriented play interactions: a longitudinal study at 7 and 12 months

CHAPTER 4

A version of Chapter 4 was submitted to the American Psychological Association peer-reviewed journal *Developmental Psychology.*

Reference:

Serra, J., Miguel, H., Araújo, F., Sampaio, A., & Pereira, A. F. (2023). *Maternal touch in object and non-object-oriented play interactions: a longitudinal study at 7 and 12 months.* [Manuscript submitted for publication]. School of Psychology, University of Minho.

CHAPTER 4

4.1 Abstract

Social touch is a crucial part of how mothers interact with their infants, with different touch types serving distinct purposes in these exchanges. However, there is still a limited understanding of how mothers' touch behavior adapts to specific interactive tasks, particularly throughout infancy. To address this gap, we observed mother-infant dyads at 7 and 12 months during three structured social play tasks: (1) play with objects, (2) play without objects, and (3) play with a difficult object. Using an adapted version of the Ordinalized Mother Touch Scale (OMTS Category), we categorized every touch performed by the mother.

The effect of the infant's age and play tasks on the proportion of time mothers touch their infants was evaluated using Bayesian beta mixed models, taking into account both the total quantity and the OMTS categories. Results showed that: (1) the frequency of maternal touch is prevalent in dyadic interactions and lowered in triadic object play; (2) the mothers used affectionate, static, and playful touch categories more often in dyadic play tasks; (3) in triadic play task mothers used object-mediated touch category more frequently; (4) the total frequency of maternal touch decreased across time; which was primarily due to a decrease in static and object-mediated touch.

Our findings add further evidence to the decrease of maternal touch from 7 to 12 months of age; suggesting that the developmental trajectory of maternal touch behavior is modulated by the infant’s evolving needs and the different challenges in object vs. non-object play tasks.

Keywords: Social touch; Mother-infant interactions; Infant’s development; Play tasks

4.2 Introduction

Social touch – broadly construed as tactile stimulation by a social partner – is an essential modality in the infant's early social life, playing an important role in the infant's social, emotional, and physical well-being, especially during the first year (Field, 2019). Social touch is prevalent during caregiver-infant interactions, with estimates ranging from 33% to 81% (Hertenstein, 2002; Stack & Muir, 1990, 1992), is an integral part of the inter-subjective space created by the partners, playing multiple functional roles (Cekaite & Mondada, 2021; Jean & Stack, 2009; Paradis & Koester, 2015). For example, social touch can be communicative (Hertenstein, 2002), i.e., it goes beyond the instrumental goals of caregiving. Nonetheless, compared with distal forms of communication, such as gaze or facial affect, social touch is relatively neglected and understudied, particularly in the context of mother-infant social interaction, a gap frequently noted by touch researchers (Field, 2010; Hertenstein, 2002; Stack, 2010). This is not the case for animal studies where the importance of specific caregiver touch behaviors is well-documented (Botero et al., 2020; Hertenstein, Verkamp, et al., 2006). Likewise, studies that examine how caregivers use touch in typical interactions, including object-oriented play tasks, are scarce (Serra et al., 2022).

4.2.1 Maternal Touch Patterns: Multiple Functional Roles and Developmental Outcomes

The existing research on touch has emphasized the importance of examining social touch, taking into account how often the mother uses touch (e.g., Underdown, Barlow, & Stewart-Brown, 2006; Hertenstein, Verkamp, Kerestes, & Holmes, 2006; Field, 1998; Field et al., 2010; Dieter, Field, Hernandez-Reif, Emory, & Redzepi, 2003), but also the qualitative aspects of touch: what are the multiple functional roles of social touch and how they are associated with developmental outcomes, in the moment or later in infancy or childhood (e.g., Stack, 2004; Hertenstein, 2002; Tronick, 1995).

Studies of maternal touch patterns have demonstrated how specific types of touch support the infant during the interactions or are associated with later developmental outcomes (Stack & Muir, 1992; Stack, LePage, Hains, & Muir, 1996; Keren, Feldman, Eidelman, Sirota & Lester, 2003, Beebe et al. 2010). For instance, Jean & Stack, (2009) found that mothers, in a still-face procedure with five-month-old infants and after the still-face period, increased the frequency of nurturing touch (e.g., stroking and caressing) when the infant exhibited high levels of distress. Findings from the still-face procedure are in line with other studies that report how mothers use affectionate/nurturing touch to relax and soothe their infants, reducing the level of infant distress (Moreno et al., 2006; Peláez-Nogueras et al., 1996; Jean & Stack, 2012; Jean et al., 2014) and promoting dyadic reciprocity (Ferber et al., 2008). Beyond the role of modulating negative emotions, maternal affectionate touch can also elicit positive ones. Peláez-Nogueras et al. (1997) examined how different types of touch influenced infants aged 2 to 4.5 months when they established eye contact with an experimenter. Specifically, they compared the effects of systematic affectionate touch (stroking), with the effects of stimulating touch types (tickling and poking). In both touch conditions, tactile stimulation was applied to the infants' body parts (legs, abdomen, and forearms) immediately after they initiated eye contact with the female experimenter. The study found that infants in the stroking condition tended to smile and vocalize more, while crying less, compared to infants in the tickling/poking condition. Moreover, Weiss et al., (2000) showed an association between maternal nurturing touch provided to low-birth-weight infants at 3 months during feeding and the level of attachment security measured when the infants were 12 months old. Nevertheless, the level of infant vulnerability, including perinatal complications, birth weight, and responsiveness, acted as a moderating factor in the influence of nurturing touch. In the case of vulnerable low-birth-weight infants, maternal nurturing touch exhibited an adverse correlation with attachment security. On the other hand, the frequency of nurturing touch has been shown to predict the security of attachment in robust low-birth-weight infants with minimal perinatal risks (Weiss et al., 2000). In another study, Weiss et al., (2001) found that higher levels of nurturing touch at 3 months predicted fewer internalizing problems (such as depression and anxiety) at 24 months of age.

Results showing the associations of touch and developmental outcomes go beyond the role of nurturing touch: for example, playful or stimulating touch (e.g., tickling, lifting, moving arms or legs) has been shown to reinforce the infant’s social behavior, increase positive affect, eye contact, and activity level (Lowe et al., 2016; Moreno, Posada, & Goldyn, 2006; Egmose et al., 2018). In accordance, Weiss et al. (2004) found that low-birth-weight infants, whose mothers use stimulating touch more frequently during the first three months of life, present better visual-motor and fine-motor skills at 12 months of age. In general, more frequent touch stimulation from mothers (such as massage, extending the infant’s arms and feet) is related to more advanced gross motor development in the infant, a finding well-demonstrated by cross-cultural studies (Adolph & Franchak, 2017; Adolph & Hoch, 2019).

Another significant functional aspect of touch involves providing care for infants – caregiving touch. This includes touch-related actions and behaviors that effectively enhance the infant's comfort, such as adjusting the infant's position on the carpet or wiping the infant's mouth. (Beebe et al., 2010; Stepakoff, 2000). Research conducted during the infant's first year of life, including both clinical and non-clinical samples, has underscored the significance of caregiving touch to the infant's development and well-being. An example from a recent study on mother-infant interactions, which examined mothers both with and without post-partum depression, and their interactions with their 4-month-old infants, revealed instances of caregiving touch were more likely to follow periods of the infant's negative affect (Egmose et al., 2018). In another study focused on post-partum depression, caregiving touch – unlike affectionate or static touch - was associated with higher maternal sensitivity, a relationship observed within both clinical and non-clinical groups (Cordes et al., 2017). In contrast, intrusive touch (such as poking, pulling, and scratching) has been associated with insecure attachment styles (Beebe et al., 2010) and with infants exhibiting more negative affect and behavior (Peláez-Nogueras et al., 1996; Weiss et al., 2001). Together, these results are consistent with the claims suggesting that social touch conveys specific information to infants (Tronick, 1995; Hertenstein, 2002) and that qualitatively different touch patterns may serve different functional purposes in parent-infant interactions (Beebe et al., 2010; Crucianelli et al., 2019; Hertenstein, 2002; Jean & Stack, 2009; Koester, 2000; Mantis et al., 2014; Paradis & Koester, 2015; Provenzi et al., 2020; Serra et al., 2020).

The frequency and types of maternal touch also undergo considerable shifts over the first year of life: the mothers adjust to touch the infant's age and to the requirements of the interactive situations (Ferber et al., 2008; Jean et al., 2009; Mercuri et al., 2023). Overall, with age, the amount of maternal touch decreases in non-object-oriented play tasks, such as face-to-face interactions (Ferber et al., 2008; Jean et al., 2009; Serra et al., 2020). Jean et al., (2009) observed infants engaging with their mothers in two settings (lap and floor) at ages 1 month, 3 months, and 5½ months and found that while holding the infants in their laps, mothers used patting and tapping touch more frequently at 1 month than at 5½-months-old. The authors also observed that mothers tickled their infants more frequently at 5½-months months than at 1 month and touched them more frequently at 1 month than at 3 months in the lap condition. On the other hand, in the floor condition, mothers used lifting movements more frequently at 1 month compared to older infants. Taken together, the previous findings point out that the mother's tactile patterns played an important role in mother-infant interactions, indicating that mothers are aware of the developmental and age-related needs of their infants and adapted their touch patterns to the specificities of the interactional context, again contributing for different functional and developmental roles of touch.

4.2.2 Maternal Touch Patterns: Multiple Interactional Contexts

However, the majority of studies assessing mothers' use of different types of touch examined only clinical populations when the infant was less than six months old (e.g., Beebe et al., 2008; Cordes et al., 2017; Ferber, 2004; Hardin et al., 2021; Jean & Stack, 2012; Provenzi et al., 2020; Stefana & Lavelli, 2017; Weiss et al., 2000). In addition, these studies are typically conducted in the setting of the still-face procedure or use face-to-face interactions - see Serra et al., (2022) for a recent review. As a result, less is known about how parental touch adjusts to other interactional contexts, such as object-oriented play tasks in the second half of the infant's first year of life. This is particularly relevant considering some of the major cognitive development milestones at this age, regarding object-oriented play: the gradual increase in the number of time infants spend playing with toys during social exchanges (Bakeman et al., 1990; Toyama, 2020; Williams, 2003) and the onset of active object exploration (Needham, 2009). By some estimates, at 12 months, infants spend more than half of their time interacting with objects at home (Schatz, Suarez-Rivera, Kaplan, Linn, & Tamis-LeMonda, 2020; Herzberg et al., 2020) and can engage in joint attention during triadic interactions that involve themselves, an object, and another partner (Bertenthal & Boyer, 2015). Parents also adjust their touch behavior accordingly, i.e., shifting from the predominant use of tactile stimulation during play (e.g., tickling and rough-and-tumble) to other forms of play, such as object-oriented dyadic play (Crawley & Sherrod, 1984; Williams, 2003). The growing interest and interaction that infants develop towards objects, the broadening of the parent-infant play repertoire (Williams, 2003) along with studies indicating that mothers adjust social touch by the infant's age and task requirements (Crawley & Sherrod, 1984; Jean et al., 2009; Mercuri et al., 2023; Serra et al., 2020), collectively emphasize touch as an additional facet of sensitive parenting. The adaptation of social touch to the infant's developmental needs and interests supports the infant in different play contexts, in particular, object-oriented play. The implication for touch research is that object-oriented play tasks are an important context in which to study developmental trajectories of mother touch behavior (in terms of distinct touch types and frequency), in particular during the second half of the first year of life, which is supported by recent studies.

Tanaka et al. (2021) examined the effect of maternal touching behavior (i.e., more physical contact or less physical contact) on object exploration in infants aged 6 to 8 months. They found that in the condition with more physical contact, the infants' time to first touch with an object was faster, and that object touch was sustained for longer. Furthermore, Longa et al., (2019) examined whether affective touch supported 4-month-old infants in processing and discriminating a novel face that did not establish direct eye contact. The study revealed that infants who received gentle strokes from their mothers during a habituation phase, as opposed to a brush touch or no touch, displayed prolonged gaze toward a new face during the paired choice test. These outcomes suggested that affective touch provided by a relevant partner may promote the infant's allocation of attentional resources to social cues, facilitating the learning of new social information.

Social touch (human contact) also increases visual attention to non-social stimuli in newborns. Babies held in the arms by a research assistant demonstrated more frequent glances toward non-social cues presented on a screen (black-and-white checkerboards); this was accompanied by heightened alertness, prolonged periods of engagement, and a stronger preference for novelty when contrasted with infants seated in an infant-seat without any human contact during the same task (Arditi et al., 2006). Similar outcomes were observed in studies involving non-human primates. Newborns that received additional physical contact, as opposed to a standard-reared control group, exhibited more explorative behavior toward novel contexts, objects, and social partners at 3 months (Simpson et al., 2019), as well as, higher levels of joint attention and cooperation skills by the end of the first year of life (Bard et al., 2014).

Despite the importance of social touch in infant cognitive development, there are very few studies that have documented how caregivers use touch in object-oriented play tasks. Research suggested that mothers engage in longer bouts of active affective touch (i.e., kisses, hugs, rubs) when interacting with their infants at 5 months compared to when they are 12 (Leiba, 2000). Furthermore, this study also found that the frequency of both active and passive (i.e., touching and maintaining close physical proximity) affectionate events seems to increase with age. Serra et al. (2020) observed that maternal touch behavior also varies across play tasks. Mothers, when asked to help their infant play with a toy above their infant's developmental level (i.e., a shape sorter), delivered more care, repositioned their infant more often in space (i.e., caregiving touch), and used more touching behaviors that assist the infant's interaction with objects (i.e., object-mediated touch) compared to standard free play with toys. However, no data is available on how mothers employ touch to facilitate interactions between infants and novel objects and how this process changes across development.

Therefore, our study aims to explore the variations in maternal touch during object and non-object-oriented tasks in 7 and 12-month-old infants. Additionally, we aim to explore whether differences exist in the trajectory of maternal touch (regarding frequency and the touch categories) across play tasks from 7 to 12 months. For this purpose, we segmented and categorized all individual maternal touch events, using an adaptation of the Maternal Touch Scale (Beebe et al., 2010; Serra et al., 2020; Stepakoff, 2000). Mother-infant dyads were observed in a structured social interaction task in a laboratory setting; mothers were asked to engage the infant in three developmentally relevant play tasks following an experimental design used in studies of parental sensitivity (Baptista et al., 2013; Martins et al., 2013): play with objects, play without objects, and object play with a difficult object (i.e., above the infant's developmental level). Thus, we included two triadic or object-oriented tasks, and one dyadic or non-object-oriented task (the play without objects task).

The present study had the following objectives: 1) analyze the effect of the play tasks on maternal touch behavior; 2) examine the frequency (as aggregate total and per type of touch) of maternal touch behaviors at 7 and 12 months; 3) compare the frequency and touch categories used by mothers, in both, object and non-object-oriented play tasks across age points.

4.3 Methods

4.3.1 Participants

The data used in this study is part of a larger longitudinal research project that examined infant's processing of affective touch (Miguel et al., 2019; Miguel et al., 2020); this project evaluated typically developing infants at three different time points: 7, 12, and 18 months (for a detailed description of the sample see Miguel, 2017). N = 59 mothers and their infants were initially recruited in parenting classes, social networks, and daycare centers in

Braga, Portugal. We examined the 7- and 12-month time points. Eight dyads at 7 months and sixteen dyads at 12 months were excluded, due to drop-out of the study, not completing the task, or having more than 25% of the video recording marked as uncodable, and/or with an obstructed view of the mothers' hands. The final sample consisted of 56 dyads, of which 38 participated in the study at both age points, while the remaining 18 dyads participated at only one age point. All infants were typically developing infants with normal birth weight (> 2500g; three infants had slightly less birth weight: 2350g, 2420g, 2440g) and no reported hearing problems or neurological conditions. For the analysis of the proportion of time mothers spent in touch events, n = 51 dyads (23 female infants, 28 male) at 7 months and n = 43 dyads (17 female infants, 26 male) at 12 months were included. The mother's total mean age was 33.3 years (SE = 4.1); forty-two had a college education and eight were unemployed. The mean gestational period was 38.9 weeks (SE = 1.3). In 34 dyads, the infant was the first child; in the remaining 22, it was the second or third child. The study protocol was reviewed and approved by the University of Minho Ethics Committee. Mothers filled out a written consent and an agreement of the videotaping of the dyad structured social interaction before they participated in the study, respecting their privacy and confidentiality for posterior use for research purposes i.e., coding of mother's touch patterns.

4.3.2 Procedure

In a child-friendly room, the mother and infant sat on the floor, on a soft carpet; mothers were instructed to engage the infant in a structured social interaction. The dyads were videotaped with a camera set up to record a side view of the pair. The structured social interaction consisted of three play tasks with a fixed order and a brief break in between each task. Each task (three per interaction x 2 age points) lasted approximately 3 minutes when the infant was 7 months of age and 5 minutes when the infant was 12 months of age.

In the first task, (1) play with objects – the dyad was requested to play freely using objects suitable to the infant's age, selected from Bayley-III and/or Griffiths 0-2 (different sets of objects were used at the 7 and 12-months timepoints); in the second task, (2) play without objects – the dyad was invited to play freely, as they usually do at home, without any objects; in the last task (3) difficult object play– mothers were asked to assist their infant in playing with one or two difficult objects, i.e., toy(s) clearly above the infant's developmental level.

Before each task, the experimenter gave general instructions about the play tasks, and the use of touch was never mentioned. Mothers were free to interact with their infants and with the objects without restrictions. In the first and second task, mothers were asked to play with their infants as they would at home; in the third task, the experimenter instructed the mother to help the infant play with the toys, using short and generic instructions. The second task was labeled as play without objects (or non-object-oriented task), instead of face-to-face interaction, because mothers were free to choose how to place themselves and the infant in the space; most of the time the dyad was in a face-to-face orientation but occasionally the arrangement could be different such as when the mother placed the infant on her lap.

To ensure that the infant was in an alert state and more available to perform the tasks, the laboratory visit was scheduled to fit the infant's eating and sleeping patterns. Before every task, the experimenter entered the room, provided general instructions, and placed or removed the objects from the floor according to the task; the period when the investigator was in the room was disregarded in the mothers' touch patterns analysis. Finally, before the first task, the mother was informed that they could stop the interaction at any time if they considered the infant uncomfortable or tired due to excessive fretting or crying.

Finally, regarding the toys offered to the dyad in the free play with objects task, they were a set of age-appropriate toys. We provided the dyad the following objects: at 7 months - bear, bell, doll, mirror, storybook, cup, spoon, a ring with string, set of cubes, and rattle; at 12 months - bear, bell, doll, mirror, storybook, cup, spoon, ball, a ring with string, pegboard, blanket, and a squeeze toy.

In the difficult object play task, the selected toys were above what a typically developing infant can do without any assistance: at 7 months of age, the dyad was provided with a soft baby ball with a rattling sound and a squeeze toy, while at 12 months a shape sorter was provided. The objects were only visible to the infant in the respective task.

4.3.3 Adapted Ordinalized Maternal Touch Scale (OMTS)

Social touch in mother-infant interactions was coded using an adapted version of Beebe and colleagues' Maternal Touch Scale (for more details see Serra et al., 2020). The original Maternal Touch Scale (Beebe et al., 2010; Stepakoff, 1999; Stepakoff et al., 2000) is composed of 21 detailed types of touch behaviors; this set of 21 codes includes five locations in the infants' body and two levels of intensity (mild/moderate and high). In a second step, the set of 21 touch behaviors is aggregated into an ordinal variable labeled OMTS (Ordinalized Maternal Touch Scale); OMTS is composed of 11 categories, ordered from the most affectionate to the most intrusive as follows: 1) Affectionate Touch; 2) Static Touch; 3) Playful Touch; 4) No Touch; 5) Caregiving; 6) Jiggle/Bounce; 7) Oral Touch; 8) Object Mediated; 9) Centripetal Touch; 10) Rough Touch and 11) High-intensity Touch. The No Touch category is included because of it is part of the original scale, where its position in the ordinal variable separates the less intrusive touches (affectionate, static, and playful) from the more intrusive ones; it is also a convenient term when calculating relative frequency.

Since the original Maternal Touch Scale was developed to code maternal touch earlier in infancy, we adapted the criteria for maternal touch coding to fit the behavioral repertoire of 7 and 12-month-old infants (see the full details of this adapted version in Serra et al., 2020). The original Maternal Touch scale was developed to measure maternal touch patterns in face-to-face interactions with 4-month-olds; infants sat in a baby chair during the interaction. In this context, maternal touch in the central areas of the infant's body (face, trunk, head, neck) was considered more stimulating than touch on the peripherical areas of the infant's body (hands, arms, feet, legs). However, this distinction between center and periphery touch is not adequate for 7 and 12-month-olds. They have a higher range of motor autonomy for exploring the environment (e.g., sitting without support, crawling, climbing, cruising, and/or walking) compared to 4 months-old infants. Thus, at 7 and 12 months the touch in the center of the infant's body (centripetal touch) is generally not used for stimulating purposes; it is used instead for repositioning the infant in the rug, supporting the infant, etc. As a result, we did not include the centripetal touch category in our adapted version of the Maternal Touch Scale. On the other hand, since our study includes two play tasks with objects, we added to the Object-Mediated category touch to code events in which mothers used their touch to assist the infant in performing a task (e.g., the mother picks up the infant's hand and demonstrates the infant how to ring a bell) – for more details see Serra et al., (2020).

4.3.4. Coding of Mother's Touch Behavior

Maternal touch patterns were coded using the ELAN version 4.9.4 software (Sloetjes & Wittenburg, 2008). Every maternal touch given with the mother's hand or face was coded using a microanalytic coding approach system: each touch event was segmented by coding onset frame (beginning of touch) and offset frame (end of touch); this was performed for the entire interaction. Because multiple touches can happen simultaneously, we segmented the maternal touch events into three separate tiers: one for hand touches, a second for touches made with the face (e.g., kissing), and a third for when the mother was touching the infant with both hands but performing different touch types with each one. After segmentation, each touch event was categorized into one of the twenty-two types of touch in the Maternal Touch Scale. We also coded periods of the interaction that were considered *uncodable* due to camera errors or a position that obstructed the view of the mothers' hands. To establish inter-rater reliability, a second trained person coded 50% of the dyads, and 25% of each play task per dyad. Kappa was calculated using ELAN version 4.9.4 (Holle & Rein, 2013), and inter-rater reliability between coders was high (k = 0.87). Our final dataset consisted of 8885 individual touch events.

Touch types were then aggregated into the categories used in our adapted OMTS. The High-Intensity Touch category was excluded from the analysis because there were zero events in the dataset. The categories Jiggle/Bounce and Oral Touch had very low frequency, with only 12 and 120 occurrences respectively out of a total of 8885 events, and we also excluded them from the final analysis. In summary, the full analysis included the following categories (labeled with the same numerical identifier as in the original OMTS): 1) Affectionate Touch; 2) Static Touch; 3) Playful Touch; 4) No Touch; 5) Caregiving; 8) Object Mediated; 10) Rough Touch.

4.3.5 Modeling of Proportion of Interaction Time with Maternal Touch

The main analysis consisted of modeling the mean proportion of interaction time with maternal touch. This was performed in two ways: first, using the mean total proportion of interaction time with maternal touch as the dependent variable (i.e., ignoring the OMTS touch category and adding the duration of all touch events into a total proportion of interaction time with maternal touch), and age and play task were predictors; second, modeling the mean proportion of interaction time with maternal touch as the dependent variable, with age, play task, and OMTS touch category as predictors. We selected a model for each of the two dependent variables using a model comparison approach.

Both response variables, the proportion of total interaction time with maternal touch, and the proportion of interaction time with maternal touch (that takes into consideration the OMTS category) were not normally distributed. They are continuous proportions, restricted to the interval [0, 1]; moreover, in the case of the proportion of time touching per OMTS category, there were several cases of zero in the proportion (e.g., a mother had zero touch events of rough touch or affectionate touch). An adequate model for this type of dependent variable is beta regression, which uses a beta-distributed response variable – see a recent review and tutorial in (Douma & Weedon, 2019).

For the first model, we have used a beta regression model. The random effects component included a random intercept for each participant. For the second model, due to the highly left-skewed distribution with many zeros (see Supplemental Figure 3), the response variable was fitted using Bayesian zero-inflated beta regression models, with a phi model to allow for differences in dispersion between touch categories (Douma & Weedon, 2019). Because the beta distribution is only defined in the interval]0, 1[, a zero-inflated model combines a Bernoulli process and a beta model. The Bernoulli process models the presence vs. absence of touch (the zero-inflated part), while the beta regression models the non-zero continuous proportion. There is also a third part, which is an explicit model of the variance, the phi model. A description of these three model components can be found in Douma & Weedon, (2019). This was included due to the large differences in dispersion evident in the sample distribution visualization - see Supplemental Figure 3. The random effects component included a random intercept for each participant. Data at the 12-month age point was previously reported in Serra et al. (2020) but the statistical analysis approach used was distinct.

Models were estimated using the *brms* package (Bürkner, 2017, 2018, 2021) that automatically translates models in R to models in the Stan framework using the *rstan* package (Stan Development Team, 2021). Development was conducted in RStudio version 1.4.1717 (RStudio Team 2021). A Normal distribution, N ~ (0, 1E-10), was used as an approximation to a flat prior in both models. All multilevel models were estimated using the No-U-Turn Sampler. This uses an algorithm that converges much quicker than alternatives, in particular for high-dimensional models, such as multilevel models with random effects (Bürkner, 2017). Four Markov chains were used, each with 50000 iterations, 25000 warmup iterations, and a thinning rate of 1. All models revealed proper convergence of the MCMC chains, according to the Gelman–Rubin $\hat{r}$ statistic ($\hat{r}$ =1.00). The effective sample size (ESS) ranged between 38955 and 151630 suggesting stable parameters estimates of limits of highest-density intervals – HDIs, far above the recommended ESS ≥ 10,000 (Kruschke, 2014; Kruschke, 2021). Model fit was confirmed through posterior predictive checks and leave-one-out (loo) cross-validation information criteria (LOOIC). LOOIC is a generalization of the Akaike Information Criterion (AIC). Compared to AIC, LOOIC does not require large sample sizes and is more suitable for models with non-Gaussian distributions, such as the beta model and the zero-inflated beta model used in this study (Vehtari et al., 2017). More details about model comparison and the best-fit model are presented in the results section. All selected models showed an overall good fit to the data. Pairwise comparisons were made using the *emmeans* package (Lenth, 2022). When reporting estimated means, and respective credible intervals, we back-transformed the data to the original units (the beta regression generalized linear mixed models used the logit link function).

4.4 Results

The main analysis consisted of modeling two response variables: (1) the proportion of total interaction time with maternal touch, computed by adding the duration of all touch events for a total of interaction time with maternal touch present; and (2) the proportion of interaction time with maternal touch. For the first, the predictors were age and play task; in the second, the predictors were age, play task, and OMTS category. Models were selected using a model comparison approach. The results of each model are presented in the following sections.

4.4.1 Proportion of Total Interaction Time with Maternal Touch

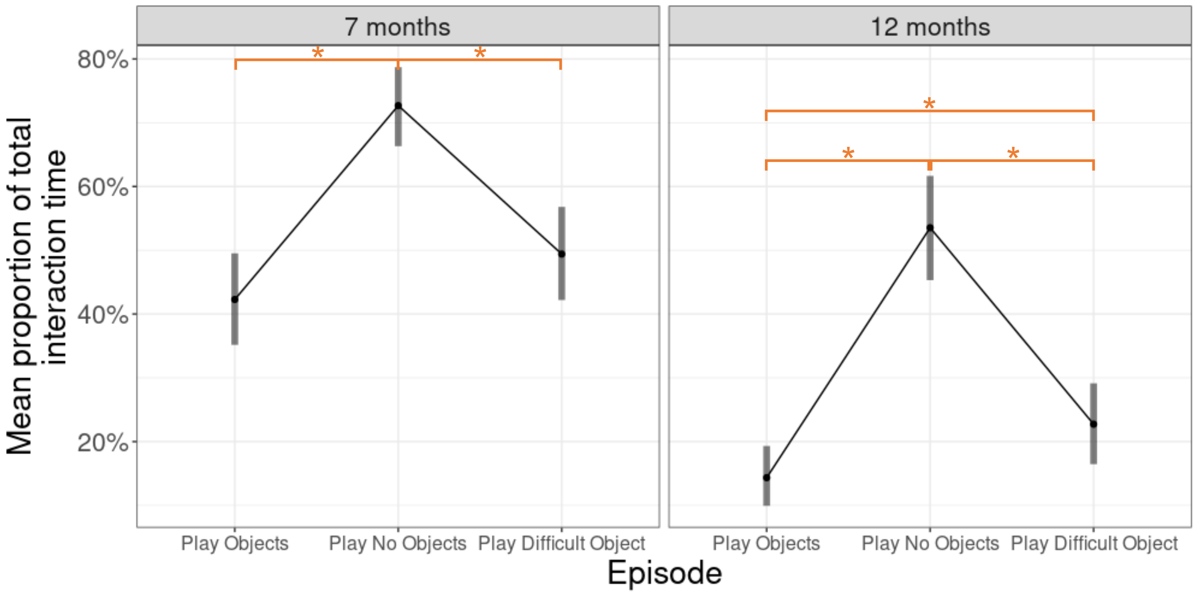
To test how well the infant's age and the play task predicted the mother's total amount of touch, we modeled the mean of the total proportion of interaction time with maternal touch using a Bayesian generalized linear mixed model, with a beta-distributed response variable, and potential predictors the infant's age (7 and 12 months), and the play task (play with objects, play without objects, difficult object play). The most parsimonious model was selected using the better predictive accuracy measure (lower LOOIC); the order of comparison was null model, age, play task, age and play task without interaction, and two-way interaction of age and play task. All models included a random intercept per dyad. According to the model comparisons, the model that included the main effects and the 2-way interaction was the best-fit model (see Supplemental Table 3 with the results of the LOOIC; model diagnostics for the selected model are in Supplemental Figure 6 and Supplemental Figure 7, and parameter estimates in Supplemental Table 4).

We examined the 2-way interaction of age and play task in the dependent variable using two comparison approaches: (1) per play task, holding age constant (see Figure 4); and (2) across age point, holding play task constant (see Figure 5).

Regarding the first approach, we found that when the infant was 7 months of age, mothers touched much more in the dyadic play without objects task (72.3%) than in the triadic play tasks (42.3% in the play with objects episode vs. 49.4% in the difficult object play episode); these comparisons correspond to a log odds ratios of 0.28 and 2.77, respectively (95% CI 0.18-0.38 vs. 1.83-3.76). Mothers continued to exhibit the same pattern when the infant was 12 months of age, touching significantly more during the play without objects (53.5%) than during either object-oriented play tasks (14.5% vs 22.8%); log odds ratios of, respectively, 0.28 (95% CI 0.09-0.22) and 2.77 (95% CI 2.44-5.75). Finally, concerning the two object-oriented tasks, mothers touched more when playing with the infant using a difficult object (22.8%) than when playing with developmentally appropriate objects (14.5%), the log odds ratio was 0.58 (95% CI 0.34-0.84).

Figure 4

Estimated Mean of the Total Proportion of Interaction Time with Maternal Touch, per Play Task, Holding Age Constant.

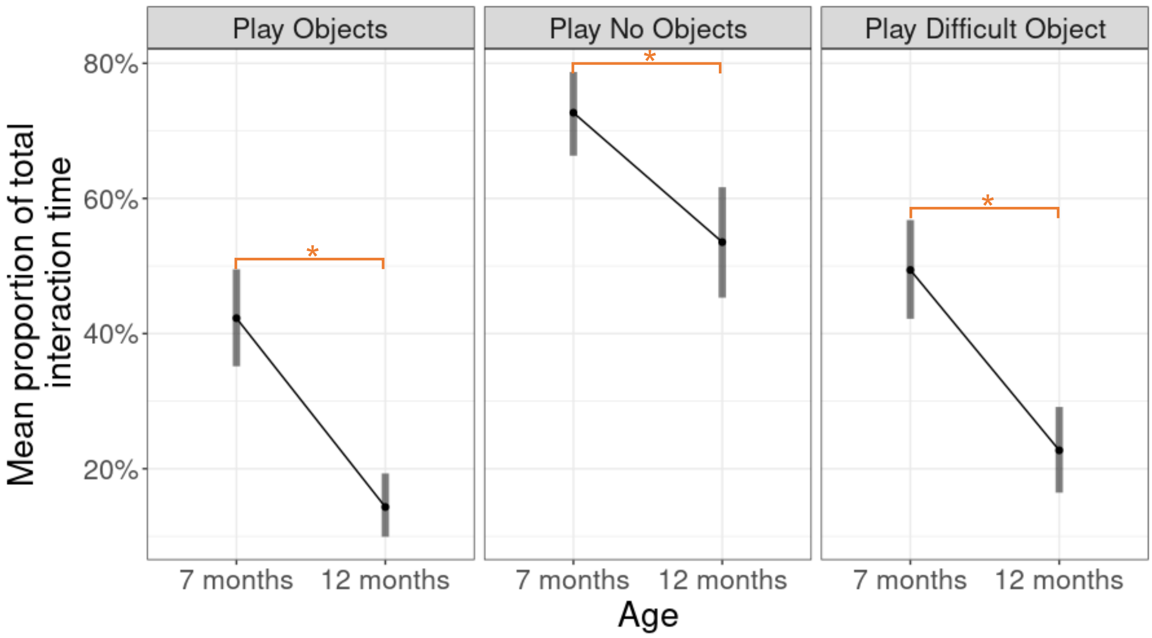


* 95% Credible interval of the contrast does not include zero.

In a second comparison, we tested the mean total proportion of interaction time with maternal touch across age points, holding the play task constant. Our model revealed that mothers touched substantially more when the infants were 7 months of age, during all play tasks. The overall proportion of time spent in contact decreased more noticeably in object-oriented tasks. In the play with objects task, mothers touched their infants 42.3% of the time at 7 months compared to 14.3% at 12 months; log odds ratio of 4.49 (95% CI 2.76-6.44). While in the play with a difficult object task, mothers used touch 49.4% of the time at 7 months compared to 22.8% at 12 months, log odds ratio of 3.40 (95% CI 2.14-4.81). Concerning the play without objects task, the decline in the prevalence of touch over age points was less pronounced, but still large, 72.6% vs. 53.5%, log odds ratio of 2.36 (95% CI 1.46-3.29).

Figure 5

Estimated Mean of the Total Proportion of Interaction Time with Maternal Touch, per Age point, Holding Play Task Constant.



* 95% Credible interval of the contrast does not include zero.

4.4.2 The Proportion of Total Interaction Time with Maternal Touch vis-à-vis the OMTS Touch Categories

In the first analysis, we found major differences in how often mothers used touch during the interaction, depending on whether the task was object-oriented or not, and how it decreased when the infant was 12 months of age. In this analysis, we have considered social touch not as an aggregate, but composed of multiple types of touch.

In a second analysis, we modeled the mean of the proportion of interaction time with maternal touch taking into consideration the mother's use of the various touch categories, as assessed by the Ordinalized Mother Touch Scale (OMTS). Our potential predictors were, as previously, the infant's age (7 and 12 months), and the play task (play with objects, play without objects, difficult object play). In addition, we also considered the OMTS touch category as a predictor (affectionate touch, static touch, playful touch, caregiving, object mediated, rough touch); see the section *Coding of Mother's Touch Behavior* for a description of the categories. We estimated Bayesian generalized linear mixed models with the following components: a beta-distributed response variable; a zero-inflated component to account for the presence of zeroes in the proportion of interaction (zeroes cannot be modeled with the beta-distributed model and for some touch categories and dyads there are zero touch events); and finally a model of the variance to account for the large differences in variance across the touch categories; see e.g. (Douma & Weedon, 2019) for a review of this approach. As in the previous analysis, the most parsimonious model was selected using the better predictive accuracy measure (lower LOOIC); the order of comparison was null model, age, play task, touch category, two-way interactions, and three-way interaction. All the models included dyads as random intercepts. For the zero-inflated component of the model, only the model structure was explored using the OMTS touch category as a predictor, and the same was done for the variance (phi) component of the model.

The model including all main effects and the 3-way interaction had the best predictive accuracy (lower LOOIC) when compared with the other models (see Supplemental Table 5, with the results of the LOOIC; model diagnostics for the selected model are in Supplemental Figure 6 and Supplemental Figure 7, and parameter estimates are in Supplemental Table 6). Comparing this model with the second-best model, we observed that the difference in LOOIC was within 2 standard errors (the cut point typically used for the LOOIC measure). Nevertheless, since our goal was to explore how mothers have used different types of touch across object and non-object-oriented tasks, and without any strong a priori hypotheses, we selected for the main analysis the saturated model with the 3-way interaction.

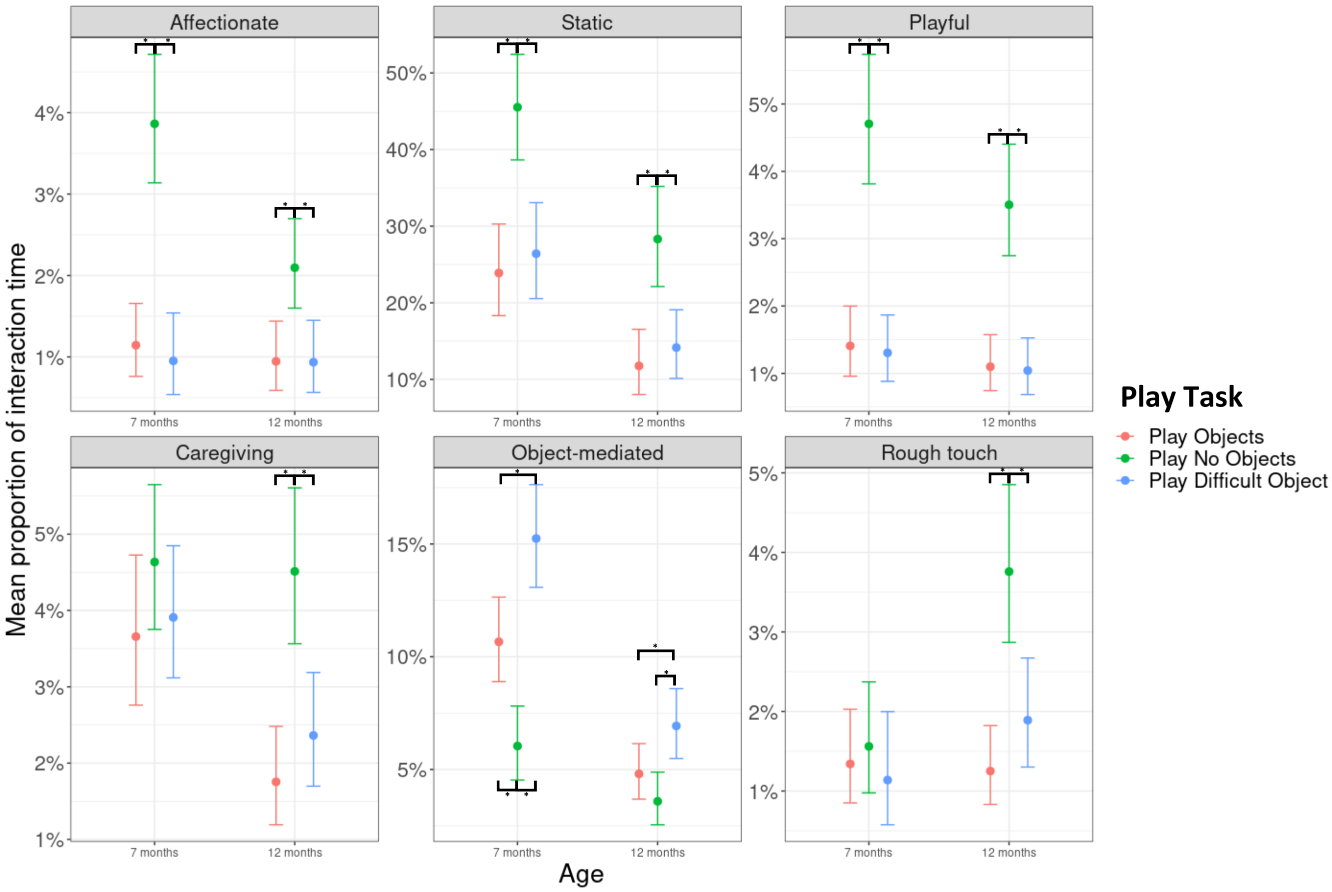
Therefore, we examined the mean proportion of time with maternal touch using two main comparisons: (1) across play task, holding age and OMTS Touch Category constant - see

Figure 6; and (2) across age point, holding play task and OMTS Touch Category constant - see Figure 7. For a detailed description of these results see Supplemental Table 7.

Concerning the first comparison, we observed differences in maternal touch behavior between play tasks (specifically in the use of OMTS categories, in each age group separately); the full results of the pairwise comparisons are depicted in Supplemental Table 8 and Supplemental Table 9 and for visualization see Figure 3. Mothers have used static, playful, and affectionate touch categories significantly more in the dyadic task play than in the triadic (i.e., object-oriented) play tasks, at both age points. In dyadic play, mothers have also utilized the caregiving and rough touch categories more frequently, but only when the infant was 12 months of age. Mothers used more object-mediated touch at 7 months of age in both triadic play tasks, compared with the dyadic play task; at 12 months of age, only the difficult object play was higher in object-mediated touch. We also observed that, at both age points, mothers had used the object-mediated category more frequently in the difficult play task than in the play with objects.

Figure 6

Estimated Mean of the Proportion of Interaction Time with Maternal Touch per Play Task, holding Age and OMTS Touch Category constant. For convenience in showing all panels in one visualization, the multiple panels are not on the same scale; also, each OMTS Touch Category panel has both age points (but the comparison is not across age points).

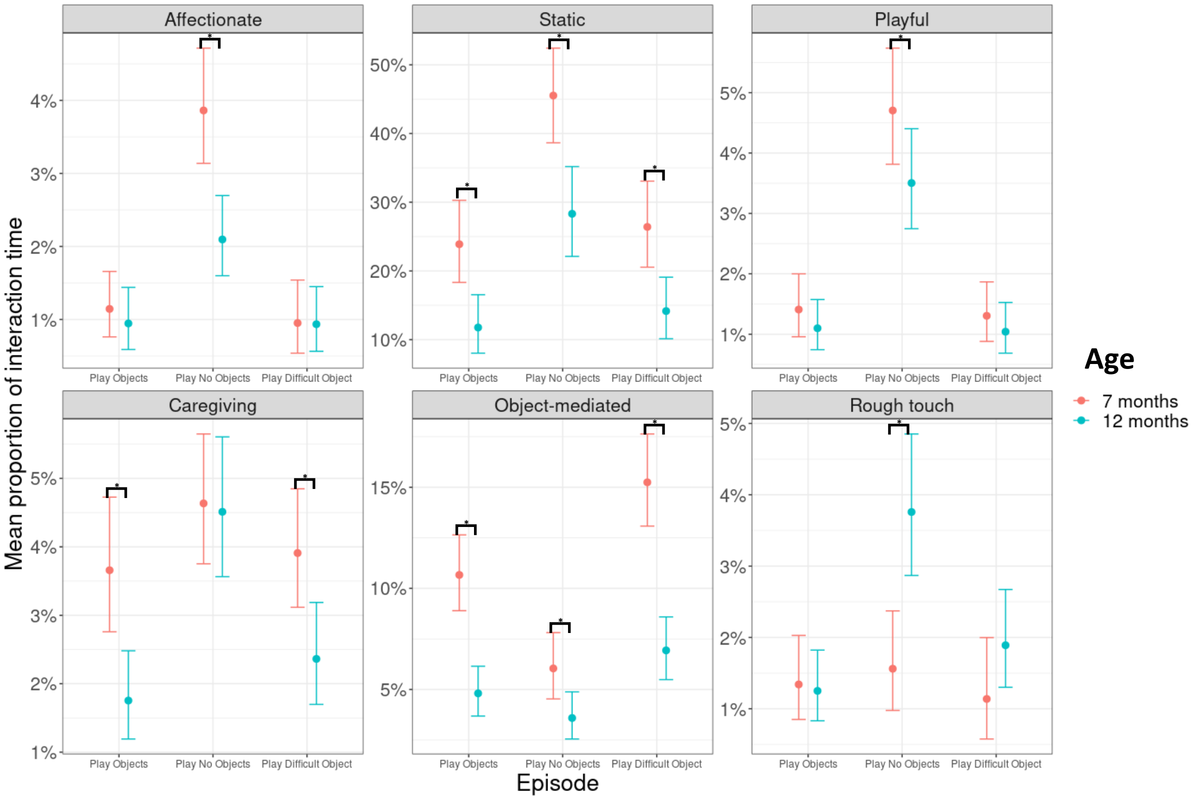


* 95% Credible Interval does not include zero.

In the second analysis, we looked for the proportion of maternal touch, across age points, holding play task, and OMTS touch category constant. These findings are illustrated in Figure 7. We found that the decline of the two most frequent OMTS touch categories – static touch in all play tasks, and object-mediated touch in the triadic play tasks – explained the overall decrease in the total proportion of interaction time with maternal touch, from 7 to 12 months of age (see Supplemental Table 10). When the infants were 7 months of age, mothers used more affectionate, static, playful, and object-mediated touch categories compared with the 12-month-old age point. The pattern with rough touch was interestingly reversed, i.e., mothers have used this touch category more at 12 months, in comparison to 7 months. Moreover, the prevalence of static, caregiving, and object-mediated touch categories in triadic play tasks significantly decreased from 7 to 12 months.

Figure 7

Estimated Mean of the Proportion of Interaction Time with Maternal Touch per Age point, holding Play Task and OMTS Touch Category constant. For convenience in showing all panels in one visualization, the multiple panels are not on the same scale; also, each OMTS Touch Category panel has three episodes (but the comparison is not across episodes).



* 95% Credible Interval does not include zero.

4.5 Discussion

In the current study, we examined the total amount and mother's use of different touch categories across play tasks that differed whether they involved object play or not. Within the object-oriented play, we included not only free play but also a condition where the object was too difficult for the infant's developmental level and asked the mother to support the infant. Participants were mothers and their typically developing infants at 7 months and 12 months of age. Four main findings derive from the present research: (1) mother's touch is prevalent in dyadic interactions and comparatively lowered in triadic object play; (2) in the dyadic play task (no objects available), mothers used the affectionate, static, and playful touch categories more often; (3) in triadic play tasks, mothers used the object-mediated touch category more frequently; (4) the total amount of maternal touch decreased from 7 to 12 months of age – this is mainly explained by the decrease in static and object-mediated touch. Each one of these findings is discussed next.

Our findings underscore that the mothers adjusted their touch behavior based on the nature of the interactive task (object-oriented versus non-object-oriented tasks), the task's complexity, and the age of the infant. Indeed, we found a significant decrease in maternal touch throughout all play tasks from 7 to 12 months, aligning with the pattern evident in prior research (e.g., Ferber et al., 2008; Fausto-Sterling et al., 2015; Leiba, 2000). One plausible interpretation of these outcomes is that during this timeframe, infants undergo significant developmental changes, including advancements in locomotor, cognitive, linguistic, and social abilities (Bertenthal & Boyer, 2015; De Onis, 2006; Green et al., 1980; Needham, 2009). Thus, these changes in touch behavior may reflect a sensitive maternal response to the infant's increasing autonomy and the evolving developmental traits specific to each age group. The main factor contributing to this downward trend was the reduction in the most frequent touch categories, static and object mediated. However, this trend was also noticeable, albeit to a lesser extent, across all other touch categories except for rough touch, as we will delve into later in this discussion.

Regarding the nature of the play task, we observed that mothers exhibited lower levels of tactile interaction in object-oriented tasks as opposed to non-object-oriented tasks, both at 7 and 12 months. This observation implies that in object-oriented tasks, mothers might have prioritized guiding and instructing their infants on interacting with objects, possibly incorporating verbal communication, and demonstrating actions as opposed to applying frequent touch stimulation. Additionally, the introduction of objects may encourage infants to explore and manipulate them independently, which can also reduce the overall need for maternal touch.

The level of complexity inherent in object-oriented tasks, particularly in the context of challenging object play, also appears to influence the way mothers structure this interaction. This is evident through the observed increase in the prevalence of object-mediated touch categories when compared to play tasks involving developmentally appropriate objects. Object-mediated category, often used for assisting infants in object-related activities or employing objects to interact with the infant, might aid in scaffolding infants to complete tasks above their current developmental level, fostering skill development (Serra et al., 2020; Wood et al., 1976). For example, by assisting a 12-month-old infant to spatially orient a shape for insertion into a slot, a task only achievable to a 24-month-old infant (Smith et al., 2014; Street et al., 2011). While this pattern is consistent across age points, a variation emerges: mothers use significantly higher amounts of object-mediated touch at 7 compared to 12 months. During this period infants' interaction with objects become more sophisticated and they spend more time exploring toys during social interactions (Bakeman et al., 1990; Schatz, Suarez-Rivera, Kaplan, Linn, & Tamis-LeMonda, 2020; Herzberg et al., 2020). This rising interest in exploring objects corresponds with the onset of joint attention (Bertenthal & Boyer, 2015), advancements in communication, reciprocity skills (Ferber et al., 2008), and independent sitting (Kretch et al., 2023; Schneider et al., 2023). Therefore, infants might reduce their dependency on caregivers for object manipulation and exploration, leading to a decreased need for maternal touch-based interactions to accomplish the task's objectives.

In contrast, non-object-oriented tasks, devoid of objects, may prompt touch to function as a primary form of communication and engagement (Hertenstein, 2002; Hertenstein, Keltner, et al., 2006; Hertenstein, Verkamp, et al., 2006), particularly within the initial year of life when infants are in the process of developing other communication skills, such as language. Dyad tasks promoted more face-to-face interactions and physical proximity, which naturally increased the opportunities for touch. Our findings reinforce this notion, showing that mothers not only exhibit a higher frequency of touch during these tasks but also employ a broader array of touch categories, in line with previous studies (Ferber et al., 2008; Jean et al., 2009; Serra et al., 2020). Specifically, static, playful, and affectionate touch categories are more frequently observed when objects are absent, across both 7- and 12-month-old infants. As infants develop and grow, their needs and abilities evolve, influencing how mothers interact with them during the no-objects play task. At seven months, infants can maintain a seated position while being held by a caregiver, which facilitates improved visual access to their surroundings (Franchak, 2019) and increases the likelihood of facing away from the caregiver (Kretch et al., 2023). Conversely, at twelve months, infants presented a broader range of motor skills encompassing crawling, standing, and walking, which allowed them to independently explore their environment (De Onis, 2006). These developmental distinctions may lead to varied uses of static touch by mothers. At seven months, static touch might be employed to physically support infants to remain sitting when playing (Jean et al., 2009; Serra et al., 2020). In contrast, at twelve months, with heightened mobility, static touch could serve touch to comfort their infants and create boundaries for their exploration of the environment, enabling them to concentrate on play activities (Mantis et al., 2019; Moreno et al., 2006; Peláez-Nogueras et al., 1997; Serra et al., 2020). Interestingly, we propose that this reasoning behind the observed change in static touch over time may similarly apply to object-oriented tasks.

Moreover, the increased frequency of playful and affectionate touch categories has been associated with reinforcing infants' social behavior, amplifying positive affect, facilitating eye contact, and elevating activity levels (Lowe et al., 2016; Moreno, Posada, & Goldyn, 2006; Egmose et al., 2018). Consequently, when objects are absent, mothers may have prioritized employing these touch categories to establish a positive and pleasant environment for the infant, capturing the infant's attention and promoting sustained engagement in the play task alongside their mother at both age points. Furthermore, the higher levels of caregiving and rough touch categories at 12 months may be related to the mother's efforts to keep their highly mobile infants engaged in dyadic play activities. This might involve physically relocating the infant to a different area - using caregiving touch – and/or interrupting their current activity to refocus their attention on the play task in a more intrusive manner, e.g., by using pulling and pushing behaviors – using rough touch (Serra et al., 2020). This last result was consistent with Green et al., (1980) study that examined the impact of infant development on mother-infant interactions in the second half of the first year, which revealed that increased locomotor capacity was associated with a rise in the number of infant activities that mothers tried to redirect or manage. Finally, our study also revealed that object-mediated touch, which we expected to be minimal during the dyadic play task, was significantly more used at 7 months than at 12 months within this task. In adapting the scale, we opted to retain the original OMTS codes, which delineated the object-mediated category involving situations where mothers facilitated touch with distinct parts of the infant's body; this included actions like holding the infant's hands and guiding them to clap, as defined by Beebe et al., (2010) and Stepakoff, (2000). This higher occurrence of the object-mediated touch category in the dyadic play task at 7 months may attributed to actions like using a part of the infant's shirt to cover their face, engaging in Peekaboo, or aiding infants in participating in gesture-based play activities, such as nursery rhymes with hand movements.

In summary, our findings demonstrate that maternal touch behavior serves multiple important functions beyond enhancing the quality of the mother-infant relationship, as indicated by prior research. It may play a crucial role in guiding and co-structuring the interactions in ways that are tailored to the infant's age and the specific demands of the task. Through touch, mothers can offer essential support, reinforce attention and positive emotions, provide comfort, and offer guidance in manipulating objects and exploring the environment. Ultimately these interactions may have a positive impact on the infant's development, promoting the acquisition of new skills and fostering growth in social, cognitive, and emotional domains.

Further research should directly investigate the relationship between paternal touch patterns and infant development, using standardized measures within a more diverse sample (our study included only highly educated mothers). This would provide a more comprehensive understanding of both the direct (e.g., how parents' touch behavior scaffolds infant exploration of objects) and indirect (e.g., how touch behavior creates conducive circumstances for encouraging object exploration) effects of specific touch patterns on infant object exploration.

Several limitations of this study should be noted and addressed in future research. Firstly, the data were derived from a larger longitudinal social touch project, where task order was predetermined (tasks increased from easiest to most challenging). Secondly, we did not consider the reciprocal influence of infant behavior in various play situations, as our focus was solely on maternal touch behavior. Thirdly, we did not investigate the father's touch behavior or the potential impact of infant gender on parental touch behavior. Additionally, other communication modalities such as language, gaze, and facial expressions were not measured. Lastly, various object-oriented touch behaviors were consolidated into a single category, object-mediated touch. Further research could explore these distinct patterns and their potential impacts on infant development.

Nonetheless, this study has yielded several significant findings that enhance our comprehension of the trajectory of maternal touch between 7 and 12 months of age as well as how touch behaviors can vary to accommodate the demands of different interactional contexts. Examining touch frequency and categories across various play tasks, revealed the influence of task nature, complexity, and infant age. The study also highlighted how touch is employed to structure interactions, presenting differences between object-oriented and non-object-oriented tasks. Object-mediated touch grew with task complexity, reflecting developmental shifts. As infants' motor skills evolve, static touch may provide support and comfort to the infant, while playful and affectionate touch could reinforce positive interactions. In sum, the study lighted up the dynamic role of maternal touch as a communication and support tool, adjusting to infant development and interaction demands.

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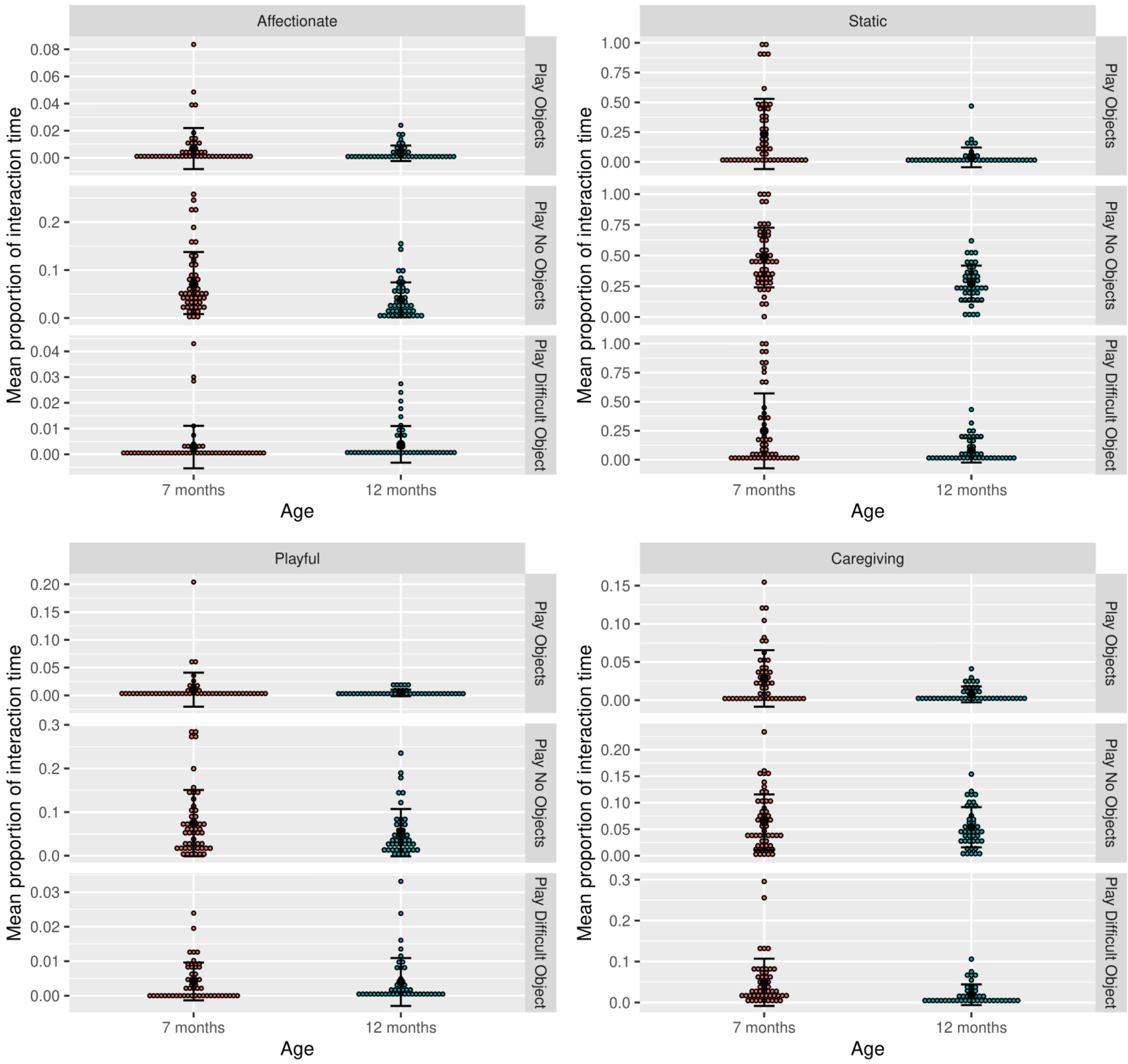
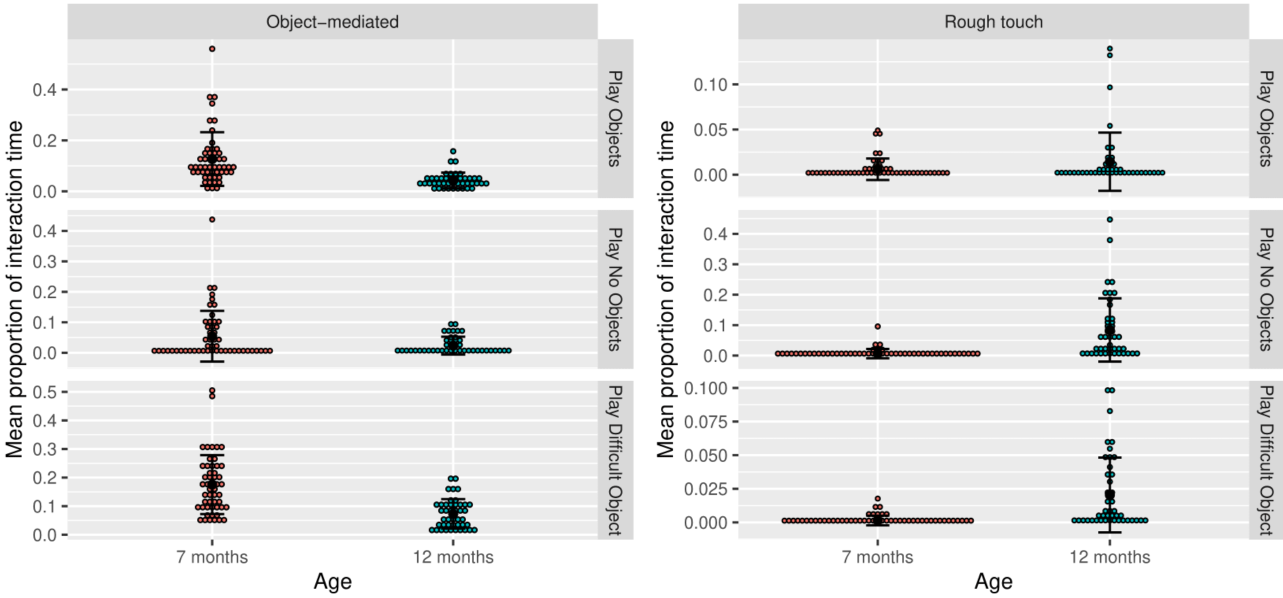
4.7 Supplemental Materials

Supplemental Figure 3

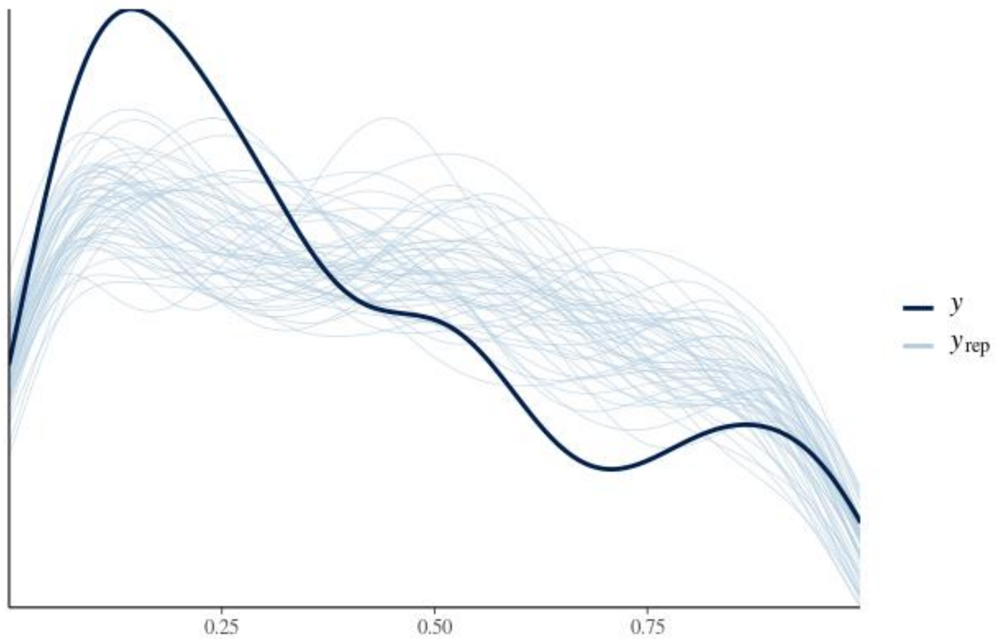
Mean proportion of interaction time mothers spent touching their infants at 7 and 12 months per OMTS category and Play task. The mean group proportion per age group and Play task is represented by the black circles and the black bars denote 1 +/− standard deviation of the mean.





Supplemental Figure 4

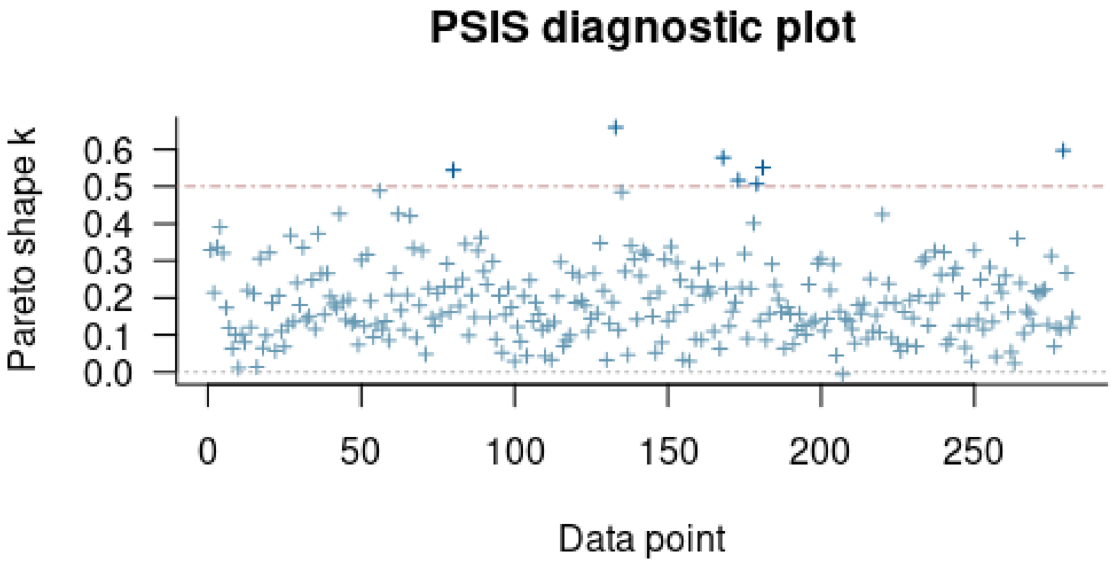
Posterior Predictive Check Plot of the Selected Model for the mean of the proportion of interaction time with maternal touch



Notes. The preferred model for fitting the total proportion of time in touch: play task + age + play task × age + (1|dyad)

Supplemental Figure 5

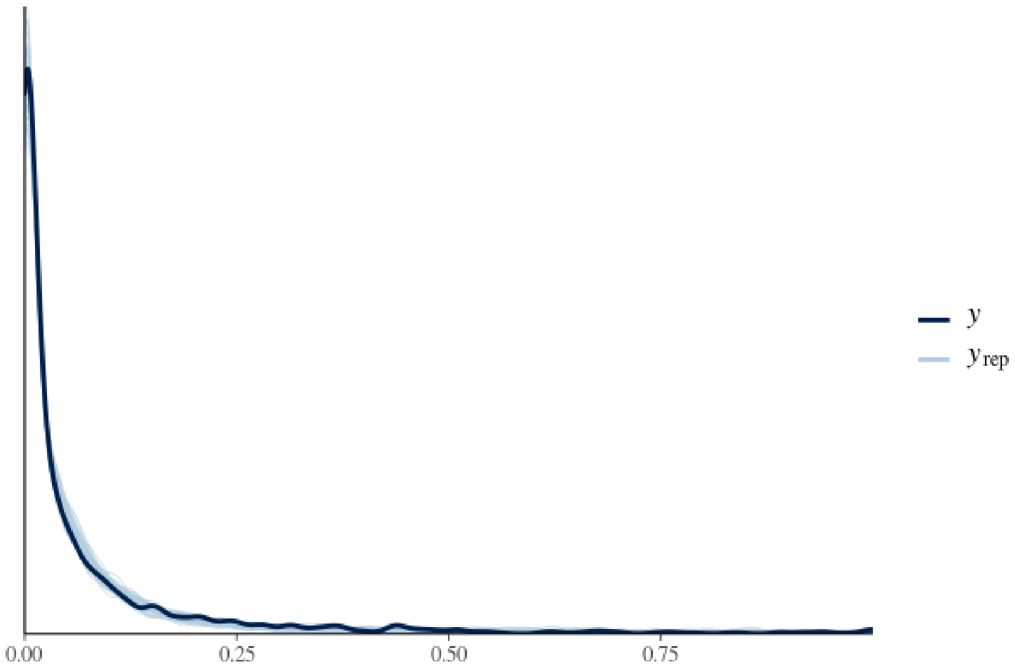
Pareto Smoothed Importance Sampling (PSIS) Plot for the Selected Model.



Note. 97.5% of Pareto k estimates are good - k < 0.5 - while 2.5% are ok - 0.5 <k < 0.7 (Vehtari et al., 2017, 2019)

Supplemental Figure 6

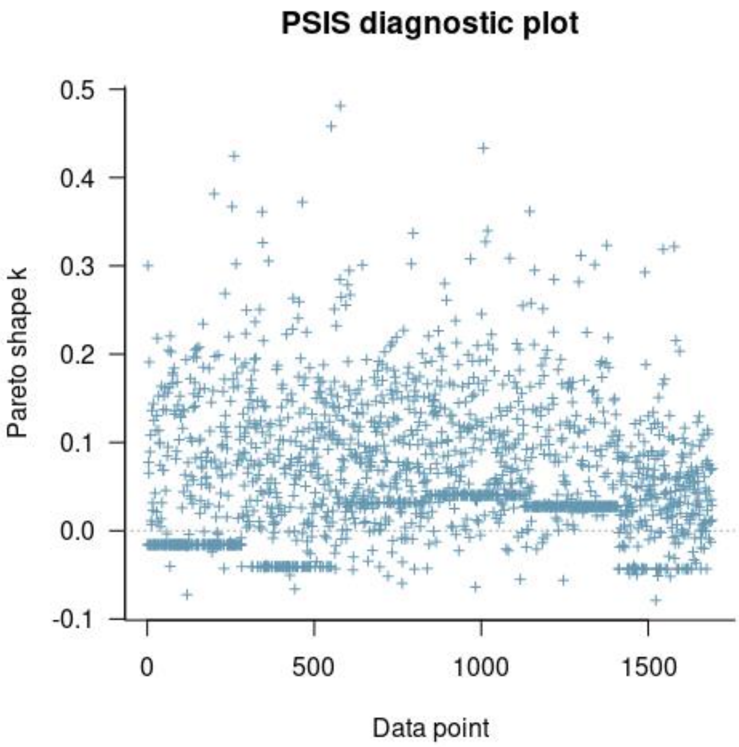
Posterior Predictive Check Plot of the Selected Model for the mean of the proportion of interaction time with maternal touch



Notes. Preferred model for fitting the proportion of time in touch by OMTS category: play task + age + touch type + play task × age x touch type + (1|dyad).

Supplemental Figure 7

Pareto Smoothed Importance Sampling (PSIS) Plot of the Selected Model for the mean of the proportion of interaction time with maternal touch.



Note. 100% of Pareto k estimates are good - k < 0.5 (Vehtari et al., 2017, 2019)

Supplemental Table ***3***

Model Comparison: Leave-One-Out Information Criterion (LOOIC)

Model	elpd_diff	se_diff	looic
Play Task + age + play task × age + (1|dyad)	0 (selected model)	0	-183.27
Play task + age + (1|dyad)	-1.25	2.30	-180.77
Play task + (1|dyad)	-44.32	7.16	-94.63
Age + (1|dyad)	-56.37	10.03	-70.52
Intercept + (1|dyad)	-82.53	9.97	-18.21

Supplemental Table 4

Posterior Summary and Convergence Statistics for the Selected Model

Parameter	Median	Lower HDI	Upper HDI	Rhat	ESS
b_intercept	-0.37	-0.59	-0.16	1.00	64594.05
b_playobjects	-0.68	-0.84	-0.52	1.00	135351.78
b_playnoobjects	0.937	0.77	1.10	1.00	121628.30
b_age7months	0.59	0.46	0.71	1.00	132980.31
b_playobjects:age7months	0.15	-0.01	0.31	1.00	145491.91
b_playnoobjects:age7months	-0.19	-0.32	-0.01	1.00	151629.63
phi	4.02	3.32	4.82	1.00	76079.88

Notes. The preferred model for fitting the total proportion of time in touch: play task + age + play task × age + (1|dyad); HDI = 95% high-density interval; ESS = Effective sample size; Rhat = Gelman-Rubin Statistics.

Supplemental Table 5

Model Comparison: Leave-one-out Information Criterion (LOOIC)

Model	elpd_diff	se_diff	looic
Play task + age + OMTS category + play task × age × OMTS category + (1|dyad)	0 (selected model)	0	-2689.54
Play task + age + OMTS category + age × OMTS category + play task × OMTS category + (1|dyad)	-1.11	4.10	-2687.32
Play task + OMTS category + (1|dyad)	-27.80	8.06	-2633.94
Play task + age + play task ×age + age × OMTS category + (1|dyad)	-87.25	14.51	-2515.04
Play task + age + age × OMTS category + (1|dyad)	-88.94	14.82	-2511.66
Play task + age + play task × age + (1|dyad)	-107.60	14.70	-2474.34
Play task + age + OMTS category + (1|dyad)	-108.69	14.78	-2472.16
Play task + OMTS category + (1|dyad)	-134.43	15.52	-2420.69
Age + OMTS category + (1|dyad)	-152.94	16.53	-2383.66

OMTS category + (1|dyad)	-182.03	17.35	-2325.48
Play Task + age + (1|dyad)	-428.49	28.73	-1832.56
Age + (1|dyad)	-440.90	28.90	-1807.74
Play task + (1|dyad)	-448.75	29.34	-1792.04
Intercept + (1|dyad)	-613.93	43.31	-1461.69

Supplemental Table 6

Posterior Summary and Convergence Statistics for the selected model

Parameter	Median	Lower HDI	Upper HDI	Rhat	ESS
b_Intercept	-3.71	-3.91	-3.51	1.00	38954.92
b_phi_intercept	3.46	3.21	3.70	1.00	49433.66
b_playobjects	-0.31	-0.54	-0.096	1.00	52258.52
b_playnoobjects	0.73	0.55	0.91	1.00	40641.74
b_age7months	0.14	-0.01	0.29	1.00	41897.27
b_touch.typestatic	2.72	2.47	2.96	1.00	49577.54
b_touch.typeplayful	0.077	-0.17	0.33	1.00	49547.17
b_touch.typecaregiving	0.545	0.32	0.78	1.00	44217.34
b_touch.typeobjectmediated	1.26	1.04	1.48	1.00	45280.19
b_touch.typeroughtouch	0.34	0.054	0.63	1.00	57678.15
b_age7months:touch.typestatic	0.28	0.070	0.48	1.00	56416.42
b_age7months:touch.typeplayful	-0.01	-0.21	0.19	1.00	52493.09
b_age7months:touch.typecaregiving	0.08	-0.11	0.26	1.00	49524.77
b_age7months:touch.typeobjectmediated	0.24	0.06	0.43	1.00	49935.14
b_age7months:touch.typeroughtouch	-0.37	-0.60	-0.15	1.00	60526.08
b_playobjects:touch.typeStatic	-0.11	-0.41	0.19	1.00	66689.34
b_playnoobjects:touch.typeStatic	-0.06	-0.33	0.20	1.00	60308.32
b_playobjects:touch.typeplayful	-0.07	-0.36	0.22	1.00	64925.76
b_playnoobjects:touch.typeplayful	0.11	-0.13	0.35	1.00	52888.22

b_playobjects:touch.typecaregiving	0.04	-0.23	0.32	1.00	61980.36
b_playnoobjects:touch.typecaregiving	-0.38	-0.61	-0.15	1.00	50434.65
b_playobjects:touch.typeobjectmediated	0.33	0.08	0.59	1.00	58755.07
b_playnoobjects:touch.typeobjectmediated	-1.18	-1.42	-0.94	1.00	54836.37
b_playobjects:touch.typeroughtouch	0.05	-0.26	0.37	1.00	69734.44
b_playnoobjects:touch.typeroughtouch	-0.33	-0.62	-0.05	1.00	64134.25
b_playobjects:age7months	-0.04	-0.26	0.18	1.00	51621.46
b_playnoobjects:age7months	0.18	0.01	0.35	1.00	40718.47
b_playobjects:age7months:touch.typestatic	0.07	-0.23	0.37	1.00	65558.59
b_playnoobjects:age7months:touch.typestatic	-0.19	-0.44	0.07	1.00	61478.84
b_playobjects:age7months:touch.typeplayful	0.039	-0.25	0.32	1.00	63481.50
b_playNoObjects:age7months:touch.typeplayful	-0.16	-0.39	0.07	1.00	52783.03
b_playobjects:age7months:touch.typecaregiving	0.21	-0.07	0.47	1.00	60918.85
b_playnoobjects:age7months:touch.typecaregiving	-0.38	-0.61	-0.16	1.00	50399.30
b_playobjects:age7months:touch.typeobjectmediated	0.10	-0.17	0.35	1.00	57625.75
b_playnoobjects:age7months:touch.typeobjectmediated	-0.29	-0.52	-0.06	1.00	57494.17
b_playobjects:age7months:touch.typeroughtouch	0.31	-0.01	0.62	1.00	66735.66
b_playnoobjects:age7months:touch.typeroughtouch	-0.42	-0.69	-0.14	1.00	67428.62
b_phi_touch.typestatic	-2.72	-3.02	-2.42	1.00	57036.42
b_phi_touch.typeplayful	-0.12	-0.46	0.22	1.00	63321.40
b_phi_touch.typecaregiving	-0.15	-0.47	0.18	1.00	59683.83
b_phi_touch.typebjectmediated	-0.63	-0.93	-0.31	1.00	60685.49
b_phi_touch.typeroughtouch	-0.49	-0.86	-0.12	1.00	69127.00
b_zi_intercept	-0.36	-0.60	-0.12	1.00	119987.02
b_zi_touch.typestatic	-1.57	-2.00	-1.16	1.00	131135.97

b_zi_touch.typeplayful	-0.50	-0.85	-0.15	1.00	123198.50
b_zi_touch.typecaregiving	-1.06	-1.457	-0.69	1.00	131999.77
b_zi_touch.typeobjectmediated	-1.70	-2.16	-1.27	1.00	135702.81
b_zi_touch.typeroughtouch	0.36	0.03	0.69	1.00	122245.94

Notes. Preferred model for fitting the proportion of time in touch by OMTS category: play task + age + touch type + play task × age x touch type + (1|dyad); HDI = 95% highest density interval; ESS = Effective sample size; Rhat = Gelman-Rubin Statistics.

Supplemental Table 7

Estimated Mean Proportion of Time in Touch per OMTS Category (CI) by Play Task and Age

Age	OMTS Category	Play with Objects	Play without Objects	Play with Difficult Object
7 Months	Affectionate	1.16% (0.74%-1.62%)	3.88% (3.10%-4.67%)	0.98% (0.54%-1.41%)
	Static	24.00% (18.25%-30.18%)	45.53% (38.64%-52.41%)	26.51% (20.38%-32.86%)
	Playful	1.43% (0.93%-1.96%)	4.73% (3.78%-5.70%)	1.10% (0.66%-1.49%)
	Caregiving	3.68% (2.72%-3.97%)	4.65% (3.73%-5.62%)	3.93% (3.10%-4.82%)
	Object-mediated	10.69% (8.85%-12.59%)	6.07% (4.44%-7.70%)	15.27% (13.07%-17.62%)
	Rough	1.37% (0.81%-1.97%)	1.59% (0.93%-2.31%)	1.18% (0.52%-1.91%)
12 Months	Affectionate	0.96% (0.56%-1.40%)	2.11% (1.56%-2.66%)	0.95% (0.54%-1.14%)
	Static	11.90% (7.73%-16.17%)	28.39% (21.97%-35.00%)	14.28% (9.92%-18.82%)
	Playful	1.11% (0.17%-1.54%)	3.52% (2.73%-4.37%)	1.06% (0.66%-1.49%)
	Caregiving	1.78% (1.16%-2.44%)	4.53% (3.52%-5.56%)	2.39% (1.68%-3.16%)
	Object-mediated	4.84% (3.65%-6.10%)	3.62% (2.50%-4.81%)	6.96% (5.44%-8.53%)
	Rough	1.27% (0.80%-1.97%)	3.78% (2.80%-4.78%)	1.91% (1.26%-2.61%)

Supplemental Table 8

Pairwise Differences of the Comparison of Each Play Task by OMTS Category at 7 Months Age Point

	Affectionate				**Static**			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
Play objects - Play no objects	-2.72e-02	-0.035	-0.019	*	-2.15e-01	-0.304	-0.128	*
Play objects - Play difficult objects	1.87e-03	-0.004	0.008		-2.51e-02	-0.108	0.056	
Play no object - Play difficult object	2.90e-02	0.021	0.038	*	1.90e-01	0.101	0.279	*
	Playful				**Caregiving**			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
Play objects - Play no objects	-3.30e-02	-0.043	-0.023	*	-9.71e-03	-0.022	0.003	
Play objects - Play difficult objects	1.05e-03	-0.006	0.007		-2.48e-03	-0.014	0.010	
Play no object - Play difficult object	3.40e-02	0.024	0.044	*	7.24e-03	-0.004	0.019	
	Object-mediated				**Rough**			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
Play objects - Play no objects	4.62e-02	0.023	0.070	*	9.44e-04	-0.006	0.008	
Play objects - Play difficult objects	-4.58e-02	-0.073	-0.019	*	1.89e-03	-0.007	0.010	
Play no object - Play difficult object	-9.20e-02	-0.119	-0.066	*	4.15e-03	-0.005	0.013	

Note. HPD = Highest posterior density region. * 95% Credible Interval does not include 0.

Supplemental Table 9

Pairwise Differences of the Comparison of Each Play Task by OMTS Category at 12 Months Age Point

	Affectionate				Static			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
Play objects - Play no objects	-1.15e-02	-0.018	-0.005	*	-1.65e-01	-0.238	-0.089	*
Play objects - Play difficult objects	9.58e-05	-0.006	0.006		-2.38e-02	-0.083	0.033	
Play no object - Play difficult object	1.16e-02	0.005	0.018	*	1.41e-01	0.066	0.217	*
	Playful				**Caregiving**			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
Play objects - Play no objects	-2.41e-02	-0.033	-0.016	*	-2.75e-02	-0.039	-0.016	*
Play objects - Play difficult objects	5.61e-04	-0.005	0.006		-6.08e-03	-0.015	0.003	
Play no object - Play difficult object	2.46e-02	0.016	0.033	*	2.15e-02	0.010	0.033	*
	Object-mediated				**Rough**			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
Play objects - Play no objects	1.21e-02	-0.004	0.028		-2.51e-02	-0.035	-0.015	*
Play objects - Play difficult objects	-2.12e-02	-0.040	-0.003	*	-6.42e-03	-0.014	0.001	
Play no object - Play difficult object	-3.34e-02	-0.052	-0.015	*	1.87e-02	0.008	0.029	*

Note. HPD = Highest posterior density region. * 95% Credible Interval does not include 0.

Supplemental Table 10

Pairwise Differences Between Infant's Age Across Play Task by OMTS Category

	Affectionate				Static			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
7M Play objects - 12M Play objects	1.98e-03	-0.004	0.008		1.21e-01	0.052	0.192	*
7M Play no objects - 12M Play no Objects	1.77e-02	0.010	0.026	*	1.71e-01	0.082	0.263	*
7M Play difficult object - 12M Play difficult object	2.06e-04	-0.006	0.007		1.22e-01	0.049	0.196	*
	Playful				**Caregiving**			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
7M Play objects - 12M Play objects	3.13e-03	-0.003	0.009		1.90e-02	0.008	0.030	*
7M Play no objects - 12M Play no objects	1.20e-02	0.001	0.023	*	1.20e-03	-0.011	0.014	
7M Play difficult object - 12M Play difficult object	2.64e-03	-0.003	0.009		1.54e-02	0.005	0.026	*
	Object-mediated				**Rough**			
Pairwise Contrast	Estimate	Lower HPD	Upper HPD		Estimate	Lower HPD	Upper HPD	
7M Play objects - 12M Play objects	5.86e-02	0.038	0.079	*	9.44e-04	-0.006	0.008	
7M Play no objects - 12M Play no nbjects	2.45e-02	0.005	0.043	*	-2.19e-02	-0.033	-0.011	*
7M Play difficult object - 12M Play difficult object	8.31e-02	0.058	0.109	*	-7.36e-03	-0.016	0.002	

Note. HPD = Highest posterior density region. * 95% Credible Interval does not include 0.

CHAPTER 5

Maternal touch and infant’s brain responses to affective and discriminative touch: an fNIRS Study

CHAPTER 5

A version of Chapter 5 was submitted to the Elsevier peer-reviewed journal *Cortex.*

Reference:

Serra, J., Lisboa, I. C., Miguel, H., Pereira, A. F., & Sampaio, A. (2023). *Maternal touch and infant's brain responses to affective and discriminative touch: an fNIRS Study*. [Manuscript submitted for publication]. School of Psychology, University of Minho.

CHAPTER 5

5.1. Abstract

In the first year of an infant's life, touch is crucial in mother-infant interaction, promoting infant development and the quality of the mother-infant relationship. Recent research has investigated the neurophysiological aspects of tactile experiences, distinguishing between discriminative touch and affective touch. Studies in healthy adults have shown that discriminative touch primarily activates the somatosensory cortex (SS), while affective touch also recruits areas in the "Social Brain," such as the posterior superior temporal sulcus (pSTS). However, a knowledge gap exists regarding the neural mechanisms involved in this relationship during the first year of life.

This study investigated whether the infant's exposure to maternal touch, quantified by the frequency of touch in a social interaction without objects, correlates with their brain responses to affective and discriminative touch in infants aged 7 and 12 months. Brain activation was recorded in the SS and pSTS by measuring changes in oxy-hemoglobin (HbO2) with functional near-infrared spectroscopy (fNIRS). Results indicate that increased maternal touch frequency at 7 months was associated with decreased HbO2 levels in the somatosensory cortex in response to affective touch but increased HbO2 responses in the pSTS to both affective and discriminative touch stimuli. At 12 months, infants whose mothers engaged in more frequent touch interactions displayed elevated HbO2 responses to affective touch and reduced responses to discriminative touch stimuli in the SS. Together, these results support that the infant’s touch experiences have a role in modulating the infant’s brain responses to both affective and discriminative touch.

Keywords*:* Social touch; Mother-infant interactions; fNIRS; Touch processing; Infancy

5.2. Introduction

Social touch, the tactile experiences that occur during social interactions, is an integral part of the mother-infant relationship in early infancy (Ferber et al., 2008; Jean et al., 2009; Stack, 2004), and for the infant, one of the earliest modalities for actively engage with their physical and social surroundings (Botero, 2016; Moszkowski, Stack, & Chiarella, 2009; Moszkowski, Stack, Girouard, et al., 2009; Moszkowski & Stack, 2007). Born highly immature, infants are completely dependent on the support of others in the regulation of basic physiological and psychological functioning, especially during the first year of life. Throughout this crucial period, mother-infant interaction often occurs through touch, with parents providing essential support in all daily activities and routines including feeding, sleeping, hygiene, and soothing (Faust et al., 2020). This type of touch is also communicative and can be used to convey information or emotional states, also defined as "social touch" (Hertenstein, 2002; Hertenstein, Verkamp, et al., 2006).

The link between touch and the infant's physical and socio-emotional development is now well-established (Field et al., 2010; Field, 2019). Research on massage and kangaroo care interventions demonstrated the association between physical contact and a wide range of beneficial outcomes for both infants and their parents, including sleep quality, increased physical growth and body weight, encouragement of parental bonding and prolonged breastfeeding exclusivity, as well as the enrichment of positive interactions between parents and infants (Campbell-Yeo et al., 2015; Moore et al., 2016; Conde-Agudelo & Díaz-Rossello, 2016; Johnston et al., 2017; Moberg et al., 2020; World Health Organization, 2022). The benefits are not restricted to the infant: physical contact has been shown to reduce anxiety, stress, and pain levels, in both parents and infants, thus contributing to the overall well-being of the caregiver-infant dyad (Field, 2016, 2018, 2021; Northolt, 2020).

These effects extend beyond early infancy, and, in general, the social environment significantly influences the perception of touch. Behavioral and neuroimaging studies found that the perception and response to social touch is influenced by various psychosocial and contextual factors, including situational elements such as exposure to painful or psychologically distressing contexts, or the characteristics of who is initiating the touch like the quality of the relationship of the social bond with the person being touched, for example (Cascio et al., 2019; Saarinen et al., 2021); see Saarinen et al., (2021) for a review. In infancy, touch can reinforce the infant's responsiveness and engagement with a caregiver, resulting in increased eye contact, activity level, and positive affect. The use of touch is associated with a higher frequency of behaviors in the infant such as smiling, vocalizing, and attentional engagement (Cekaite, 2016; Egmose et al., 2018; Fairhurst et al., 2014; Jean et al., 2014; Lowe et al., 2016; Moreno et al., 2006). Parental touch has also been associated with the formation of social attachment, as mothers who engaged in more frequent affectionate touch were more likely to have securely attached infants than mothers who engaged in little affectionate touch (Weiss et al. 2000). Mateus et al. (2021) found that infants of less sensitive mothers (measured in a play task at 7 months of age) have a higher fNIRS activation to touch over the left somatosensory cortex, measured at 12 months.

The effect of the frequency of tactile experiences in the perception and processing of touch in individuals is supported in other studies. In a behavioral study with adults, Sailer & Ackerley (2019) found that individuals who reported experiencing infrequent touch in their daily lives exhibited a decreased ability to distinguish between different stroking speeds and tended to rate touch applied at an CT-optimal speed as less enjoyable compared to adults who had frequent exposure to touch. Using fMRI, Brauer et al., (2016) observed that 5-year-old children who were exposed to higher levels of maternal touch, during a play task, also exhibited increased resting-state functional connectivity in brain areas that are part of the so-called “social brain network”, specifically in the rpSTS (right posterior superior temporal sulcus). In a study of the effect of past experiences of maternal touch in 7-month-old infants, measured with the *Parent-Infant Caregiving Touch Scale (PICTS)*, Addabbo et al., (2021) showed that *the infant's attention to social stimuli is associated with the frequency of maternal touch*. Specifically, infants of mothers who provided more frequent touch displayed reduced avoidance of angry faces, while the infant was receiving stroking touch and watching videos of happy and angry facial expressions.

Despite the significant importance of maternal touch behavior in the overall development of the infant, supported by behavioral, physiological, and neuroimaging data (e.g., Carozza & Leong, 2021; Cascio et al., 2019; Field, 2019; Kostandy & Ludington-Hoe, 2019; Mrljak et al., 2022), the proximal sense of touch is a relatively neglected modality, especially compared with the distal senses such as visual or audition systems (Thesen et al., 2004). This is more so the case regarding the association between maternal touch behavior and the neural processing of tactile stimulation in the infant.

In the current study, we reanalyzed data from a project that examined touch longitudinally at 7 and 12 months of age with an innovative approach combining a micro-analytical observational approach with brain functional measures. Infants' brain responses to discriminative and affective touch were measured using fNIRS; details are described in Miguel et al., 2020; Miguel, Gonçalves, et al., 2019 and Miguel, Lisboa, et al., 2019). The mother-infant dyads were also observed in a structured social interaction and maternal touch coded using a micro-analytic method (Serra et al., 2023). In this article, we assessed the association between maternal touch behavior and infants' brain responses to affective and discriminative touch. First, we briefly discuss the affective vs. discriminative touch dimensions and review some of the neuroimaging evidence for brain areas involved in processing touch.

The tactile experience is mediated by two orthogonal systems that stem from physiological differences: discriminative touch and affective touch. Discriminative touch, mediated by low-threshold myelinated Aβ fibers, responds to faster tactile stimuli and enables the detection of changes in properties such as vibration, texture, and shape. It facilitates exploration and discrimination of stimuli from the environment, including identifying objects (McGlone et al., 2007, 2014). Affective touch involves a different type of afferents called C-tactile fibers (CT), predominantly located in hairy skin but also sparsely distributed in glabrous skin (Watkins et al., 2021). C-tactile fibers are specialized in responding to gentle and slow stroking, that resembles a caress, with a speed range of 1-10cm/s (Olausson, Wessberg, Morrison, McGlone, & Vallbo, 2010; Löken et al., 2009; Essick et al., 2010). These fibers are particularly sensitive to light pressure and are activated by the approximate temperature of human hands, around 32ºC (Ackerley et al., 2014). Optimal stimulation of CT fibers has been associated with affiliative interactions or affective touch exchanges between individuals (Gallace & Spence, 2010; Croy et al., 2022), including the intimate connection between mothers and their infants. Brain activation responses are also differentially associated with each of the two affective and discriminative dimensions of the tactile experience (McGlone et al., 2014; Morrison, 2016).

Neuroimaging studies in healthy adults show that discriminative fibers mainly activate the somatosensory cortex I and II - S1 and S2 (McGlone et al., 2014; Morrison, 2016), while CT fibers activate the somatosensory cortex, but in addition, also recruit other areas of the so-called "social brain". The social brain network is involved in processing social stimuli and encompasses brain regions such as the insula, medial prefrontal cortex (mPFC), temporoparietal junction (TPJ), and posterior superior temporal sulcus (pSTS) (Adolphs, 2009; Frith, 2007; Morrison, 2016; Bennett et al., 2014; Gordon et al., 2013; Voos et al., 2013; Davidovic et al., 2019).

Developmental studies observed similar neural responses to affective touch in infants, adolescents, and adults, recruiting brain regions such as the somatosensory cortex, insula, and pSTS. For example, in a study using diffuse optical tomography (DOT), Maria et al., (2022) investigated the processing of affective touch, specifically CT-optimal brushing in the right forearm at 3 cm/s, in two-year-old children. The findings revealed insular activation in response to CT-optimal stimulation, comparable to that observed in adults (Maria et al., 2022). Similarly, Björnsdotter et al., (2014) measured the brain response to affective touch in children and adolescents (5-17 years). This study used fMRI with adult-defined brain regions of interest (somatosensory cortex, insula, and pSTS) and found comparable levels of activation in these regions when compared with a control group of adults (Björnsdotter et al., 2014).

In infancy, the available evidence suggests that the brain areas involved in processing affective touch develop at different rates, as shown by the earliest age when brain activation can be detected. In a fMRI study, Tuulari et al. (2017) tested infants aged 11 to 36 days by administering a gentle brush stroking to the right anterior shin region and documented activation in the postcentral gyrus and posterior insular cortex. Similarly, Jönsson et al., (2018) using diffuse optical tomography (DOT), observed significant activation in the insular cortex and temporal lobe of two-month-old infants when their forearm was slowly stroked with a soft brush compared to fast stroking.

For the pSTS, brain activations were detected only later in the first year. At five months of age, Pirazzoli et al., (2019), in a study with fNIRS, found no specific cortical activation in the posterior superior temporal sulcus (pSTS) region in response to affective touch (human touch strokes) compared to non-affective touch stimuli (cold metallic spoon strokes). Miguel, Lisboa, et al., (2019) conducted an fNIRS study on infants at 7 months of age and also found a lack of activation in the pSTS region when comparing affective touch (soft brush strokes) to discriminative touch (light taps with a wooden block) on the infants' forearm. Kida & Shinohara, (2013) described, in a fNIRS study, that gentle touching of the palm (with a velvet fabric) resulted in bilateral activation of the anterior prefrontal cortex in 10-month-old infants, but not in 3- and 6-month-old infants, when compared to touch with a rounded wood (i.e., discriminative touch). Other work suggested that activation in the pSTS to affective touch may not emerge until around ten months of age (Kida & Shinohara, 2013; Miguel, Gonçalves, et al., 2019). In accordance, Miguel, Gonçalves, et al., (2019) in a longitudinhal approach showed that affective touch was able to recruit the pSTS at 12 months but not at 7 months, mirroring the neural response observed in older children and adults. In summary, there are specific brain responses to affective and discriminative touch, with affective touch eliciting additional activation within the "social brain" network.

5.2.1 Current study

While touch research indicates that there is a positive association between the quality of a caregiver's touch behavior and an infant's early development, there is limited understanding of the neural correlates underlying this relationship. Therefore, in this study, we tested if early caregiving experiences, specifically frequency of maternal touch at 7 and 12 months of age, are associated with infants' cortical responses to affective and discriminative touch. Infants were tested at both age points by an experimenter who applied two touch stimuli: a watercolor brush (affective touch) and a wooden cube (discriminative touch), while the infant viewed a silent movie and fNIRS activations were recorded. The fNIRS array used a montage with two areas of interest, the left somatosensory region and the right posterior superior temporal sulcus. Our dependent measure was the baseline-corrected activation to discriminative and affective touch. Also at both age points, mother and infant were tested in a free-play without objects task. All maternal touch events were segmented from the interaction and the total proportion of interaction time with maternal touch was derived from the touch event data. Using a linear mixed model approach, we asked if the proportion of interaction time with maternal touch (a proxy to the infant's early experiences of touch) predicts the fNIRS activation, above and beyond what is predicted by the experimental factor (discriminative vs. affective).

5.3 Method

5.3.1 Participants

The data utilized in this study is a subset of a longitudinal research project aimed at investigating infants' processing of affective touch; see results reported in (Miguel et al., 2020; Miguel, Gonçalves, et al., 2019; Miguel, Lisboa, et al., 2019). This larger project involved the assessment of typically developing infants at three distinct time points: 7 months, 12 months, and 18 months, with a comprehensive sample description available in Miguel (2017). Our analysis specifically focused on the data collected at the 7- and 12-month age points because the attrition rate at 18 months was very high. Participants were recruited from various sources, including parenting classes, social networks, and daycare centers in the Braga, Portugal area.

At the first age point, 7 months, we included 30 infants; 19 additional infants were excluded due to fussiness (n = 2), not completing the minimum number of acceptable trials (three) for inclusion in the fNIRS task (n = 12), and a lack of mother-infant interaction data (n = 4). At the second age point, 12 months, we tested 45 infants; 21 infants were excluded due to fussiness (n = 4), not completing the minimum of three acceptable fNIRS trials for inclusion (n = 7), data acquisition issues such as motion artifacts and noisy data (n = 7), experimental errors (n = 2), and a lack of mother-infant interaction data (n = 2).

Parental consent was obtained for all participating infants, and ethical guidelines for research involving human subjects were strictly adhered to throughout the study. Mothers were given detailed information about the study and provided written informed consent before the infants' participation. All procedures were approved by the University of Minho Ethics Committee.

5.3.2 Procedure

At both the 7 and 12 age points infants were tested in two tasks: a touch task where an experimenter applied two types of touch to the infant’s right arm, while the infant viewed a silent movie and fNIRS was recorded; and a mother-infant structured social interaction task that was video-recorded. The sessions followed the same procedure for both age groups. When the parent and the infant arrived at the lab, the experimenter explained the experimental procedure and asked the parent to sign the consent form. Infants were always first tested in the fNIRS procedure, thus, after signing the consent form, the mother and infant were invited to enter the fNIRS experimental room.

The fNIRS recording room had no windows and was only dimly lit. Inside the room, the experimenter started by taking measurements of the infant’s head and then placed the cap. After the cap was placed, the infant was positioned in front of a computer screen (60cm distance from the screen; screen size: 53*30cm) and in a Jelly Mom Baby Chair to ensure minimal physical contact with the mother; the mother sat in a chair in front of the computer and the baby chair was on her lap. Above the computer screen, a video camera recorded the procedure for offline coding. When the infant was calm and comfortably seated in the baby chair and the mother's lap, the experimenter started the screening of the silent movie. The experimenter then positioned herself on the rear-right side of the infant to administer the touch stimuli using a watercolor brush (affective touch) or a wooden cube (discriminative touch) – see next section with details of experimental design used. Throughout the experiment, there was no visual interaction between the experimenter and the infant. Parents were explicitly instructed not to engage with the infant unless he or she became restless. As needed, breaks were incorporated to maintain the infant's engagement. The fNIRS recording ended either upon the infant's completion of the four blocks of trials or if the infant became fussy. At the end of the fNIRS procedure, the experimenter removed the cap from the infant's head and asked the infant and the parent to participate in the play task. A pause between the two tasks was also included if needed.

Then, mothers and infants were moved to a room with a foam mat on the floor. Mothers were instructed to play with their infants on the mat as naturally as possible as if they were at home. The task was a structured social interaction with three episodes, a design used in developmental psychopathology studies: (1) free play with objects: play freely using age-appropriate selected from Bayley-III and/or Griffiths 0–2; (2) free play without objects: play freely, as they usually do at home, without any objects; and (3) challenging object play: play with an object that was above the infant's developmental level. Instructions were provided in general terms and no mention of touch was made. A camera placed on a tripod recorded the whole interaction from a side view. Each of the three episodes lasted approximately 3 minutes when the infant was 7 months of age, and 5 minutes when the infant was 12 months of age. These durations were considered age appropriate and taken from previous studies (Martins et al., 2013).

Only the maternal touch data from the second episode (free play without objects), was used because this produced the largest proportion of interaction with touch events – see Serra et al., 2023 for the full report on the behavioral data that includes the three episodes. See the section below for details on the coding of the touch events in the interactions.

5.3.3 Experimental Design for the Touch Task with fNIRS

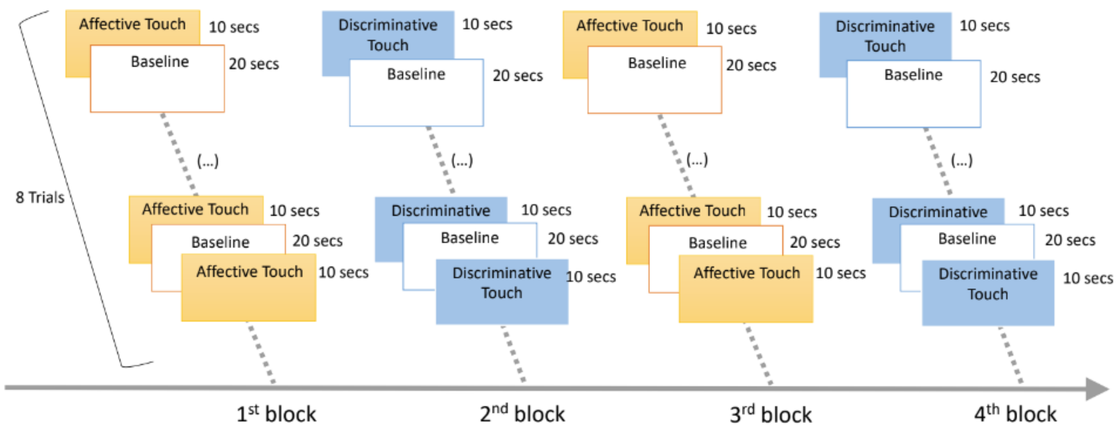
5.3.3.1 Touch Task. Two different sets of tactile stimuli were employed in the infants' right dorsal forearm (bare arm) to represent the affective and discriminative aspects of touch. The affective touch consisted of a gentle and slow stroking of a watercolor brush at a speed of 8 centimeters per second (Bennett et al., 2014; Kaiser et al., 2016). This velocity was employed because it has been demonstrated to specifically target CT fibers (Löken et al., 2009). An experimenter who received training for this purpose applied strokes in a proximal-distal direction in the infants' forearm (Triscoli et al., 2013). For the discriminative touch, the experimenter applied pressure with a wooden block (measuring 2 × 2 cm) onto the infants' forearm, moving it also in a proximal-distal direction. To match the distance covered by the brush, the wooden block was applied at a rate of three times per second. The discriminative stimuli did not include any stroking movement, ensuring that the fibers stimulated were the Aβ fibers.

5.3.3.2 Design and NIRS Recording. Infants were tested with the same experimental design both at 7 and at 12 months of age. We used a within-subjects block design, with two experimental conditions (affective and discriminative touch), and one baseline condition (Miguel, Gonçalves, et al., 2019) – see Figure 8 for a schematic of the experimental design. During the baseline and the experimental conditions, infants watched a continuous silent movie, the Czech cartoon "Krteček**"** (Fairhurst, Loken, & Grossmann, 2014).

There were two alternating blocks of each experimental condition (affective and discriminative). Each block was composed of 8 trials and every trial comprised of 10 seconds of touch (discriminative or affective) followed by a subsequent 20-second baseline interval (rest). Infants participated in two blocks of the two experimental conditions (i.e., 4 blocks in total). Blocks were counterbalanced between subjects.

Figure *8*

Schematic representation of the experimental design for the touch task. One trial consisted of 10 seconds of touch stimulus applied by the experimenter on the infant's right forearm (affective or discriminative) followed by a 20-second baseline period (rest). One block was composed of 8 trials. Infants participated in a maximum of 4 blocks.

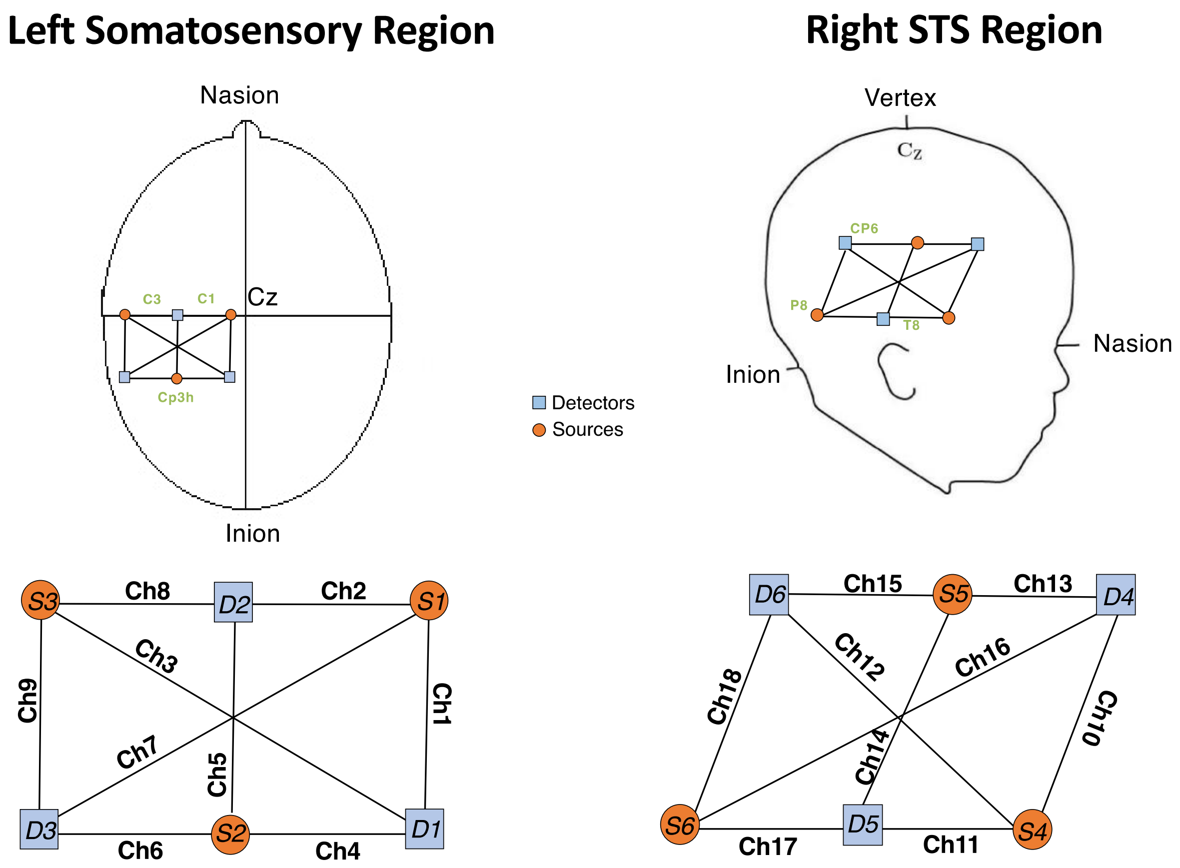


During the whole procedure, infants' hemodynamic responses in the right temporal region (designed to cover the right STS region) and left somatosensory region were recorded using fNIRS. All infants were tested using the UCL-NTS system (Everdell et al., 2005). Participants wore an elastic cap (Easycap, GmBH), built according to the 10-5 system (Jurcak et al., 2007). The cap was composed of six light sources (emitting continuous near-infrared light at two fixed wavelengths of 780 and 850 nm) and six detectors (the system captured data at 10 Hz). The sources and detectors were positioned around a total of 18 channels: 9 channels placed over the right STS region and 9 channels over the somatosensory region – see Figure 9 for a schematic representation of the two probe arrays. All channels had between 20mm and 25mm source-detector separation, except for the longest channels 3, 7, 12, and 16 (that crossed the middle of the two arrays) which had around 50mm of source-detector separation.

Before the touch task started, we took measurements of the infant's head (distance between the *nasion* and the *inion*, distance between the right pre-auricular and the left pre-auricular point, and head circumference) to ensure the correct alignment of the cap on the infant's head, according to the 10-5 system (Jurcak et al., 2007). Based on the head circumference measurements, distinct caps were employed at seven- and twelve-month-old infants (measuring 44 and 46 cm).

Figure 9

Schematic representation of the infant's head exhibiting the approximate locations of the sources, detectors, and channels in the left somatosensory region (left side of the panel) and the right STS region (right side of the panel). Blue squares and orange circles represent the detector and source locations respectively; lines connecting sources and detectors represent the channels; 10-5 coordinates are superimposed in green.



5.3.4 Measures

5.3.4.1 Data Processing of fNIRS Data. The videos from the individual fNIRS sessions were analyzed offline by an observer who was unaware of the inclusion criteria. To be included in the analysis, infants had to successfully complete a minimum of three valid trials (Lloyd-Fox et al., 2015). For a trial to be considered acceptable, it had to satisfy the following criteria: (1) the infant remained motionless, refraining from any arm movements during the stimulus administration; (2) the infant did not direct their gaze toward either the experimenter or the mother during the stimulus administration; (3) the infant refrained from physical contact with either the experimenter or the mother during stimulus delivery. At seven months of age, infants completed an average of 6.65 ± 3.06 affective touch trials, with a range of 3 to 14 trials, and 7.25 ± 2.82 discriminative touch trials, ranging from 3 to 17. Meanwhile, 12-month-olds completed an average of 6.68 ± 2.15 affective touch trials, with a range of 4 to 13 trials, and 6.32 ± 2.52 discriminative touch trials, ranging from 3 to 12.

The fNIRS raw data, sampled at 10 Hz, was converted into the NIRS format and analyzed in the HOMER2 software package (Huppert et al., 2009) running in MATLAB (The MathWorks, Inc., Natick, MA, USA). Before any signal processing was applied, we visually inspected raw intensity data, per subject, on all nine channels; this led to the elimination of the four longest channels of the arrays (channels 3, 7, 12, and 16), since intensity raw data was practically non-existent on these channels in all participants (Lisboa et al., 2020; Miguel, Gonçalves, et al., 2019). Thus, further data corrections and analyses were performed considering only the remaining fourteen channels and trials.

Light intensity data was transformed into optical density units and assessed for motion artifacts using Principal Component Analysis (PCA) with a threshold set at 0.9 (Cooper et al., 2012). Because we only selected trials in which the infant remained still and without arm movement, the rejection of trials using PCA was deemed a preferable approach over other correction techniques (e.g., wavelet motion correction). Subsequently, the data underwent low-pass filtering at 0.5 (Lloyd-Fox et al., 2015). The change in concentration of the hemoglobin chromophore was then calculated following the modified Beer-Lambert Law, assuming a path length factor of 5.13 (Duncan et al., 1995). Mean concentration changes in oxy-hemoglobin (HbO2) and deoxy-hemoglobin (HHb) were baseline corrected using the 2s before experimental stimulus onset, and block averaged using the following time epochs: 2s of baseline, 10s of stimulus onset, and 18s of post-stimulus offset.

5.3.4.2 Coding of Mother's Touch Behavior. Maternal touch events were coded using an adapted version of Beebe and colleagues' Maternal Touch Scale (Beebe et al., 2010; Stepakoff, 1999), as described in Serra et al., (2020). We segmented each touch event, whether delivered by hand or face, by coding its onset frame (start of touch) and offset frame (end of touch) for the entire interaction. Since multiple touches can occur simultaneously, we organized maternal touch events into three separate tiers: one for hand touches, another for touches involving the face (e.g., kissing), and a third for instances when the mother used both hands, each performing different touch types. Touch event segmentation was done using the ELAN version 4.9.4 software by (Sloetjes & Wittenburg, 2008). Moments of the interaction that were deemed uncodable, due to camera errors or obstructions that hindered the view of the mothers' hands, were marked. To ensure reliability between raters, a second trained individual coded 50% of the dyads and 25% of the free play task, per dyad. Inter-rater reliability, assessed using Kappa in ELAN version 4.9.4 (Holle & Rein, 2013), was found to be high ($k = 0.87$). Our final dataset consisted of 8885 individual touch events. The duration of the task was 3 minutes at 7 months and 5 minutes at 12 months. The measure taken from the maternal touch coding was the proportion of interaction time with maternal touch (sum of the duration of all maternal touch events / interaction duration).

5.3.5 Statistical Analysis

An initial exploratory data analysis was performed by visually inspecting the baseline-corrected HbO2 and Hbb concentration change across all channels. This visual check revealed potential activations in several channels, and in at least one condition and age point, including channels: 1, 2, 8, and 9 (on the somatosensory region); and channels 10, 11, and 14 (on the right STS). Our primary analysis consisted of building a model of the mean concentration change (baseline corrected) using 5-second epochs after stimulus onset, i.e., mean concentration changes in the following time windows:]0, 5],]5, 10],]10, 15],]15, 20], and]20, 25]. Visual inspection of the dependent variable using a QQ-plot revealed deviations from the Normal distribution, particularly at the tails, prompting us to apply a power transformation with an exponent of 5/7 to the data, which we used in all subsequent analyses, see (Lisboa, Miguel, et al., 2020b, 2020a) .

For modeling, we followed a longitudinal data analysis approach (Diggle et al., 2002; Mirman, 2016). As potential predictors we considered the following categorical predictors: time window (5 levels:]0, 5],]5, 10],]10, 15],]15, 20], and]20, 25]), age (2 levels: 7 Months and 12 Months), and condition (2 levels: affective and discriminative); in addition, we also considered the proportion of interaction time with maternal touch as covariate. In the random effects component of the model we included a random intercept per dyad, We fitted separate linear mixed models for each channel and chromophore; model estimation was done using the *nlme* package in R (Pinheiro et al., 2018).

Model selection was made using a model comparison approach with a log-likehood test to decide if additional predictors should be included. The order of inclusion of predictors was: null model, time window, age, condition, 2-way interactions and three-way interaction, proportion of interaction time with maternal touch; saturated model (4-way interaction).

Statistical inference involved computing 95% confidence intervals for estimated means and conducting one-tailed tests against the baseline of zero (>0 for HbO2 and <0 for HHb). Activation within a time window was deemed significant if the corrected *p*-value for the contrast with the baseline was < .05. When at least one condition had a significant activation (inside a time window) we computed all pairwise comparisons of the interaction age x condition, holding the time window constant (*p*-value corrected using Sidak method (Šidák, 1967)), and also computed the slope of the covariate (proportion of interaction time with maternal touch) for the interaction age x condition, holding the time window constant.

When reporting estimated means and confidence intervals, we did not back-transform the data to the original units (inverting the power transformation). All statistical tests were performed using the R package *emmeans* (Lenth, 2022). The calculation and statistical test of slope of the covariate was done using the *emtrend* function in *emmeans*.

5.4 Results

To provide a clearer presentation of our findings and our modeling approach to fNIRS data, we first present the results comparing discriminative and affective touch, and at 7 and 12 months of age. In the second part, we present the main findings that take into account the effect of the proportion of interaction time with maternal touch in the infant's brain responses to discriminative and affective touch. The analysis consisted of fitting linear mixed models using time window, age, condition, and proportion of interaction time with maternal touch as potential predictors (see Methods). The model comparison step concluded that the best-fit model was the saturated model (that includes the 4-way interaction time window, age, condition, and proportion of interaction time with maternal touch) – i.e., globally, adding the proportion of interaction time with maternal touch as a predictor explained more variance of the mean concentration change above what was explained by time window, age, and condition. Visualization of the mean concentration change, per channel, and for the interaction age point x time window x condition is depicted in Figure 8 of Supplemental Materials (for the subset of channels that had at least one activation). We report both oxyhemoglobin (HbO2) and deoxyhemoglobin (Hbb) activations for completeness, but when interpreting the findings focused solely on HbO2 hemodynamic activity, following the approach in previous fNIRS studies (Lloyd-Fox et al., 2016; Dravida et al., 2017; Luke et al., 2021).

5.4.1 Affective vs. Discriminative Touch

Significant activations were detected in both the affective and discriminative touch conditions and in both age groups. At the 7-month age point, we observed activations solely in the channels located in the somatosensory cortex. In the affective condition, we observed a significant increase in HbO2 concentration at channel 1, specifically in the time-windows: [15, 20[, $t(42) = 3.22$, $p < .05$; and [20, 25[, $t(42) = 3.01$, $p < .05$. Similarly, in the discriminative condition and channel 1, there was a significant increase in HbO2 during the time-windows [10, 15[, $t(42) = 3.29$, $p < .05$; and [15, 20[, $t(42) = 2.71$, $p < .05$. Additionally, for channel 2, a significant increase in HbO2 concentration was observed during the time-window [10, 15[, $t(42) = 2.86$, $p < .05$).

At 12-month-olds, the affective touch condition had a significant increase in HbO2 in channel 9 (somatosensory cortex) in the time-window [15, 20[, $t(42) = 3.23$, $p < .05$, and a significant decrease of Hbb at channel 2 in the time-window [15,20[, $t(42) = -2.87$, $p < .05$. In the discriminative touch condition, there was a significant decrease of Hbb at channel 8 during the time-window [0,5[, $t(42) = -3.11$, $p < .05$. For the channels located in the posterior superior temporal sulcus, significant effects were observed but only in the affective touch condition. There was a significant increase in HbO2 at channel 11 during the time-window [0, 5[, $t(42) = 2.85$, $p < .05$ and, at channel 14 during the time-window [15, 20[, $t(42) = 3.23$, $p < .05$. Finally, there was a significant decrease of Hbb at channel 10 during the time-window [20,25[, $t(42) = -2.69$, $p < .05$.

5.4.2 Association Between Maternal Touch and the Infant's Brain Response to Affective/Discriminative Touch

The main analysis consisted of testing the trend (slope) in the covariate (proportion of interaction time with maternal touch). This was done per channel (for the subset of channels that had at least one activation) and for the interaction age x condition, holding the time window constant (i.e., within one particular value of the time window, the slope was calculated and tested for the combinations in age x condition). A statistically significant *positive* slope means that mothers who touch more are associated with *increased* mean concentration change in the infant's touch task; a *negative* slope means that mothers who touch more are associated with *decreased* mean concentration change in the infant's touch task. Only channel 1 (in the left somatosensory cortex region) and channel 14 (in the right temporal cortex region) had at least one significant slope. The results can be observed in Figure 10 which shows the trend per time window. All the slopes that were statistically significative are presented in Table 4.

Concerning affective touch, at 7 months, infants of mothers who touched more during the free play task had a higher HbO2 concentration change in channel 14 and inversely had a lower HbO2 concentration change in channel 1. At 12 months, only one channel had a significant slope: infants of mothers who touched more during the free play task had a higher HbO2 concentration change in channel 14. Regarding discriminative touch, at 7 months, infants of mothers who touched more during the free play task had a higher HbO2 concentration change in channel 14. At 12 months, they had a lower HbO2 concentration change in channel 1.

In summary, infants of mothers who touched more during the free play task had the following pattern for affective touch: higher HbO2 activation in channel 14 in the right temporal region, both at 7 and 12 months; lower HbO2 activation in channel 1 in the left somatosensory region, but only at 7 months. For discriminative touch, infants of mothers who touched more during the free play task had the following pattern: higher HbO2 activation in channel 14 in the right temporal region, but only at 7 months; lower HbO2 activation in channel 1 in the left somatosensory region, but only at 12 months.

Table 4

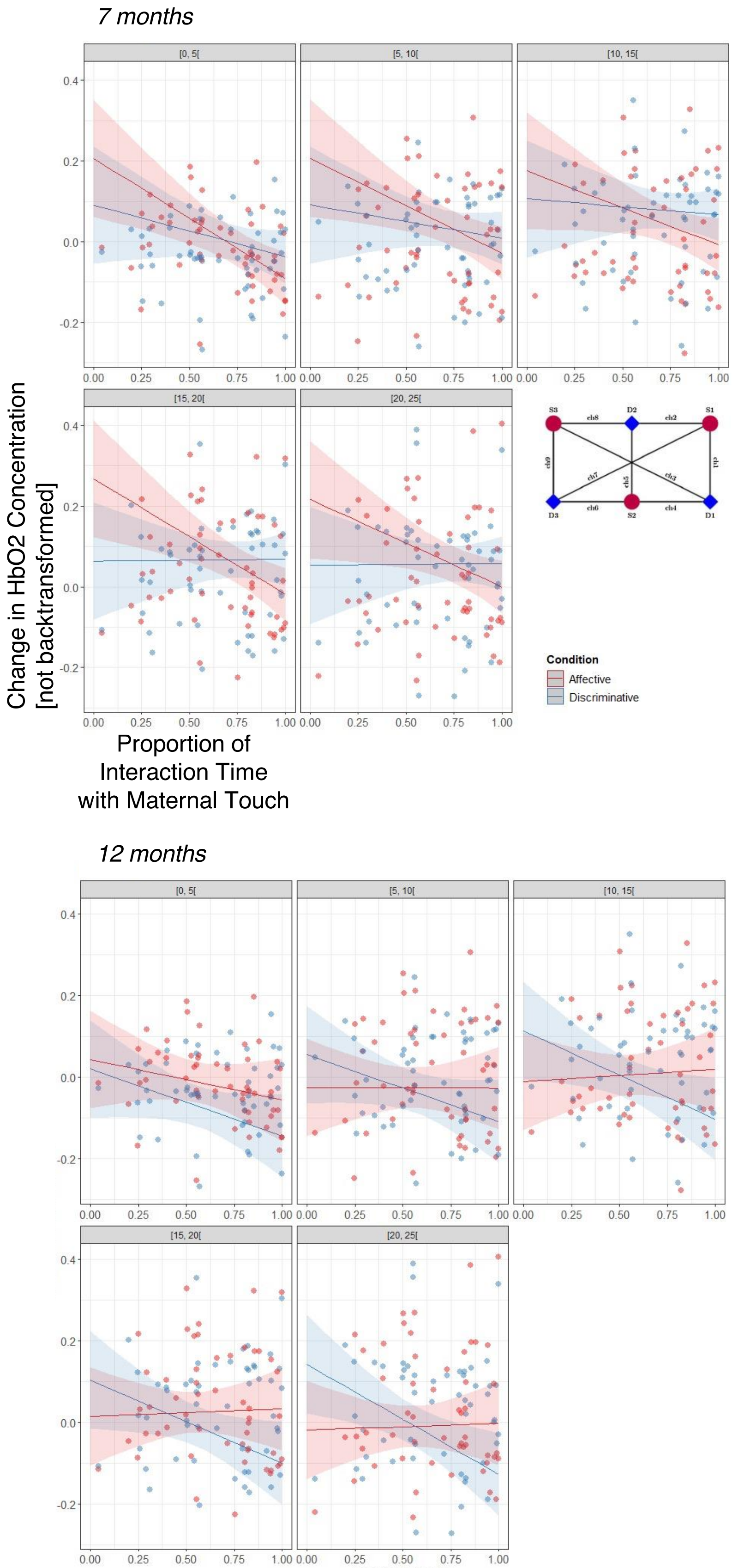
Trend (slope) of proportion of interaction time with maternal touch. The table contains only the subset of channels that had at least one HbO2 activation and one significant slope. The slope β was computed per channel, for the interaction age x condition, holding time window constant.

Affective Touch						Discriminative Touch					
Age	Channel	Time window	ß	SE	Corrected *p*-value	Age	Channel	Time window	ß	SE	Corrected *p*-value
7 mo	1	]0, 5]	-0.298	0.099	0.003	7 mo	14	]0, 5]	0.185	0.088	0.038
		]5, 10]	-0.235	0.099	0.018		14	]15, 20]	0.220	0.090	0.013
		]15, 20]	-0.286	0.099	0.004						
		]20, 25]	-0.216	0.099	0.030						
	14	]10, 15]	0.177	0.089	0.046						
		]15, 20]	0.279	0.089	0.002						
		]20, 25]	0.199	0.089	0.025						
12 mo	14	]5, 10]	0.252	0.093	0.007	12 mo	1	]10, 15]	-0.216	0.105	0.039
		]10, 15]	0.290	0.093	0.002		1	]15, 20]	-0.269	0.105	0.010
		]20, 25]	0.315	0.903	0.001						

Figure 10

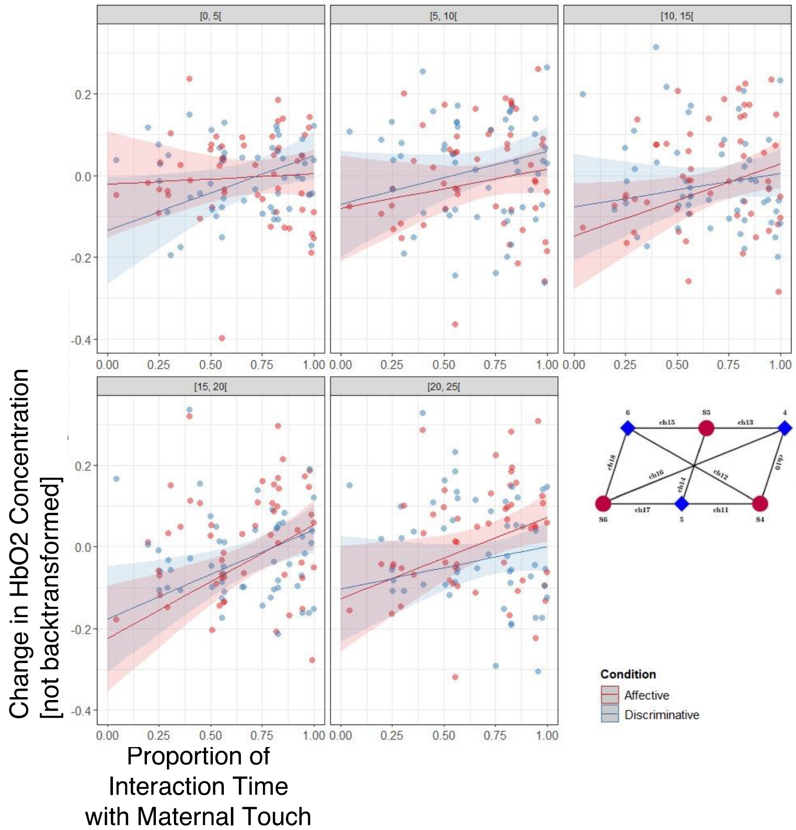
Scatter plots of HbO2 concentration change and proportion of interaction time with maternal touch. The slope of proportion of interaction time with maternal touch, estimated by the model, is superimposed for affective touch (red line) and discriminative touch (blue line). The plots are presented for channel 1 (situated over the left somatosensory region) and 14 (positioned over the right temporal region of the cortex); each individual panel corresponds to one time window and each point in the plot represents an individual infant. The shaded red and blue areas represent the 95% confidence intervals. To illustrate the data trend, all associations are included, even when the slope is not statistically significant.

Channel 1

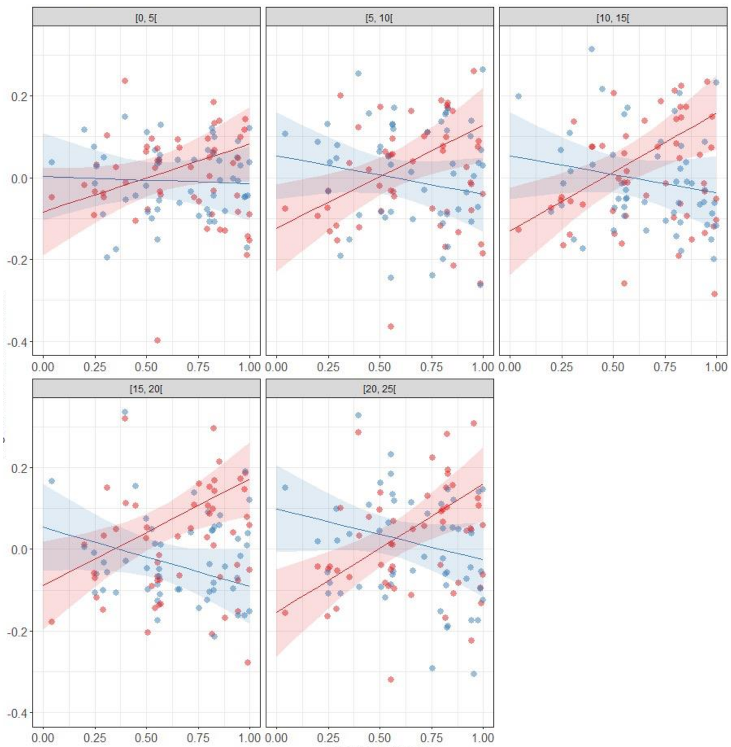

7 months
[0, 5[
[5, 10[
[10, 15[
[15, 20[
[20, 25[
0.4
0.2
0.0
-0.2
0.00
0.25
0.50
0.75
1.00
Change in HbO2 Concentration
[not backtransformed]
Proportion of
Interaction Time
with Maternal Touch
S3
D2
S1
D3
S2
D1
ch8
ch2
ch9
ch7
ch5
ch3
ch1
ch6
ch4
Condition
Affective
Discriminative
12 months

Channel 14

7 months



12 months



To gain further insights into our results, we also conducted a post-hoc pairwise comparison of the estimated mean HbO2 concentration change – see Table 5. All pairwise comparisons were computed for the two-way interaction age x condition, holding channel, and time window constant (*p*-value correction was done using the Tukey method). Only pairwise comparisons in channel 14 were significant. We found a significant decrease of HbO2, from 7 months to 12 months, for discriminative touch on time window [15, 20[. No significant differences were found in the affective touch from 7 to 12 months. Finally, our results also showed that when mother touch more in their infants the hemodynamic response increases for affective touch and decreases for discriminative touch, in channel 14 on time windows [5, 10[, [10, 15[, [15, 20[and [20, 25[but only at 7 months.

Table 5

Significant Hb0$_2$ responses to discriminative and affective touch between 7 and 12 months

7 M Affective – 12 M Affective						7 M Discriminative – 12 M Discriminative					
Channel	Time window	M	SE	t	Corrected *p*-value	Channel	Time window	M	SE	t	Corrected *p*-value
No significant results						14	[15, 20[	0.365	0.122	3.000	0.015
7 M Affective - 7 M Discriminative						12 M Affective - 12M Discriminative					
Channel	Time window	M	SE	t	Corrected *p*-value	Channel	Time window	M	SE	t	Corrected p-value
No significant results						14	[5, 10[	0.347	0.117	-2.977	0.016
							[10, 15[	0.380	0.117	-3.260	0.007
							[15, 20[	0.407	0.117	-3.486	0.003
							[20, 25[	0.439	0.117	-3766	0.001

Note. Channel 14 is located in the temporal region.

5.5 Discussion

In this study, we examined the association between the frequency of maternal touch an infant receives and the infant's brain responses to affective and discriminative tactile stimuli, in two regions: left somatosensory cortex; right temporal cortex (covering the STS, Superior Temporal Sulcus). Maternal touch was measured using a play task without objects and in a novel environment. Infant’s brain responses to touch were measured using fNIRS during a touch task; two tactile stimuli were applied to the infant's forearm in the touch task: a wooden block, designed to activate the discriminative touch pathway; and slow water brush strokes, designed to activate the affective touch pathway. Participants were measured longitudinally at 7 and 12 months.

Our contribution was to build on an examination of the association between maternal touch and infant’s brain activations to touch. The approach was modeling the mean concentration of HbO2 change and testing if the frequency of maternal touch explained additional variance; after, a detailed analysis of the association between the covariate (frequency of maternal touch) and the dependent measure was conducted, by testing the slope in the covariate. To the best of our knowledge, this is the first study to explore this association specifically in infants; previous reports concern 5-year-old (Brauer et al., 2016). We observed that how often an infant receives maternal touch is a predictor of the infant’s brain responses, beyond what is explained by other predictors (time, age, and touch condition). There were two channels in the fNIRS array that had HbO2 activations and for which the slope of the frequency of maternal touch covariate was different from zero: channel 1, located in the somatosensory cortex; and channel 14, located in the pSTS.

Our results at 7 months indicated that infants of mothers that touch more had *reduced* activation in the somatosensory cortex, but only when the infants were exposed to affective touch. In contrast, infants of mothers who touch more had *higher* activation in the STS for both affective and discriminative touch. However, at 12 months, unlike 7-month-olds, there was an interaction between maternal touch and hemodynamic response to affective and discriminative touch: in the STS, infants of mothers that provided higher levels of touch, had an *increased* activation for affective touch, but no trend was detected for discriminative touch; in the somatosensory cortex, infants of mothers that provided higher levels of touch had not detectable slope to affective touch but had *decreased* responses to discriminative touch. Each one of these findings is discussed next.

At 7 months, maternal touch behavior was associated to the infant’s brain activation to affective and discriminative touch in both the somatosensory cortex and pSTS. Specifically, infants who experienced more maternal touch displayed reduced HbO2 levels within the somatosensory cortex but higher levels of HbO2 in the STS when exposed to affective touch. These findings may indicate that mothers who expose their infants to more touch interactions could enhance early developmental changes in the infant's neural processing. Moreover, typical mother-infant interactions during the early stages of development tend to be marked by a high frequency of maternal tactile stimulation, particularly touch with affectionate goals toward their infants (Ferber et al., 2008; Jean et al., 2009; Stack, 2004). Therefore, this heightened exposure to maternal touch could potentially reduce the metabolic demand, as indicated by lower HbO2 levels in the somatosensory cortex. This, in turn, might increase the infant's sensitivity to social cues and tactile experiences, leading to the activation of more mature brain regions involved in processing social touch, such as the STS.

We also documented an association between levels of maternal touch and heightened responses to discriminative touch in the STS. At 7 months, but not at 12 months, there were no significant variations in how maternal touch influenced neural responses to both affective and discriminative tactile stimuli. These findings suggested that 7-month-old infants in contrast to 12-month-olds, may not reached the necessary neural maturity to differentiate between the nuanced characteristics of these two tactile stimuli (gentle brush strokes vs. light taps of touch), despite variations in maternal touch frequency. To potentially facilitate this differentiation at 7 months, it may be required to recreate more naturalistic conditions that enhance the activation of CT fibers, such as encouraging mothers to gently caress their infants (Mayorova et al., 2023). This approach is consistent with prior research that has highlighted various factors, aside from stroke velocities, such as human touch temperature (Ackerley et al., 2014) and the social bond with the infant (Croy et al., 2016; Croy et al., 2019; Croy et al., 2022) which have been shown to enhance CT-fibers optimal stimulation.

Furthermore, in examining the relationship between maternal touch frequency and the two dimensions of tactile stimuli, we observed interesting similarities between the findings at 12 months and those at 7 months. There were no statistically significant differences in the association patterns between affective touch over the STS between age points. This observation holds significance, especially when considering that some studies have reported the primary recruitment of social brain areas, including the STS and prefrontal cortex, in processing affective stimuli between 10 to 12 months of age (Kida & Shinohara, 2013; Miguel, Gonçalves, et al., 2019). Our results suggest that consistent exposure to higher levels of maternal touch during the first year of life may instigate neural adaptations within the STS, making it more responsive to social cues transmitted through touch at an early age (i.e., 7 months). This also suggests that maternal touch, as an early and consistent source of sensory stimulation, may play a pivotal role in shaping the neural mechanisms underpinning the processing of affective touch during infancy. Similar results were found with 5-year-old children who experienced more maternal touch during face-to-face interactions which exhibited greater resting-state functional connectivity in social brain areas, particularly the STS (Brauer et al., 2016). However, to our knowledge this is the first study to explore this association in infants, as such, further investigation is warranted to elucidate the precise mechanisms and implications of these suggested adaptations, as well as how they are related to other psychosocial factors present in the infant natural environment, such as other communication modalities, the infant motor development, the infant's response to maternal touch behavior and the different types of touch performed by the mother in the interaction.

Our interpretation of the findings should, nevertheless, consider some limitations of this study. The sample in this study from a homogeneous community sample of mostly middle-class college-educated women from the North of Portugal, without strong indicators of psychopathology; the sample size was also relatively modest – this warrants expansion in future research to enhance the generalizability of these findings. Additionally, further investigation is needed to explore the precise mechanisms underlying these observed neural responses, including a more nuanced examination of the specific characteristics of maternal touch behaviors, such as touch intensity and the functional role of the touch behavior.

Future research endeavors should also explore the functional consequences of these neural responses. How do these changes in neural processing relate to behavioral and socio-emotional outcomes in infants? Does the evolving sensitivity to maternal touch play a role in shaping the quality of parent-infant interactions and attachment relationships (Addabbo et al., 2021; Mateus et al., 2021)?

5.6 Conclusion

In conclusion, this study provides valuable insights into the intricate relationship between maternal touch behavior and infant neural responses to tactile stimuli during the first year of life. The observed changes in hemodynamic patterns suggest that the infant brain is dynamically adapting to maternal touch experiences, which, in turn, influence the processing of both affective and discriminative touch. It underscores the significance of maternal touch in shaping early neural development and lays the foundation for further exploration into the multifaceted nature of touch in infant development and its long-term implications for social and emotional well-being. As we continue to unravel the complexities of early tactile experiences, we move closer to comprehending the profound influence of caregiving on infant neurodevelopment and overall thriving.

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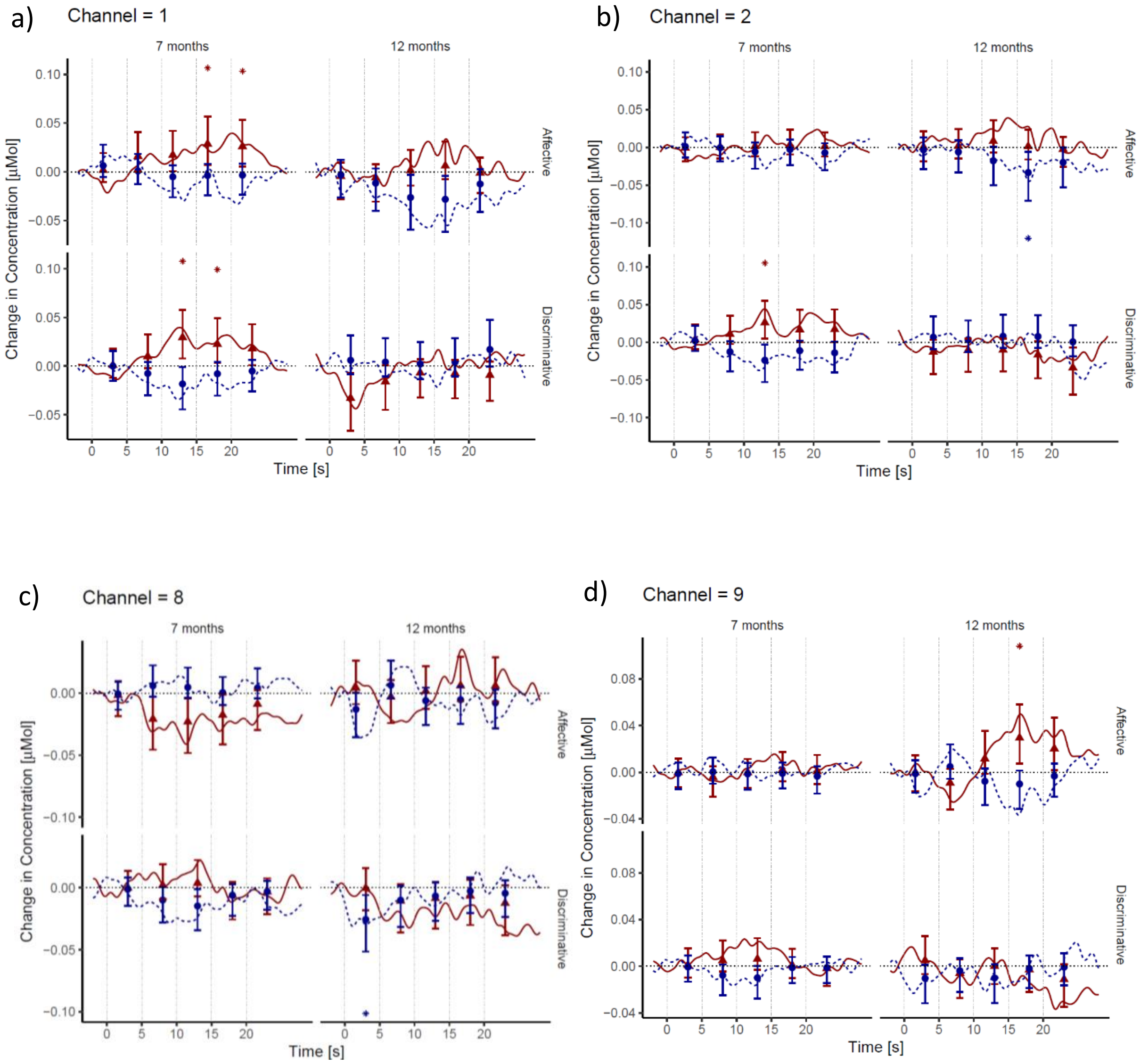
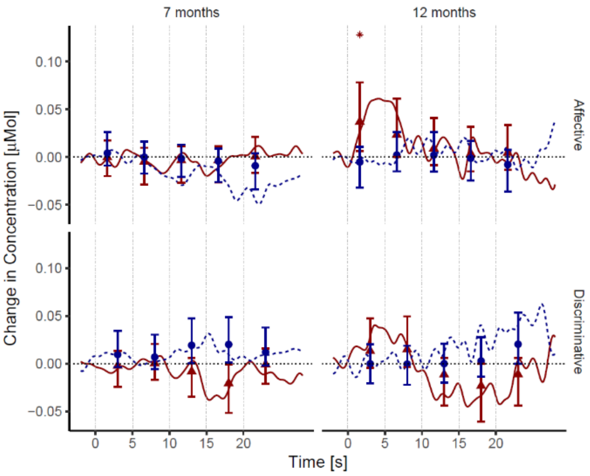
5.8 Supplemental Materials

Supplemental Figure 8

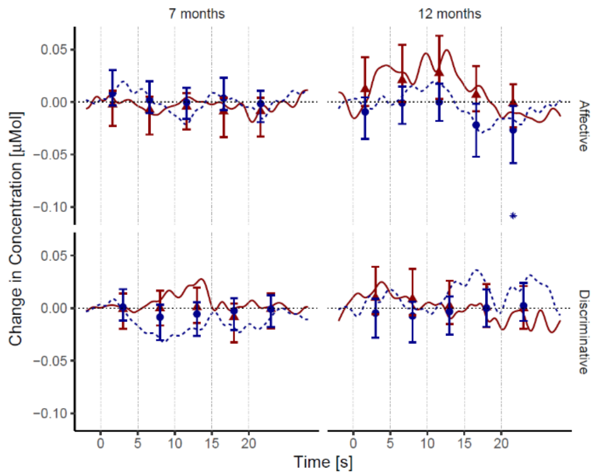
Grand mean average of baseline corrected HbO2 and Hbb concentrations for the two experimental conditions (affective and discriminative touch) in both age points (7 months and 12 months) on somatosensory cortex and posterior superior temporal sulcus channels.



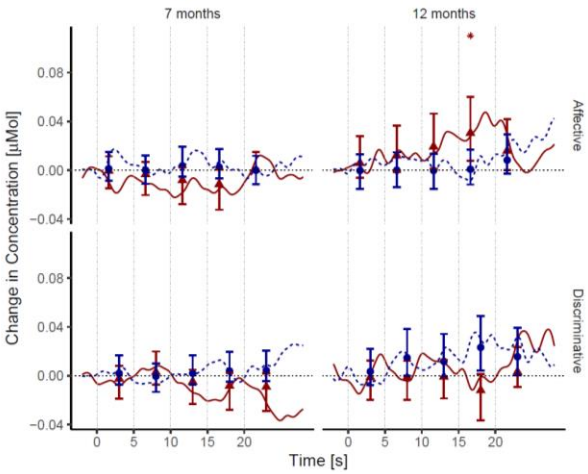
e) Channel = 11



f) Channel = 10



g) Channel = 14



Note: The plots representing the channels of the somatosensory cortex are labeled as a), b), c), and d), while the plots representing the channels of the posterior superior temporal sulcus are labeled as e), f), and g). The zero timepoint marks experimental stimulus onset; the total trial duration was 25 seconds. Lines plot the grand mean concentration changes in HbO2 (red line), and Hbb (blue dashed line). For all epochs,]0, 5],]5, 10],]10, 15],]15, 20],]20, 25], we calculated the estimated mean along with its corresponding 95% confidence interval. When the corrected *p*-value for the comparison with baseline was significant, we placed an asterisk above the respective confidence interval (single-tailed test, greater than zero for HbO2, and below zero for Hbb).

CHAPTER 6

General Discussion

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6.1 General Discussion

Touch plays a crucial role in caregiver-infant interactions, with caregivers employing different types of touch for various purposes, such as expressing affection, stimulating, playing, or comforting the infant. To analyze touch behavior, several observational coding systems have emerged in the past three decades, primarily focused on parent-infant interactions. These observational measures offer benefits such as detail, objectivity, and applicability in capturing the nuances of natural interactions. Nonetheless, due to the fragmentation of disciplines and research groups, each emphasizing different facets of touch, methodologies, measures, and distinctions between clinical and normative samples, an integrated perspective on this topic has been lacking (Field, 2019). Consequently, the social touch construct remains poorly defined and understood (Cascio et al., 2019; Gliga et al., 2019), contributing to significant disparities in the study, operationalization, and definition of touch across various instruments.

There is, nevertheless, the ongoing progress in conceptualizing and operationalizing social touch and substantial advancement has been made in recent decades. Prior research has underscore the importance of exploring various types of touch and their functional roles, supported by studies showing how this impacts a wide array of developmental processes, including infant’s emotional regulation (Moreno et al., 2006; Peláez-Nogueras et al., 1996; Jean & Stack, 2012; Jean et al., 2014), attachment styles (Weiss et al., 2000; Beebe et al., 2010), and infants' attentional and exploratory behaviors in response to social cues (Della Longa et al., 2019; Addabbo et al., 2021).

However, touch research has primarily focused on maternal touch behavior in infants under six months, especially in still-face or face-to-face interactions performed in highly controlled laboratory environments. Conversely, research that explores how parental touch adapts in more naturalistic and dynamic interactional contexts is limited, particularly within object-oriented play tasks. Indeed, in a recent report, the World Health Organization highlighted that play interactions in infancy serve as a crucial mode of active engagement, promoting early learning and responsive caregiving (WHO et al. 2018). These object-oriented play interactions are significant contexts for the development of essential cognitive milestones that typically emerge in the second half of the infant first year of life, for example object exploration and joint attention during object play tasks (Bertenthal & Boyer, 2015;

Needham, 2009). Furthermore, some studies suggest that social touch may have a role in the development of infants' object exploration (Tanaka et al., 2021; Della Longa et al., 2019; Simpson et al., 2019; Bard et al., 2014).

However, our comprehension of how mothers employ tactile interactions during naturalistic play tasks, whether object-oriented or non-object-oriented, in the first year of life (7 and 12-month-old infants, in this dissertation) is still lacking. This gap in knowledge is significant due to our incomplete understanding of how maternal touch develops and its potential influence on critical cognitive and motor skills, including object exploration, joint attention, crawling, and walking during this essential developmental phase (Botero, 2016). Additionally, our exploration of contextual factors, such maternal touch frequency, are relate to infants' brain responses to affective and discriminative touch (Cascio et al., 2019), are still in its early stages. These considerations provided the basis for the four studies discussed in the current dissertation, which I will elaborate on in the following sections.

In our first study (**Chapter 2**), we conducted a systematic review with the primary aim of organizing the diverse literature on observational measurement of parental touch behaviors. We selected work that concerned interactions with infants under 24 months. Despite significant efforts to create observational measures for assessing the complexity of parental touch, discussions surrounding the diverse conceptualizations and operationalizations of touch remain limited. Moreover, the process of selecting the most suitable observational instrument can be a challenging task, given the multitude of practical and psychometric factors that must be taken into account. The review covered factors such as measure availability, psychometric reliability, the specific construct being measured, the target population, interaction context, and instrument popularity. As such, our systematic review, conducted in accordance with PRISMA guidelines, identified 45 studies that incorporated an observational measure of touch. From this pool of studies, we identified 12 distinct instruments originating from various countries, with the United States being a prominent contributor to touch research. Our findings also indicated an increasing interest in investigating caregiver touch patterns, especially from 2010 to 2022~~.~~ The majority of studies were concentrated on infants below six months of age and were predominantly carried out in face-to-face interactions or still-face procedures. Notably, the Mother Touch Scale (MTS) stood out as the most frequently used assessment tool in these studies. Subsequently, we outlined the key features of each observational tool and organized them into categories guided by established conceptual frameworks for touch analysis found in prior literature (Burgoon et al., 1996 cited in Hertenstein et al., 2006; Brzozowska et al., 2021; Hertenstein, 2002). These categories were determined based on their approaches to assessing caregiver touch behavior: strictly observational (emphasizing observable touch behaviors), functional (assessing the functional role of touch behaviors), or mixed (integrating both observational and functional aspects).

It is important to highlight that 75% of the instruments included a functional assessment of touch behavior only in the last 20 years, suggesting a research trend towards better understanding of the role touch performs in the interaction. Although we observed that some observational tools share similar features or organizational structures due to their development from previous tools, numerous challenges persist. These challenges cover the process of coding touch using a microanalytic method: it can be time-consuming and entails a steep learning curve, the terminology used to describe behavioral and functional aspects of touch is inconsistent, variations in the operationalization of categories describing similar types of touch, and the absence of detailed guidelines for replicating coding systems. Additionally, there is also a lack of the neuropsychological perspective of touch, which includes the relationship between affective touch and CT- fibers. A recent review has explored this relation, as well as the semantically related terms found in the literature, such as affectionate touch and social touch, shedding some light on the extent to which these different terminologies are interconnected (Schirmer et al., 2023). Future studies concerning terminological and consistency of definitions for the different “functional” role of touch should be addressed in further research.

Regarding psychometric evaluation, the studies related to these instruments were limited, with a notable absence of formal validity assessments. To enhance accuracy and reliability, the field would greatly benefit from more comprehensive psychometric research. Achieving greater uniformity and consistency in assessing touch constructs, developing machine learning algorithms to facilitate the coding process (e.g., Doyran et al., 2023), and providing open-access materials for formal training and instrument replication are potential avenues for advancement in the field. Finally, our review assessed the current state of research in this field, identified potential topics warranting further investigation, and explored potential directions for future studies. This review has also laid a solid groundwork for the enhancement of standardized and consistent observational assessment tools.

As mentioned earlier in this chapter, a considerable knowledge gap remains regarding how mothers employ touch to structured infant interactions(Field, 2010; Hertenstein, 2002; Stack, 2010), particularly in the context of object-focused play tasks during the latter half of an infant's first year. This gap has also been elucidated in our systematic review. Indeed, object-oriented play during the first year of life is pivotal for the emergence of crucial developmental milestones, including object exploration and joint attention (Bakeman et al., 1990; Bertenthal & Boyer, 2015; Needham, 2009). Consequently, the second and third studies of this dissertation aimed to explore how mothers use touch to interact with their infants during social interactions. We used a structured social interaction task comprising three distinct tasks: (1) free play with toys, (2) free play without toys, and (3) object play with a challenging toy.

In our study 2, detailed in **Chapter 3**, we sought to investigate how mothers utilized social touch in their interactions with 12-month-old infants. We chose to analyze this age group first since infants present more complex play interactions with adults, compared with 7 months old (De Onis, 2006; Bertenthal & Boyer, 2015). Our choice was also influenced by our plan to investigate the association between maternal touch and the infant's brain response to affective touch in the pSTS in our next study, and this response was also suggested to emerge by the end of the first year of life (Miguel, Gonçalves, et al., 2019). We found that the frequency of maternal touch varies depending on the nature of play task, with mothers touching their infants less during triadic object-oriented tasks compared to dyadic interactions without toys. The levels of touch observed in the dyadic play task were consistent with previously reported values (Hertenstein, 2002; Jean et al., 2009; Stack, 2004; Stack & Muir, 1990, 1992). Moreover, the categories of touch used by mothers varied based on the task demands (e.g. Ferber et al., 2008; Jean & Stack, 2009). In dyadic interactions without toys, mothers employed various touch categories, including static, playful, caregiving, affectionate, jiggle/bounce, and rough touch. These categories could be used to provide physical support, maintain engagement, and elicit positive affect from infants (e.g. Cordes et al., 2017; Egmose et al., 2018; Ferber et al., 2008; Lowe et al., 2016; Stack & Muir, 1992). The findings suggested that these categories of touch may serve as a sensitive tool used by mothers to maintain their highly mobile and exploration-oriented 12-month-old infants engaged in dyadic interaction. The exception was rough touch, which we hypothesize might also be used to enhance infant engagement in the interaction but through more intrusive touch-types, such as pulling or pushing.

On the other hand, when engaged in object-oriented tasks, the presence of objects may reduce the necessity for tactile stimulation to maintain the infant's attention and engagement in the tasks. Interestingly, during challenging object-oriented play tasks, mothers increased their use of touch compared to object-play tasks. They specifically used a higher frequency of object-mediated touch, possibly attempting to assist the infants in completing a task beyond their developmental capabilities, such as spatially orienting a shape for insertion into a slot is typically achieved only by 24-month-olds (Smith et al., 2014; Street et al., 2011). This category of touch may have a role in scaffolding the development of new skills (Wood et al., 1976), such as guiding the infant's hand to help them fit the pieces into the shape sorter toy. This study suggested that mothers adapt their tactile behavior in accordance with the challenges and complexities posed by the task demands, aligning with the developmental skills of their infants.

Considering the results of study 2, which showed the effect of the play tasks on maternal touch patterns at 12 months old, in a third study (**Chapter 4)** we explored the trajectory of maternal touch using the same play interactions with infants, at 7 and 12 months. This was done using the same experimental design and coding system as the previous study, with infants at 7 and 12 months. The experimental design and coding system were the same as described in study 2; however, the interaction times at 7 months were shorter, lasting 3 minutes and objects selected for play were developmentally appropriate. To uniformize these differences in task duration, we used the proportion of time spent in touch as our dependent variable. Our findings indicated an overall decline in maternal touch across all play tasks from 7 to 12 months. When the infant was 7 months of age, mothers still continued to touch their infants more frequently during dyadic interactions compared to triadic object-oriented play, aligning with the results of Study 2. This decreasing trend is also consistent with previous research (e.g., Ferber et al., 2008; Fausto-Sterling et al., 2015; Leiba, 2000) and may be related to infants significant developmental changes, including advancements in locomotor, and cognitive, linguistic, and social abilities observed in this period (Bertenthal & Boyer, 2015; De Onis, 2006; Green et al., 1980; Needham, 2009). These changes in maternal touch behavior suggest that mothers’ touch behavior is sensitive to the growing autonomy and evolving developmental characteristics specific to each age group. The primary contributor to this overall decline was the reduction in the most common touch categories, particularly static and object-mediated touch. However, this trend was also evident, albeit to a lesser extent, across all other touch categories (affectionate, playful, caregiving), apart from rough touch in dyadic play at 12 months. The increase of rough touch category may be an intrusive way to physically move their high mobile infants to a different location or interrupt their ongoing activities to redirect their attention for the dyadic task. This finding is consistent with a study by Green et al., (1980), which suggested that increased infant locomotor skills led to more instances of mothers intervening and guiding their infants' activities in the latter part of the first year.

The tasks assigned to the mothers all required the infants to remain seated and engaged in the given activity (dyads played on mat on the floor). Maternal use of static touch appears to be an important tool for achieving this goal. However, it's important to note that infants have different developmental needs based on each age point age, which could explain variations in the static touch frequency. For instance, independent sitting typically develops between 4 and 9 months of age (De Onis, 2006), while joint attention emerges after 9 months (Bertenthal & Boyer, 2015). Consequently, at seven months, mothers may use static touch to provide physical support, helping infants remain seated during play and enhancing their task-related attention. In contrast, at twelve months, infants are more mobile, though static touch may serve to provide comfort and set boundaries for their exploration, allowing them to focus on the play activities proposed, particularly in the absence of objects.

Moreover, the complexity of object-oriented tasks, especially those involving challenging object play, influences how mothers structure their interactions with their infants. This complexity is reflected in the increased use of the object-mediated touch category, which may assist infants in activities involving objects and promote skill development. Essentially, the object-mediated category may have the potential to support infants to complete tasks beyond their developmental level, thus scaffolding skill development (Wood et al., 1976). For instance, mothers might use their hands to guide their 7-month-old infants in producing sounds with a squeezing toy. Alternatively, as also described in Study 2, they may assist their 12-month-old infants in tasks typically only achievable by 24-month-olds. This pattern is consistent across different age points; however, mothers use considerably more object-mediated touch at 7 months compared to 12 months. One possible explanation for these differences may be related to the acquisition of motor skills. At 12 months infants' interactions with objects become more advanced, and they allocate more time to exploring toys during social engagements, as suggested by Bakeman et al., 1990; Herzberg et al., 2020; and Schatz et al., 2020. This increasing interest in object exploration aligns developmentally with the emergence of joint attention (Bertenthal & Boyer, 2015) improvements in communication and reciprocity skills (Ferber et al., 2008), and the attainment of independent sitting abilities, crawling and walking (Kretch et al., 2023; Schneider et al., 2023; Toyama, 2020). Consequently, infants may gradually rely less on caregivers for object manipulation and exploration, thereby reducing the need for maternal touch-based interactions to fulfill their objectives. From a methodological perspective, there is an alternative explanation for the high levels of object-mediated touch at 7 months: these could be related to the specific choice of objects. Compared to the 12-month task, the 7-month task incorporates two challenging toys instead of one, which were intended to assist infants with lower levels of sustained attention in maintaining engagement with the task. However, this approach may also heighten the requirement for maternal supervision and assistance in supporting the infant with the task.

Additionally, in this study, we employed a Bayesian zero-inflated beta mixed model, as compared to the approach used in the previous study and commonly described in the literature exploring this topic (e.g., Ferber et al., 2008; Jean et al., 2009; Mantis & Stack, 2018). This choice was made because response variables did not follow a normal distribution and also because these variables represent continuous proportions, confined within the range of [0, 1]. Moreover, in the case of the proportion of time spent in each OMTS category, there were many instances where the proportion was zero (for example, when a mother had no instances of rough touch or affectionate touch). Beta regression, a model designed for such dependent variables with a beta-distributed response, was considered appropriate. The beta distribution is defined only in the interval (0, 1), and a zero-inflated model was employed, combining a Bernoulli process to model the presence or absence of touch (the zero-inflated part) and a beta regression to model the non-zero continuous proportion; the model also incorporated a third component, the phi model, which explicitly addresses the variance in the data (Douma & Weedon, 2019). Furthermore, Bayesian estimation allowed considerably more flexibility given the limited sample size, large number of parameters, the zero-inflated distribution and provides more intuitive inference without penalty resulting from multiple comparisons (Matzke et al., 2018; Wagenmakers et al., 2018).

In summary, our research highlights the versatile nature of maternal touch, extending beyond its role in strengthening the mother-infant relationship, a concept well-established in previous research (Hertenstein, Verkamp, et al., 2006; Underdown et al., 2006). It also assumes a pivotal function in structuring play interactions, adapting to the infant's age and the specific demands of the situation. Through tactile interactions, mothers deliver crucial support, regulate infant attention and promote positive emotions, provide support, and offer guidance in navigating objects and exploring their surroundings. These interactions hold the potential to exert a positive influence on infant development, facilitating the acquisition of novel skills and fostering growth across social, cognitive, and emotional domains.

Moreover, a significant knowledge gap exists regarding the connection between contextual factors, such as caregivers' interactions with infants, and the infant's neural processing of specific tactile stimuli (affective and discriminative touch), during early life. To address this gap, the fourth and final study in this dissertation (**Chapter 5**) was conducted. We aimed to investigate whether the frequency of maternal touch experienced by infants during an object-free play session at two age points, 7 and 12 months, is associated with the infants' neural responses to affective and discriminative touch in the pSTS and somatosensory cortex. The brain responses were assessed using a previously published fNIRS dataset (Miguel, Gonçalves, et al., 2019) and behavioral data were the same collected in study 3.

At 7 months, our study revealed that there was an association between maternal touch frequency and infant brain's responses to affective and discriminative touch, depending on the specific brain region measured. Infants experiencing more maternal touch exhibited reduced HbO2 levels in the somatosensory cortex but higher levels in the STS when exposed to affective touch. These results suggest that increased maternal touch interactions may enhance early neural development in infants, aligning with the influence of internal and external experiences on neural responses (Bales et al., 2018; Carozza & Leong, 2021). This heightened maternal touch exposure could potentially reduce metabolic demand, as indicated by lower HbO2 levels in the somatosensory cortex, making infants more sensitive to social cues and tactile experiences, ultimately activating mature brain regions for processing social touch, indicated by the higher levels of HbO2 on STS.

Moreover, we found that increased maternal touch was positively associated with heightened brain responses to discriminative touch in the STS. This effect was observed at 7 months but not at 12 months, suggesting that 7-month-old infants might not have reached the necessary maturity to differentiate between nuanced tactile stimuli (stroking with a brush vs taping using a wooden block), regardless of variations in maternal touch frequency. To promote this differentiation at 7 months, creating more naturalistic stimuli that enhance the activation of CT fibers, such as gentle maternal caressing, may be necessary. This approach aligns with previous research highlighting factors such as touch temperature and the social bond with the infant, which can enhance optimal CT-fiber stimulation (Ackerley et al., 2014; Croy et al., 2016; Croy et al., 2019; Croy et al., 2022).

Our examination of the relationship between maternal touch frequency and two dimensions of tactile stimuli revealed similarities between findings at 7 and 12 months, particularly regarding affective touch responses in the STS. While some studies suggest the primary recruitment of social brain areas such as the STS by the end of the first year of life (Miguel, Gonçalves, et al., 2019), our results indicate that consistent exposure to higher levels of maternal touch during early development may be implicated in neurodevelopmental changes in the STS at 7 months. This suggests that maternal touch, as a consistent source of sensory stimulation, may play a pivotal role in shaping neural mechanisms for processing affective touch in infancy. While similar results were found in 5-year-old children who experienced more maternal touch (Brauer et al., 2016), further research is needed to understand the precise mechanisms and implications of these adaptations and their relation to other psychosocial factors in an infant's environment, such as communication modalities, motor development, and various types of maternal touch.

At 7 months, increased maternal touch was associated with increased levels of HbO_2 in the STS in response to both affective and discriminative touch. However, at 12 months, infants with higher maternal touch levels showed increased HbO_2 responses to affective touch in the STS and decreased responses to discriminative touch in both regions. These results may suggest that the differentiation between affective touch and discriminative touch stimuli only mature at 12 months of age.

The results of this study have significant implications for our understanding of early social and tactile development. The observed alterations in neural responses indicate that infants' brains are actively adjusting to maternal touch experiences, potentially influencing the development of more advanced social and tactile processing abilities. These developmental adaptations are essential for infants as they navigate the complex world of social interactions.

6.2 Limitations and Future Directions

In light of the coverage of this dissertation, this section presents a discussion of limitations and potential avenues for future research that were addressed for each study, with the exception of studies 2 and 3, which are closely interrelated.

Study 1 is, to our knowledge, the first systematic review of observational tools for measuring parental touch behavior during infancy. The review involved a comprehensive search in various datasets without year limitations, providing a detailed description of these tools, their characteristics, and their usage in the literature. It may serve as a valuable resource for researchers when selecting tools for observational studies focusing on parent-infant interactions up to 24 months. However, it specifically covers structured observational instruments designed to assess the quality and quantity of parental touch, excluding studies including multimodal instruments that include various interaction modalities (e.g. Feldman et al., 2004; Feldman & Eidelman, 2007) and self-report measures (e.g., Wilhelm et al., 2001; Trotter et al., 2018). Even though, recent research indicates that self-report and observational measures should be used together to enhance the understanding of touch behavior in parent-infant interactions (Brzozowska et al., 2021). Moreover, only a limited number of gray literature publications, such as conference papers and dissertations, were included in this analysis. Thus, there is need for broader inclusion of various measures and methods, including self-reports and neurophysiological measures, in future research on touch behavior assessment.

Moreover, in future research, it is crucial to develop more instruments, such as The Mother-Infant Touch Scale (Crucianelli et al., 2019) and The Functions of Mother-Infant Mutual Touch Scale (Mantis et al., 2013; Mantis & Stack, 2018), that comprehensively measure both infant and caregiver touch behaviors, acknowledging the bidirectional nature of interactions. Additionally, validating observational touch measures and considering cross-cultural aspects to boost research credibility. Researchers should also work into clarifying assumptions about what intentionality means in parental touch behavior. Furthermore, the field can benefit from improved standardizing the terminology in of touch construct promoting greater conceptual uniformity. On the other hand, extending research to study caregiver touch behaviors with infants beyond 6 months in everyday situations and naturalistic contexts (home, day care institutions) may promote a more ecological view of touch behavior. Finally, examining the interaction of touch behavior with other sensory modalities and its influence on overall infant development is essential to be considered in future research.

Study 2 and 3 have addressed some of the gaps identified in study 1 since we focused on enhancing our comprehension of how maternal touch is employed to structure both object and non-object-oriented play tasks during the second semester of the infant's life. Nevertheless, our data were part from a larger of a larger longitudinal social touch project, where task order followed a predetermined sequence from easiest to most challenging. Thus, we did not counterbalance the tasks between participants, thus we do not know if there was an effect of the task order and how it impacts maternal touch behavior. Nevertheless, this particular design is used extensively in developmental psychopathology studies and is meant to produce a gradient of stress in the dyad. Moreover, our study concentrated exclusively on maternal touch behavior and did not explore infant's touch and the reciprocal influence of infant behavior in different play situations. The various object-oriented touch behaviors were grouped into a single category, object-mediated touch, which could benefit from further exploration to understand distinct patterns and their potential impact on infant development. Furthermore, although we have similar proportions of boys and girls in our sample, we did not consider the influence of infant gender on parental touch patterns. Since infants' gender has suggested to effect caregiving touch this variable should be consider in further research (Fausto-Sterling et al., 2015).

Future research should also explore the relationship between paternal touch patterns (both mother and father) and infant development (cognitive, motor, socio-emotional), utilizing standardized observational measures in a more diverse sample (as our study primarily included highly educated mothers). This approach would offer a more comprehensive understanding of both the direct impact (e.g., how parents' touch behavior supports infant object exploration) and the indirect effects (e.g., how touch behavior creates conducive conditions for encouraging object exploration) of specific touch patterns on infant's global development.

Finally, study 3 brings some light to how maternal touch frequency is associated to infant's brain response to affective and discriminative in somatosensory and STS cortex. However, some methodological challenges were pointed by Miguel, Gonçalves, et al., (2019) whose fNIRS data we used in this study such as, a notable attrition rate among participants, particularly at 12 months; the use of a silent movie as baseline that was intended to engage infants, but its potential impact on hemodynamic responses and needs further investigation; the study could not exclusively target CT afferents, which are difficult to isolate in infants; and the limited number of channels in the fNIRS system constrained the examination of cortical regions and bilaterality. Future research should incorporate more channels to cover regions of interest in both hemispheres. Moreover, we used the total proportion of touch as measure of maternal touch behavior in this study. However, as we showed in study 1 and 2, this measure includes several touch categories from more affectionate to more intrusive. Thus, although we have found an association between maternal touch and infants brain response to affective and discriminative touch future studies should focus also in understanding this association considering each touch category separately, or at least considering broader categories such affectionate, stimulative, and intrusive touch. The most frequent touch category in both age point was not affectionate but static touch was we can observe in study 2 and 3. Since, static touch (e.g., hold the infant in their parent's arms or lap) do not present the CT-optimal characteristics to activate these fibers, it is important to replicate this study to better understand if there are other types of touch that can also activate these fibers and how this tactile information is processed in the social brain. It has been shown that human touch performed by a caregiver presents higher hemodynamic responses to affective touch(Mayorova et al., 2023). As such, it is important to replicate this study not only in more naturalistic environments but also exposing the infants to their caregiver's touch behavior.

6.3 Conclusions

This thesis makes a relevant contribution to the field of touch by offering an up-to-date review of existing observational instruments in literature. It categorizes these instruments based on their primary characteristics, pinpointing commonalities, and inherent challenges within each category. This structured approach to the dispersed literature on the observation of parental touch behaviors during interactions may facilitate the selection of the most appropriate observational instrument for future research and may contribute to the development of more consistent and psychometrically reliable tools for measuring touch. Moreover, identifies key attributes of studies employing these tools, such as target population and interaction context, thus identifying potential gaps in the existing literature that warrant further exploration.

Indeed, the outcomes of this systematic review revealed a predominant focus on infants aged below six months in non-naturalistic laboratory settings, primarily centered on controlled face-to-face interactions and still-face procedures. These findings reveal a gap in the literature which our subsequent studies aim to address. These follow-up studies examine the trajectory of maternal touch during more naturalistic interactions involving both object-oriented and non-object-oriented play tasks in the latter part of an infant's first year of life. Through these studies, we contribute to the field by analyzing how mothers use touch to structure interactions with and without objects, adapting to the developmental needs of the infant and the task's complexity.

Finally, to the best of our knowledge, we conducted the first study examining how maternal touch experienced during infancy is associated with the infant's brain responses to affective and discriminative touch in the pSTS and SS cortex in the first year of life. This thesis provides encouraging evidence to a relatively unexplored area within the literature, shedding light on the role of contextual factors in the development of the social brain during infancy.

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