Virtual Reality (2024) 28:170
https://doi.org/10.1007/s10055-024-01060-6

ORIGINAL ARTICLE

Haptics in social interaction with agents and avatars in virtual reality: a systematic review

Giulio Jacucci[1] · Andrea Bellucci[2] · Imtiaj Ahmed[1] · Ville Harjunen[3] · Michiel Spape[3,4] · Niklas Ravaja[3]

Received: 16 November 2023 / Accepted: 10 October 2024 / Published online: 14 November 2024
© The Author(s) 2024

Abstract

Incorporating the sense of touch through haptics in virtual spaces enables people to communicate emotions and engage in more naturalistic and meaningful social interactions. Advances in haptics and virtual reality technologies and applications have been essential to support researchers in the exploration of mediated social touch in virtual environments. The aim of this work is to review the last decade of research on haptics and virtual reality technologies investigating social touch behavior between human avatars as well as between humans and non-human virtual agents. Our systematic review organizes the variety of the conducted research in three dimensions: the context against which mediated social touch is studied, the types of haptics and virtual reality technology used, and empirical studies including data collected and outcome measures. We discuss the results of the analysis of the three dimensions and present implications for future research. We pinpoint the importance of considering in-the-wild studies and emerging issues on social virtual reality; understanding human touch perception for people with different physical and cognitive abilities, and; creating development tools to broaden the exploration of advanced technological setups.

Keywords Haptics · Mediated social touch · Agent · Avatar · Virtual reality

1 Introduction

Social interaction is increasingly mediated by computers. Over the course of a few decades, we have witnessed how technology started mediating our interactions through voice, text, videos, and soon different formats of mixed reality. Current developments point towards increasing the importance of Virtual Reality (VR) for social platforms, with possibilities to expand modalities of interaction, in particular including the sense of touch. This provides additional tools for more effective emotional and self-expression, and opportunities for networking and communicating. Social touch, specifically computer-mediated touch, has received attention in a variety of fields including neuroscience, psychology, virtual reality and haptics (Huisman 2017; Van Erp and Toet 2015; Della Longa et al. 2022). Mediated social touch in VR, i.e., the simulation or replication of social and emotional tactile interactions and physical contact between individuals within a virtual environment, has the capacity to regulate physiological reactions, amplify trust and fondness, facilitate the formation of connections between humans, and trigger behaviors that foster social cooperation (Van Erp and Toet 2015).

Considering the recent advances in VR technologies and applications, it was the right moment to systematically review the last decade of research on haptics-augmented interaction of humans with a virtual other, either a computer agent or an avatar representation of another human, and to reflect on next steps of research with attention to development of haptics and VR technologies. The aim of this work is to review the existing body of research on mediated touch in virtual environments, focusing on interaction applying haptics with avatars and agents. We analyze contributions by highlighting the context of the research, indicating the

---

✉ Giulio Jacucci
giulio.jacucci@helsinki.fi

[1] Department of Computer Science, University of Helsinki, Helsinki, Finland

[2] Department of Computer Science and Engineering, Universidad Carlos III de Madrid, Madrid, Spain

[3] Department of Psychology and Logopedics, University of Helsinki, Helsinki, Finland

[4] Institute of Collaborative Innovation, Centre for Cognitive and Brain Sciences, University of Macau, Macau, China

situations in which social touch has been studied, the technology used, and empirical studies including data collected and outcome measures in specific contexts.

VR has the potential to offer a rich medium for multimodal communication as haptic hardware can be integrated to provide a realistic sense of experiencing the virtual world physically (Sinclair et al. 2019). The user can touch or be touched in VR by virtual agents or avatars, and can feel the touch via haptics. The recent development of VR authoring tools make it easier to embed humans like virtual agents or avatars and provide scripted functionalities, such as body gestures, and facial expressions, which provides a highly controlled environment that supports the replicability of experiments with human participants and allow to investigate the interplay of different non-verbal modalities in affective interactions with virtual agents. However, while there are many possibilities, haptic technologies are not standardized, well-integrated, or ubiquitous. A wide range of haptics was used for studying social interaction with agents/avatars. Early research focused on the affective outcomes of a study, without giving significant attention to the types of haptics being used for touch presentation. Possibly, this is due to the study context and suitability of the available technological solutions. However, the choice of haptic technology can also impact the user experience. For instance, receiving a vibrotactile touch could be akin to a notification event, much like the vibration alerts we receive on our mobile phones when a message arrives. Alternatively, it might evoke romantic sensations when visualizing a partner's kiss. In contrast, a pressure or squeeze might simulate the feeling of someone holding your hand or initiating a handshake. Thus, haptic technology has the potential to influence one's perception of touch (Ahmed et al. 2016).

Previous reviews and surveys focusing on social touch (Haans and IJsselsteijn 2006; Van Erp and Toet 2015; Huisman 2017; Saarinen et al. 2021; Della Longa et al. 2022; Olugbade et al. 2023) have introduced fundamental neurophysiological mechanisms as well as psychological and behavioral effects of social touch. Neurophysiological level mechanisms from receptors to perception allow to distinguish, for example, between discriminative and affective touch with important implications to placement and haptic techniques (Huisman 2017). Previous research agrees that social touch can be replicated in a mediated environment through haptic technology. For instance, the Midas touch effect, the idea that interpersonal touch has the ability to positively influence prosocial behavior, generosity, and compliance, can be demonstrated in a mediated and simulated environment (Spape et al. 2015; Harjunen et al. 2018). Foundation and background of social touch help to understand the possible effects on wellbeing (Van Erp and Toet 2015), bonding, attitude and behavior (Haans and IJsselsteijn 2006). Effects such as how touch impacts physiological or mental wellbeing (Della Longa et al. 2022), how it can help to communicate or elicit emotions (Saarinen et al. 2021), or how it can function as a behavior modulator (Van Erp and Toet 2015), highlight the importance of social context in mediated social touch.he emotional context surrounding physical contact impacts how the touch is perceived, interpreted and experienced and what kind of behavior it promotes (Huisman 2022).

Mediated social touch has been found to successfully communicate emotions depending on the devices and techniques used, with force feedback being the most promising haptics for this purpose (Huisman 2017). Reviews acknowledge limitations of technology. For instance, the haptic stimuli used, such as vibrotactile or force feedback, offer only partial approximation of an actual human touch (Huisman 2017). Some haptic techniques are more suitable for communication of affect (Van Erp and Toet 2015) and others more suited, for example, for stress-reducing responses (Saarinen et al. 2021). However, analysis on technological possibilities in previous reviews remains in the background, possibly because simple rudimentary haptics allow for the replication of some social touch phenomena and study of physiological, behavioral and emotional response in controlled laboratory experiments.

The most recent surveys consider a variety of different technology setups for augmenting affective touch, providing a comprehensive review of affective haptic system design, including interaction with objects and robots (Saarinen et al. 2021; Olugbade et al. 2023), and detailed analysis of trends and challenges in the field (Vyas et al. 2023). However, these reviews do not explicitly discuss haptic interaction in VR (Vyas et al. 2023) and only touch upon haptic-augmented interaction between humans and virtual entities incidentally (Olugbade et al. 2023).This gap motivated a scoped review focused specifically on mediated social touch with avatars or agents in VR. While haptics-augmented touch with avatars and agents is still an emerging field, it is now moving beyond explorations with more formal and established methodologies, using controlled studies, validated protocols, and standardized measures as well as theoretical frameworks and technology setups (Huisman 2017). The most recent review of studies summarizes psychosocial contextual factors modulating responses to social touch exposure distinguished toucher's characteristics and situational factors (Saarinen et al. 2021). Understanding the most central situational and toucher-related contextual factors provides a viable theoretical framework applicable to all mediated social touch situations. More research is called for in comparing different haptics techniques, for example considering C Tactile (CT) afferents[1] and neurophysiological responses.

---

[1] CT afferents are sensory receptors found in the skin of mammals, primarily activated by gentle tactile stimuli and typically unresponsive

This work is essential for developing haptic technologies that can provide richer and more nuanced sensations in VR, supporting multisensory experiences and conveying concurrent haptic stimulation alongside social cues.

In this work, we report results of a systematic review of recent research on haptic-mediated touch with avatars and virtual agents to answer the following questions:

1. In which **contexts** mediated social touch has been studied in the existing research literature?
2. What VR and haptic **technologies** have been used given the types of contexts in terms of VR setup, modality of interaction, haptics techniques and hardware?
3. What **empirical studies** with what data and outcome measures have been published considering different contexts, in particular what independent and dependent variables are considered in experiments?

In Sect. 2 we describe the method used to retrieve the selection of articles analyzed in this review, following guidelines and best practices for systematic review reports (Page et al. 2020). In Sect. 3 we report the results of the systematic review, organized according to the dimensions defined by our research questions: contexts, technology and empirical studies. In Sect. 4 we discuss the results of the three review objectives and present implications for future research as emerging from our classification, emphasizing the need of conducting in-the-wild studies considering the effect of mediate physical touch on issues of social VR platforms such as harassment; including participants from different groups (e.g., disabled individuals) and; developing support tools to broaden the exploration of advanced technological setups.

2 Method

The selection of publications covered by this work was done through several steps detailed in the following. Overall, the procedure was completed in a systematic way, ensuring reproducibility, and was informed by the PRISMA protocol (Page et al. 2020).

Phase 1 (Identification): Source selection and query formulation

The choice of search engines to adopt was based on the areas covered by the engine and the flexibility in issuing customized queries. After several trials, we chose Web of Science (WoS) as a search engine to perform queries and retrieve publications. The exact query used was:

TS=((haptic OR *tactile) AND (virtual OR VR) AND (agent OR avatar OR character) AND (touch* OR interpersonal OR affective OR social OR mediated OR interaction OR communication) NOT robot).*

The query was devised to retrieve publications simultaneously covering the topics of haptics in virtual reality, virtual agents, and different forms of interaction, and to include related synonyms to this end. We conducted our search on the WoS Core Collection, a comprehensive index that aggregates citation indexes covering the most significant journals, books and proceedings across various fields such as sciences, social sciences, and art & humanities. The *TS* field searches in publications title, abstract, author keywords and *Keywords Plus*[2] (topic search). We wanted to focus on human-virtual agent interaction and we excluded the search term *robot* to filter out, for instance, research on human-robot interaction. The search returned 240 results.

Phase 2 (Screening): Exclusion of publications based on general criteria

We removed one duplicate entry. Since the goal of this review was to cover recent advances in the field, we excluded results published prior to 2010, resulting in the exclusion of 44 entries from the initial set of results. Executing the search on the WoS Core Collection automatically excluded sources that were not in English, as well as patent descriptions, standards, extended abstracts, and Master or PhD theses. We conducted an initial title/abstract manual screening and considered ineligible 107 additional publications. Examples of irrelevant sources were: (i) previous surveys and literature reviews that broadly covered haptic technologies and mixed reality; as well as publication on (ii) pseudo-haptics, that is, the simulation of haptic feedback using non-physical means (e.g., illusion of physical sensations through vision); (iii) haptic feedback used to implement input mechanisms such as text-entry in virtual reality, locomotion techniques or teleoperation.

Phase 3 (Eligibility): Exclusion of publications based on content and scope

In this third phase, the goal of the full-text examination was to narrow down the publications and exclude sources that (i) did not cover haptics interaction with agents or avatars in virtual environments ($n=23$), e.g., interaction exclusively with virtual objects and (ii) did not involve interactions in a social context ($n=42$), e.g., studies on hand illusion or body ownership not involving social interaction.

Phase 4 (Inclusion): Publications included in the review

We identified 45 additional publications from backward and forward snowballing citation searching (Wohlin 2014) from the retrieved publications that matched the screening

---

to painful sensations.

[2] Unlike author keywords, Keywords Plus® are automatically-generated terms from the titles of cited papers.

criteria. We used a saturation point approach, stopping the snowballing process when new references did not contribute new articles to the new set of publications. After a full-text analysis, we added 9 publications to the studies included in this review, reaching a total of 32 records.

The overall procedure for exclusion and creation of the set of reports is represented in Fig. 1. We employed Zotero[3] to create and manage the collection of sources.

3 Results

To provide an initial glance into the dataset we created a co-occurrence map of keywords extracted from titles and abstracts of the 32 selected reports. Figure 2 shows a network map visualization of co-occurrences using the VOSViewer[4] software for bibliometric analysis (Eck and Waltman 2010). Circles represent the frequency of a word (larger circles for more frequent words) and edges represent co-occurrences of keywords, that is, two keywords that occur in the title and/or abstract of the same report: the thicker the line, the more co-occurrences of two keywords were found in the set of reports. After excluding non-significant words (e.g., “paper”), and grouping words according to synonyms (e.g., we grouped “agent” with “virtual agent”), the tool extracted 52 unique keywords. We used a threshold of 3 co-occurrences, which means that only keywords that co-occurred in at least 3 reports were considered. As shown in Fig. 2, and as expected from the query, “virtual agent”, “touch”, “social touch” and “interaction” were the most recurring words.

At first glance, the default clusters provided by the bibliographic software show that there is an emphasis in the literature on the user experience and emotional aspects of interacting with virtual environments and agents. The literature studies the effect of social touch on contexts such as emotional expression or user behavior. There is also a clear trend on collecting data on different aspects of the mediated touch experience such as the sense of presence, co-presence and embodiment. Another area of inquiry focuses on haptic technology and devices used to provide the desired user experience, including the integration of different modalities and configurations (i.e., bodily placement of the haptic technology), for instance considering haptic feedback together with facial expression of an agent. Of course the clusters are not mutually exclusive and some of the items could be manually arranged into other dimensions. For instance, “self report” identifies the type of data collected in empirical

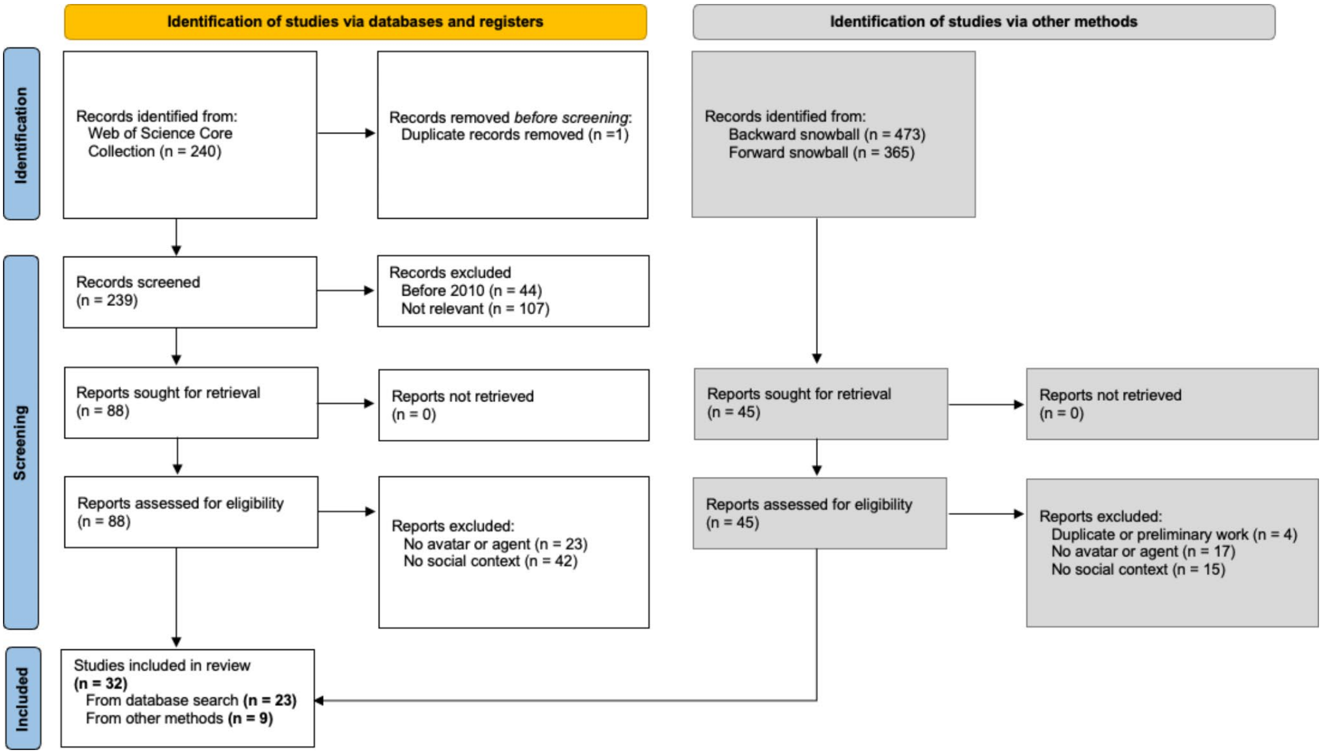

Fig. 1 PRISMA-informed procedure for filtering papers covered by this review

---

[3] A free, open-source and multi-platform software tool to manage bibliographic data, available at https://www.zotero.org.

[4] A software tool for visualizing network graphs of bibliometric data, available at https://www.vosviewer.com/.

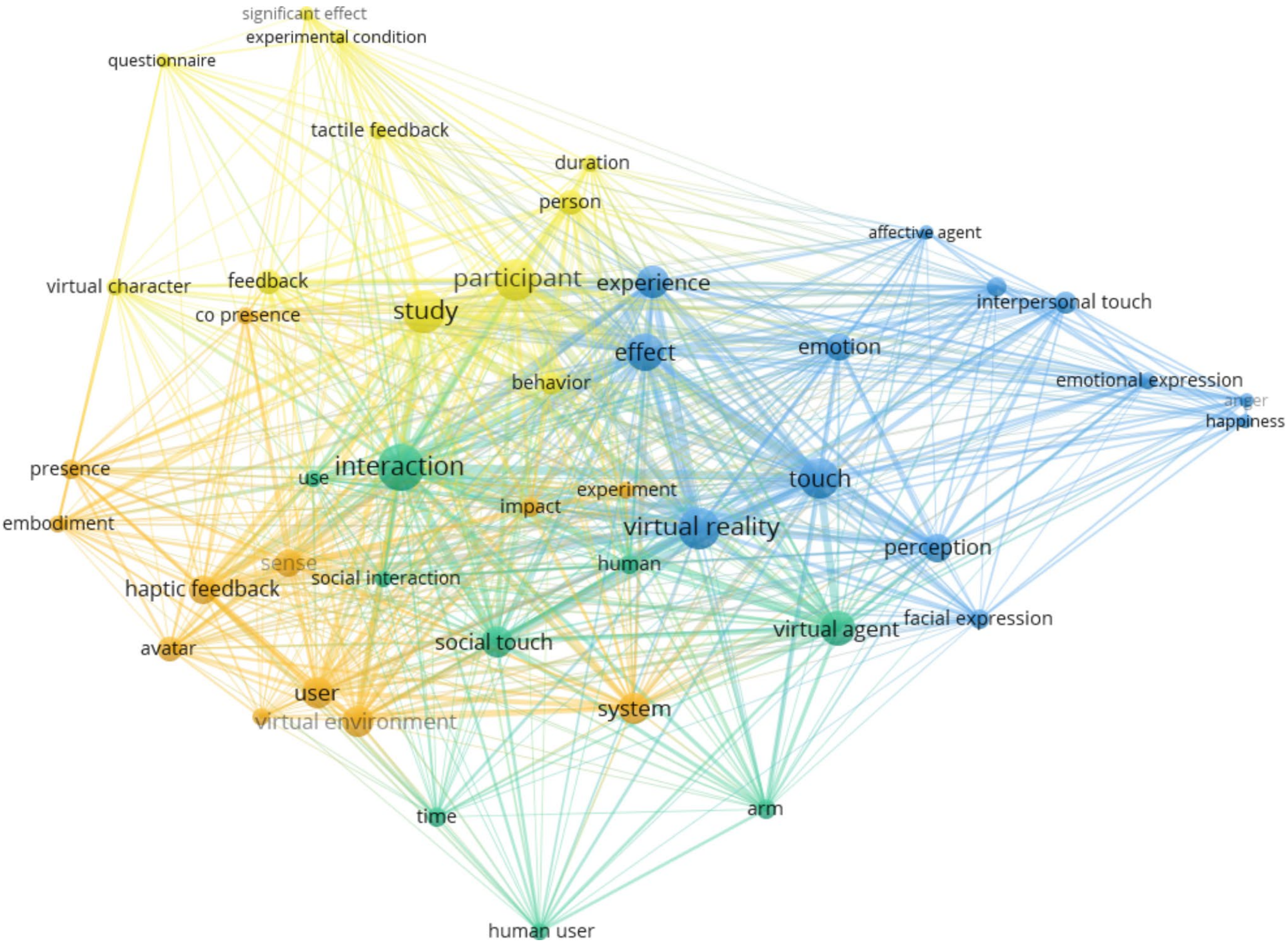

Fig. 2 Co-occurrence of keywords in titles and abstracts of the selected reports. *Source*: VOSViewer

studies, such as self-reported subjective experience through questionnaires.

In the following, we have structured the results according to the three research questions that drove our review to understand contexts, technology and empirical studies on haptics for social touch with virtual agents and avatars.

Context. With the "context" of the research, we mean the focus or aim of the research which determines the underlying scenario or use cases for experiments. This specific perspective, which has not been explicitly part of previous reviews, provided the dimension of for what reason social touch has been employed, for example, to support a particular task or experience or to investigate a specific phenomenon. An overview of contexts can help structure the analysis and identify overlooked topics in particular vis-à-vis current trends which, in turn, allow us to evaluate the relevance of research themes as well as highlight future research direction.

Technology. As previous reviews have not focussed on this aspect, we aimed at analyzing technologies used in the research such as VR hardware and software, authoring tools for immersive environments, technologies for avatar or agent implementation, haptics technologies, as well as logging sensors for data collection. This helped us to investigate the existence of established setups developed for the research use of haptics in affective interaction with virtual agents for different contexts. Focus on technology helped also to identify what kind of mediation technology could be relevant in immersive environments given the contexts.

Empirical studies. The dimension of the empirical studies focuses on data collection (e.g., questionnaire, EEG, ECG, EDA) and outcome measures (i.e., emotional, physiological). It helps to review, organized by their context, what studies have been conducted, with which dependent and independent variables and what are the findings, offering a lens to understand what new hypothesis could be investigated.

3.1 Context of the research

Table 1 shows our categorization of the reviewed articles into three contexts, that is, in which situations the effects

Table 1 A summary of the contexts of research on haptic-augmented interaction with avatars/agents

Context	Description	Aim	Reports
Emotional expression	The exchange of emotions, feelings and intentions through physical contact, such as hugs, handshakes, or other forms of tactile interaction between individuals	Understand the impact of emotionally-loaded tactile feedback during social interaction with avatars or virtual agents in different scenarios, including the effect of haptic feedback on emotional response and its influence on the perception of avatars and agents	1. Cui et al. 2021 8. Harjunen et al. 2017 9. Ravaja et al. 2017 12. Ahmed et al. 2016 13. Gaffary et al. 2015 15. Huisman et al. 2014 16. Tsetserukou and Neviarouskaya 2012 17. Rahman and El Saddik 2011 18. Ahmed et al. 2020 20. Boucaud et al. 2019 22. Hoppe et al. 2020 23. Boucaud et al. 2023 26. Maunsbach et al. 2023
Notification	Inform or alert individuals about specific events or conditions.	Understand the function of haptic feedback in providing tactile sensory cues to enhance awareness, guide attention or prompt action during their interactions with avatars or virtual agents. No direct intentional social touch either from virtual agents or avatars, or toward them	3. Buck et al. 2020 4. Krogmeier et al. 2019 5. Tani et al. 2019 7. Lee et al. 2018 10. Ahmed et al. 2017 11. Hassani et al. 2016 14. Froese et al. 2014 28. Venkatraj et al. 2024 30. Hecquard et al. 2023 31. Venkatesan et al. 2023
Changing behavior	Influence or modify users' actions or decisions in a desired direction	Use of haptic technology to study the impact of social touch in shaping user behavior, whether by encouraging specific responses, altering decision-making processes, or reinforcing certain social dynamics	2. Świdrak et al. 2020 6. Harjunen et al. 2018 19. Spapé et al. 2019 21. Tremblay et al. 2016 24. Bourdin et al. 2013 25. Zhao et al. 2018 27. Dzardanova and Kasapakis 2022 29. Koilias et al. 2020 32. Berton et al. 2022

A number is assigned to reports in each context to identify the report in the following sections

of haptic interaction with avatars or agents has been investigated, namely: *emotional expression*, *notification* and *changing behavior* Table 1 reports a brief description, the aim of the studies and the retrieved reports for each context, mapped with a number that will be used to identify the paper in the following sections of the review.

3.1.1 Emotional expression (1, 8, 9, 12, 13, 15, 16, 17, 18, 20, 23, 26)

Thirteen articles studied the impact of haptic feedback on users' perception and experience of emotionally-loaded physical interactions, such as hugs, handshakes, or other forms of tactile interaction, in a social VR context. This category focuses on the use of haptics to augment affective interaction and convey feelings and emotions as used for instance in non-verbal communication and enhance the emotional aspects of interaction. Works in this category aim at studying the effect of haptic feedback on emotional response as well as its influence on the perception of avatars/agents. The reviewed works covered this context in different scenarios: interaction in a public space (Cui et al. 2021) and with crowds (Venkatesan et al. 2023), face-to-face interaction in a private space or virtual room (Harjunen et al. 2017; Ravaja et al. 2017; Ahmed et al. 2016; Gaffary et al. 2015; Ahmed et al. 2020; Boucaud et al. 2019; Maunsbach et al. 2023), or in a collaborative game (Huisman et al. 2014; Boucaud et al. 2023). All these articles included a user study and reported the affective outcomes.

Remote communication can be enhanced by using avatars and adding haptic touch to enable experiencing intimate touch from others in virtual environments. Rahman and El Saddik (2011) explored how virtual characters can show gestures and kisses during intimate chats, enhancing the emotional connection between users. Similarly, Tsetserukou and Neviarouskaya (2012) demonstrated a communication system, iFeel_IM!, where virtual characters displayed emotional responses on behalf of users, using different haptic prototypes to convey emotions such as joy, sadness, anger, and fear.

Ahmed et al. (2016) explored the effectiveness of different haptic technologies in conveying affective touch. They examined how mediated interpersonal touch influences the perception of touch (e.g., naturalness) and overall emotional experience, including the sense of co-presence, by varying both the haptic technology used and the emotional expression of the toucher. By comparing these technologies, the research aims to understand how haptic feedback can be optimized to enhance emotional communication.

Recent works have studied the role of haptic feedback in shaping user experience and perceptions of interactions with agents and avatars in VR. Cui et al. (2021) investigated the impact of tactile feedback during virtual hugs with a virtual character, aiming to understand how different tactile feedback patterns affect users' experience and perceived realism of the interaction. Hoppe et al. (2020) explores the impact of social touch on the perceived human-likeness of virtual agents in virtual reality environments. The research investigates whether introducing social touch, such as a tap on the shoulder, can blur the distinction between human-controlled avatars and computer-controlled agents, thereby enhancing the perceived agency and social presence of virtual characters. Maunsbach et al. (2023) investigate how different types of haptic feedback influence the social experience of individuals initiating touch in VR environments. The study aims to understand how varying haptic sensations impact the perception of co-presence, friendliness, and the overall pleasantness of social interactions when users initiate touch with a remote person's avatar.

Other works investigated the emotional response to touching or being touched by an agent, together with additional visual cues from the agent. Huisman et al. (2014) aimed to understand the potential of mediated social touch to enhance social and emotional connections in virtual environments with virtual agents, investigating how vibrotactile feedback influence participants' perception of an agent's personality traits such as trustworthiness, warmth and politeness, which are closely related to emotional and social interactions. Ahmed et al. (2020), Boucaud et al. (2019) and Boucaud et al. (2023) studied the effect of visual emotional cues (e.g., facial expression or gestures) while touching an agent, investigating the interplay between perceived emotional expressions and users' haptic behaviors. These works contribute to the development of more sophisticated and realistic virtual social agents, exploring whether and how the emotions displayed by virtual agents affect the way users touch these agents (Ahmed et al. 2020) and understanding how to create a more credible and emotionally engaging interaction (Boucaud et al. 2019) as well as the social acceptability an emotional impact of agent-initiated touch (Boucaud et al. 2023).

Also Harjunen et al. (2017), Ravaja et al. (2017) and Gaffary et al. (2015) integrated facial expression to the experience of being touched by an emotional agent. Ravaja et al. (2017) examined how the emotional expressions of the virtual agent influence the user's perception of touch behavior, while Harjunen et al. (2017) focused on the influence of individual differences and gender on the perception of interpersonal touch. Gaffary et al. (2015) explored the complementarity between visual and kinesthetic modalities in expressing emotions. They focus on how facial and kinesthetic expressions are perceived separately, investigating which modality is more effective for recognizing specific emotional dimensions such as pleasure and arousal. The study aimed to enhance the understanding of multimodal emotional communication and provide insights into the optimal use of visual and kinesthetic cues in affective interactions.

3.1.2 Use of haptics as tactile notification (3, 4, 5, 7, 10, 11, 14, 28, 30, 31)

Ten articles **applied haptics to provide tactile notification as a form of awareness during social interactions with virtual agents or avatars**, **without direct intentional social touch either from or toward them**. The research in this category highlights the function of haptic feedback in providing sensory cues that guide or inform users during their interactions in virtual environments. The literature shows that haptics as an awareness mechanism can been used in different social situations, for example, to support social practices (Tani et al. 2019), enhance users' immersion (Lee et al. 2018) provide feedback for in-game events (Ahmed et al. 2017), enhance awareness of the physiological state of others (Hecquard et al. 2023), notify violation of peripersonal space (Buck et al. 2020), provide the sensation of a bump with others (Krogmeier et al. 2019; Venkatesan et al. 2023), co-regulate interactions (Froese et al. 2014); enhance coordination in joint tasks (Venkatraj et al. 2024), and support language learning (Hassani et al. 2016).

Hassani et al. (2016) demonstrated an intelligent virtual environment for language learning. They employed virtual agents and combined visual, auditory, and haptic interaction channels with the purpose to improve the speaking and listening skills of English learners. While there is a social component in the interaction, since the agents simulate conversational partners, the haptic feedback in this context is primarily educational and is used to notify learners about errors or to reinforce correct responses.

Seven studies aimed to understand the impact of tactile notification on user experience during social interactions with virtual characters. Lee et al. (2018) focused on developing a virtual doll companion and a tangible prop that integrates haptic feedback responding to the virtual doll's facial expressions and physical interactions, aiming to enhance user immersion in virtual environments. Buck et al. (2020) investigated the extent of peripersonal space in immersive VR and whether the type and appearance of agents modulated the virtual peripersonal space boundary. Ahmed et al. (2017) explored the concept of affective symbiosis in a VR gaming environment. They investigated how haptic sensory cues, combined with emotional expressions of virtual agents influences users' emotional and physiological responses during competitive gameplay. Hecquard et al. (2023) aimed to enhance the emotional connection between users and the virtual agents by conveying the agent's stress levels through haptic feedback. Tani et al. (2019) used haptic feedback as a notification mechanism to simulate the sensation of pathogen droplets striking the user's body during a virtual infection experience, enhancing the realism and educational impact of the virtual reality environment, with the goal to increase people's knowledge of hygiene and trigger behavioral changes.

The studies from Krogmeier et al. (2019) and Venkatesan et al. (2023) both involved participants being incidentally bumped by virtual characters. The aim of the research differs. Krogmeier et al. (2019) centers on understanding how different parameters of haptic feedback—such as intensity, timing, and position—affect participants' perceptions of presence, embodiment, and realism of the interactions. Venkatesan et al. (2023) investigated how different types of haptic feedback influence participants' awareness and perception of positive and negative emotions when navigating through virtual crowds.

Two studies explored tactile notification as a means to increase awareness of embodied experiences in social interactions with avatars. Froese et al. (2014) investigated how real-time interaction dynamics, facilitated by tactile feedback when the hand of users' avatar overlapped, contribute to the detection of agency and the experience of another's presence. Venkatraj et al. (2024) explored how haptic feedback can be used as a non-verbal communication tool to enhance coordination, awareness and the sense of agency in virtual avatar co-embodiment scenarios. The study aims to understand the impact of haptic feedback on the sense of agency, co-presence, and body ownership during shared virtual interactions.

3.1.3 Changing behavior (2, 6, 19, 21, 24, 25, 27, 29, 32)

The nine studies in this category focus on **understanding how touch affects interpersonal communication and shape behavior during virtual social interactions**. In these studies, haptic-enhanced social touch is employed as a method for measuring underlying attitudes and biases, revealing how touch can subtly impact interpersonal dynamics in virtual environments and how virtual touch can be used to study actual social touch in physical reality.

Dzardanova and Kasapakis (2022) investigated the impact of vibrotactile haptic feedback on users' first impression of non-player characters and their surrounding spaces and how this can be exploited to direct users' behavior and experience. Tremblay et al. (2016) used haptic feedback to simulate physical contact during a hug to investigate the influence of anti-fat attitudes on physical interaction with virtual humans. The study aimed to understand how implicit biases, such as anti-fat attitudes, can shape behavior during virtual social interactions, particularly in terms of touch-related behaviors.

Three studies adopt a social decision-making game as a way to operationalize communication and study the influence of touch on the compliance to accept an offer made by a virtual agent in VR. In a typical economic decision-making game, one player acts as the proposer and another as the receiver. The proposer makes an offer by dividing a sum of money between him/her and the receiver. The receiver can accept or reject the offer. However, if the receiver rejects an offer, then none of the players receives anything. Harjunen et al. (2018) and Spapé et al. (2019) combined touch with the emotional facial expression of a virtual agent to influence the user emotionally regardless of the trial condition (propose or receive). Swidrak et al. (2020) investigated the influence of social status and culture on touch, designing an economic decision making game experiment with high and low social status agents (portrayed by different visual appearances) and male participants from two cultural backgrounds (Polish and Catalan). In the proposer condition, the participant had the option to touch the virtual agent. In the responder condition, the agent makes an offer and touches the participant. In both conditions, participants experienced the touch sensation through the vibration of a handheld controller.

Two studies investigated the effects of tactile feedback on participants' movement behavior during interactions with a virtual crowd (Koilias et al. 2020; Berton et al. 2022). The studies aimed to understand how different tactile feedback conditions can influence movement behavior, such as speed and direction, as well as alter interaction patterns, focusing on behavioral changes induced by the tactile sensory feedback.

The remaining studies aimed to understand how mediated social touch can be used to shape social behavior and decision-making. Zhao et al. (2018) explored the potential of haptic-enabled virtual touch as a persuasive tool that can shape consumer behavior. They investigated whether touch on the upper arm from a virtual shop assistant simulated through haptic feedback can alter shopping behaviors, such as the amount of time spent in a store, money spent and overall evaluation of shopping experience. Bourdin et al. (2013) explored whether the physical sensation of social touch, such as a tap on a shoulder, can increase compliance with a request to perform an embarrassing task such as singing in public.

3.2 Technologies to study haptics in social interaction with agents/avatars

In this section, we categorize the VR technology (e.g., virtual environment platform, tools for avatar design, display and interaction devices) and haptics technology employed in the reviewed articles, according to the research context.

3.2.1 VR technologies

Table 2 shows the VR tools and technologies reported in the reviewed articles as a function of research context. State-of-the-art VR authoring environments and immersive VR technologies were used for the three research contexts of *emotional expression*, *notification* and *changing behavior*. Unity[5] was the most used VR development platform and a tethered Head-Mounted Display (HMD) such as the Meta Quest Rift[6], the Quest 2 for research after 2020, and the HTC Vive, HTC Vive Pro[7], was the most used display technology to present the immersive VR scene. Freely accessible tools such as Fuse, Mixamo, and Unity were widely used for designing and animating the agents and avatars to provide visual cues enabling emotional behavior. Users' avatars were presented either as full bodies or only the right hand was shown depending on the study objectives. A wide range of interaction devices were used including regular keyboard and mouse, force and position tracker, gesture tracking sensors, and eye gaze tracker, including 3D motion tracking systems such as the Optitrack[8] or Xsens[9].

Agent and avatar embodiment varied from full body representations to just one hand, from abstract to humanoid. In all three context categories full or partial body embodiments were used. For example in Froese et al. (2014) participants move their 'avatars' (abstract objects) along an invisible virtual line and could make haptic contact with three identical objects, two of which embodied the other's motions, but only one, the other's avatar. In Gaffary et al. (2015) instead the embodiment is mostly the face through the use of MARC, a framework to generate visual expressions with a virtual avatar.

In the *emotional expression* category, other works also employ facial expressions such as in Harjunen et al. (2017), Ravaja et al. (2017), and Ahmed et al. 2016 corresponding to different emotions. Such expressions of emotion are generally also validated with participants to verify that they convey the right emotion independently from how the expressions were obtained for example manually or through actors. Some older works such as Rahman and El Saddik 2011; and Tsetserukou and Neviarouskaya (2012), the embodiment is implemented through Second Life, a platform now discontinued. This would be analogous nowadays to using a social VR platform such as VRChat to develop the embodiment for avatars and agents. Other works like Bocaud et al. 2023 employ a different strategy where the agent is represented by a humanoid embodiment controlled through the GRETA platform, which generates and synchronizes speech, facial expressions and gestures. While the participant human embodiment is a silhouette.

Considering the *notification* category the studies employ the widest variety of embodiments. In Venkatesan et al. (2023) the choice of the virtual environment to study social touch in a crowd situation, is a 360 degree video. In Venkatraj et al. (2024) which studies sharing the same embodiment, to create a co-embodied avatar, "shared hands" are used in the virtual world as gender neutral representation. In Lee at al. (2018) the agent representation is a cartoon virtual doll capable of emotional expressions. In Krogmeier et al. (2019) the scenario for the study is a participant standing on a busy crosswalk, with a virtual character walking by. The scenario was developed with Autodesk 3ds Max, the virtual characters in the scene were designed in Adobe Fuse, and all was imported into Unity.

In the *changing behavior* category some scenarios are developed with more detail as in Zhao et al. (2018), that studies the effects of social touch on shopping behavior. Here the environment developed with Unreal included two virtual shops, a virtual shop assistant who touched participants on the upper arm while greeting. In Tremblay et al. (2016) as the aim is to study behavior related to anti-fat attitude, and the full body virtual humans were developed using 3ds Max, models had two types of body size (normal and overweight) for each sex.

All in all, the design and implementation of embodiment for avatars and agents varied greatly in parts of the body, humanois versus cartoons or even abstract, and tools used for development. Works within a category utilized diverse embodiments and seemed to be determined by specific framing of hypotheses or research questions. This diversity makes the comparison of studies more difficult, it would be interesting to consider how sharing of experimental VR environments and embodiments might make studies more replicable and facilitate contribution building on each other.

---

[5] Unity, https://unity.com/.

[6] Meta Quest, https://oculus.com.

[7] HTC, https://vive.com.

[8] Optitrack, https://optitrack.com/.

[9] Xsens, https://www.movella.com/products/xsens.

Table 2 VR tools and technologies used in the affective interaction with agents/avatars

Context	VR platform	Display	Agent, avatar, and animation design tools	Body ownership	Interaction devices
Emotional expression (1, 8, 9, 12, 13, 15, 16,17, 18, 20, 22, 23, 26)	Unity[1,8,9,12,18,20, 22,23], MARC[13], SecondLife[16,17]	Vive[1,18,22,23,26], Quest[8,9,12], PCscreen[13, 16,17], Tablet[15] CAVE [20]	Fuse[1,8,9,12], Mixamo[1,8,9,12], SALSA[1], MARC[13], FaceShift[8,9,12], Unity[1,8,9,12,18,20,22,26], SecondLife[16,17], Rocketbox[26]	Full body[1,16,17,22,23], Right hand[8,9,12,18, 20,26] Head [13]	Kinect depth sensor[1], Vive controller[22,23], Geomagic Touch X[13], Touch screen[15], Leapmotion[8,9,12,23], Keyboard[8,9,12,16,17 18, 20], Pressure input[18], Pointing device[17],Eye tracker[18], STRATOS[26]
Notification (3, 4, 5, 7, 10, 11, 14, 28, 30, 31)	Unity[3,4,5,7,10,30,31], Unreal[28], Virtools[11]	Vive[3,7,30], Quest[4,5,10,28,31], PCscreen[11,14]	Fuse[3,4,10], Mixamo[3,4, 10], Ikinema Orion[3], FaceShift[10], Unity[10,30,31], Unreal[28], Leap hand[10], 3ds Max[11], Insta360[31]	Full body[3,4,11,30], Abstract[14], Both hands[28], Right hand[10] None[31]	Vive controller[3,30], Vive trackers[3], Quest controllers[28], Leapmotion[10], Keyboard[10], Microphone[5, 11], BNO55 sensor[7], Falcon[11], Trackball mouse[14]
Changing behavior (2, 6, 19, 21, 24, 25, 27,29,32)	Unity[2,6,19,27,29,32], XVR[24], 3ds Max Interactive[21], Unreal[25]	Vive[2,27,29], Quest[6,19,21], CAVE[24], Pimax[32], Unspecified HMD[25]	Fuse[2], Daz3D[6,19], Unity[6,19,32], Leap hand[6,19], 3ds Max[21,29], XVR[24], Unreal[25], Mixamo[27,29], Xsens Animate[32]	Full body[2,24,32], Both hands[21], Right hand[6,19,27], Unspecified[25] No self-avatar[29]	Vive controller[2], Leapmotion[6,19], Keyboard[6,19], Omni[21], Optitrak[24], Microphone[24], Wireless wand[24], Haptic Glove[27], Xsens[29,32]

Quest = Meta Quest Rift/Meta Quest 2 HMD, Vive = HTC Vive/Vive Pro HMD, Pimax = PImax VR Headset, Fuse = Adobe Fuse, MARC = MARC framework, SALSA = SALSA LipSync suite, Rocketbox = Microsoft Rocketbox Avatar Library, STRATOS = Ultraleap STRATOS Explore, Omni = Phantom Omni Haptic Device, Optitrack = Optitrack Motion Capture System, Leap hand = Leapmotion's default hand model

3.2.2 Haptic technologies

Table 3 summarizes the haptic technologies reported in the reviewed articles, categorized by research context. The table reveals that both vibrotactile and force feedback actuators were commonly discussed in the literature. Vibrotactile actuators are particularly popular due to their quick response times and ease of integration into ad-hoc, rapid prototypes.

Among vibrotactile actuators, C2 tactors and vibrotactile motors are the most common choice. Both devices create vibrations using a moving magnet, but they differ in their vibration characteristics and applications. C2 tactors produce faster and smaller vibrations, making them ideal for providing subtle, precise sensations at the point of contact, i.e., localized haptic feedback. In contrast, vibrotactile motors generate slower and larger vibrations, typically used for broader, less precise haptic feedback. The use of vibrotactile actuators varies considerably in the reviewed works, whether they were sourced from electronic components to create custom-built devices, or they were embedded in off-the-shelf devices. Vibrotactile actuators sourced from individual electronic components offer greater flexibility in design and functionality, allowing the selection of specific types of actuators, such as Eccentric Rotating Mass (ERM) motors (Venkatesan et al. 2023), or C2 tactors (Ahmed et al. 2016), as well as higher degree of configurability and control of the haptic feedback. The controllers of commercial HMD for immersive VR, such as the Meta Quest or Vive, are equipped with vibrotactile motors, allowing the controllers to vibrate in response to in-game events or user interactions. More recent studies such as Buck et al. (2020) or Venkatraj et al. (2024) use these built-in haptic technology instead of implementing ad-hoc hardware. Haptic vests such as the bHaptics[10] contain multiple vibrotactile actuators distributed across the vest and are generally used to provide vibrotactile feedback on larger areas of the body like the torso, such as in Koilias et al. (2020), Cui et al. (2021) and Krogmeier et al. (2019).

An audio haptic exciter, also known as boneshakers, generates vibrations from sound using an electromagnet, which can be felt through solid objects. In contrast to C2 tactors, which are designed for fine and localized haptic feedback, audio haptic exciters produce stronger sensations over a wider area. They achieve this by generating bending waves that can stimulate bone structures, offering both vibration and audio stimuli.

Linear actuators enable accurate and controlled linear motion, which is essential for creating realistic haptic feedback. They can be powered by servo motors or pneumatic actuators. Linear actuators are versatile and can be used in various haptic feedback applications. Servo motors are electric motors that can be precisely controlled in terms of position, speed, and force using sensors and controllers. This precise control helps simulate various tactile sensations to mimic a touch, such as pressure or squeezing. Pneumatic haptic devices use air or gas pressure to generate forces or movements that can be felt by the user, providing a range of sensations These devices can produce both soft and hard sensations, such as squeezing, pushing, or pulling. Additionally, there are high-end, ready-made solutions like the

---

[10] https://www.bhaptics.com/es/.

Table 3 Haptic technologies used in social interaction with agents/avatars

Context	Implementation	Actuator	Actuation	Body location	Touch type	Toucher
Emotional expression (1,8,9,12,13,15,16,17,18,20,22,23,26)	Custom-built[8,9,12,16,17,18,20,22] Ready-made[1,13,15,23,26]	Vib motor[1,15,17,20,23], Exciter[8,9,12], C2[12], Servo motor[8,9,12], Pneumatic[12, 18], Geomagic[13], Heat-able foil[22], Passive tangible[22,26], STRATOS[26]	Vibration[1,8,9,12,15, 16,17,20,23], Force[8,9,12,13,16,18], Tactile simulation[26], Passive tangible[22,26]	Hand[8,9,12,13,16,18,20,26], Arm[15, 20,23], Chest[1,16], Abdomen[15,16], Sides[16], Neck[17], Shoulder[22]	Hold hand[8,9,12,13,18], Press[15], Hit[20], Tap[20,22,23], Stroke[20,26], Neutral[20], Kiss[17], Hug[1,16], Tickle[16]	Agent/Avatar[1,8,9,12,15,20,22,23] User[13,16,17,18, 20, 26]
Notification (3,4,5,7,10,11,14,28, 30, 31)	Custom-built[5,7,10,14,30,31] Ready-made[3,4,11,28]	Vib motor[3,4,5,14,28,30,31], Servo motor[7,10,30,31], Exciter[10], Falcon[11]	Vibration[3,4,5,10,14,2830,31], Force[10,11,30,31]	Hand[3,7,10,11,14,28], Chest[4], Trunk[5,30], Wrist[30], Shoulder[31]	Bump[4,31], Tactile feedback[3,5,7,10,11,14,28,30] Hold mallet[10]	Agent[4, 31] User[7,10] No toucher[3,5,11,14,28, 30]
Changing behavior (2,6,19, 21, 24, 25, 27,29,32)	Custom-built[2,6,19,25,32] Ready-made[21,24,27,29]	Vib motor[2,24,29,32], Exciter[6], Servo motor [6,19,25], Omni[21], Manus[27]	Vibration[2,6,24,27,29,32], Force[6,19,21,25]	Hand[2,6,19,21,27], Trunk[29], Arm[2,24,25,32], Shoulders[24]	Hold hand[6,19], Brief touch[2,25,27], Tactile feedback[29,32], Hug[21],Tap[24]	Agent[2,6,19,2,29,32] User[2,21,24,27]

Vib motor = Vibrotactile motor, Exciter = Audio haptic exciter, C2 = C2 tactor, Pneumatic = Pneumatic actuator, Falcon = Falcon haptic device, Geomagic = Geomagic Touch X, STRATOS = Ultraleap STRATOS Explore, Omni = Phantom Omni Haptic Device, Manus = Manus VR Prime One Haptic Glove

Geomagic Touch X, Falcon, Phantom Omni, Ultraleap STRATOS Explore, or the Manus VR Prime One devices. Geomagic Touch X (Gaffary et al. 2015), Falcon (Hassani et al. 2016) or Phantom Omni (Tremblay et al. 2016) are haptic devices that employ motors, sensors, and linkages to physically render the shape, texture, and resistance of virtual objects through force feedback. The Ultraleap STRATOS Explore uses ultrasonic waves to create tactile sensations in mid-air. It allows users to feel virtual objects and interactions without physical contact, by focusing ultrasound waves on specific points on the skin to simulate the sensation of touch (Maunsbach et al. 2023). Manus VR Prime One is an advanced haptic device designed for VR applications that is equipped with sensors that capture position and orientation of fingers and hands and provide vibrotactile feedback (Dzardanova and Kasapakis 2022).

One study (Hoppe et al. 2020) built a silicone rubber hand to be used as a passive tangible to convey the sense of being patted on the shoulder. Maunsbach et al. (2023) also used a rubber hand in one of the conditions of their study. Hoppe et al. (2020) passive tangible featured a heat-able foil in the palm to simulate human heat patterns.

For the three contexts, the hand was the most used body location for providing the tactile feedback (20 out of 32). This is due to the majority of the articles in these categories simulated non-intimate or formal touch during interaction with others, where people use a brief touch. This can be ascribed to different reasons. Casual touch is more convenient to study, with hands in particular being relatively accessible. Hand-to-hand interaction is also more prevalent as a form of communication in non-intimate relationships, therefore likely more important for such applications. Lastly, the hands are particularly sensitive to tactile sensations, due to a higher number of cutaneous nerves in the volar of hands and fingers (Vallbo and Johansson 1984) and C-tactile afferents in the manual dorsals (McGlone et al. 2014), for which reason neurologist and psychophysicists have typically focussed on these areas and we know more about the role of these regions on affective touch perception.

Works in the *emotional expression* context also considered intimate communication with partners, and hence, not surprisingly, different sensitive parts of the body, from lip to abdomen, and hand to finger, were targeted to provide a tactile sensation of hug, kiss, and tickle. Interestingly, in these cases the intimate touch was initiated by the user whereas, in the other contexts, the touch was mostly received from an agent or avatar.

Surprisingly, few works studied the effects of different touch technologies on the user experience. Ahmed et al. (2016) purposely focused on assessing which haptic technologies are the most effective for interpersonal touch in affective VR with touching agents with emotional facial responses. Reports of users' subjective experiences revealed that force feedback actuators were perceived as more natural, inducing greater emotional interdependence and enhanced co-presence than vibrotactile actuators. A servo motor-based glove providing touch sensation by squeezing the user's hand was evaluated as the most effective technology to support these experiences. Venkatesan et al. (2023) investigated how different types of haptic feedback, including tactile and torque feedback, influenced participants' emotional responses while navigating through virtual crowds. In line with findings from Ahmed et al. (2016), they found that haptic stimulus delivering tactile and torque cues was perceived as more realistic for virtual collisions. Cui et al. (2021) developed an haptic vest with vibrotactile actuators that vibrate when the hug occurs and gathered users' preferences. Participants favored brief vibrotactile pulses over continuous vibration during the virtual hug. Additionally, the interaction was perceived as more realistic when a visual feedback accompanies the tactile stimulus.

As was the case in the previous section for VR implementation and avatars, works used an ample variety of haptic technologies for example using different actuators (vibrotactile, servo motor, etc.). Some haptics tools were commercial and others were implemented by the research groups. Body locations varied including hand, arm, chest, abdomen, sides, neck, shoulder, as well as touch type: hold hand, press, hit, tap, stroke, kiss, hug, or tickle. Only rarely works compare different haptic technologies, most notably Ahmed et al. (2016). However, the comparison usually addresses only limitedly all the possible scenarios in different context categories so that it is difficult to compile guidelines of what technologies should be used for which experiment. Technologies also in this space develop continuously, with novel actuators considering for example ultrasound haptics, or novel commercial devices.

3.3 Empirical studies

Table 4 summarizes the empirical studies, their designs, including data collected, independent and dependent variables and main findings according to the context. Self-reported items or questionnaires was the most common data collection technique used across the three categories. A few of the articles provided a partial set of questionnaires (Hassani et al. 2016; Gaffary et al. 2015; Huisman et al. 2014). The rest of the articles provided the full questionnaire or its reference. Behavioral and physiological data were also collected in some studies, for instance Krogmeier et al. (2019) collected self-reported subjective experience data and galvanic skin response (GSR) during the experiment, Ahmed et al. (2017) and Dzardanova and Kasapakis (2022) collected subjective experience and physiological data (EDA, ECG), Ravaja et al. (2017) collected EEG signals and measured Somatosensory-Evoked Potentials (SEPs) in different time windows. Complex physiological signals, such as fEMG, were collected in studies on emotional expression (Ahmed et al. 2020).

All the empirical studies reviewed were conducted in a laboratory environment. Participants interacted with the system in a sitting position, except for five studies (Cui et al. 2021; Buck et al. 2020; Krogmeier et al. 2019; Venkatesan et al. 2023; Boucaud et al. 2023) that were conducted entirely with participants in a standing position. Additionally, in the study by Huisman et al. (2014), participants were initially in a standing position and were asked to sit at the end as part of the experiment.

All the articles reporting results from empirical studies presented an experimental factorial design, and assigned trials and participants in a randomized order. Tsetserukou and Neviarouskaya (2012) conducted a preliminary observational study to evaluate the effectiveness of their haptic prototypes in eliciting emotions, such as joy, sadness, anger, and fear. Rahman and El Saddik (2011), Lee et al. (2018) and Tani et al. (2019) were the only works that reported the design and implementation of an haptic system without an empirical study.

All the studies relied on the self-reported items for measuring the VR experience, emotional experiences, perception of agent, touch experience, and emotion recognition. Although the questionnaire items were slightly varied across the studies, they covered some common categories. For example, VR experience items include realism of the VR environment, interaction with virtual characters, body ownership, presence, and co-presence (Cui et al. 2021; Ahmed et al. 2016; Venkatraj et al. 2024); emotional experience items include emotional reactivity and contagion (Cui et al. 2021), the perception of pleasure, arousal and dominance dimensions (Gaffary et al. 2015), and emotional interdependence (Ahmed et al. 2016; Ahmed et al. 2020).

Commonly, repeated measure ANOVAs were used to analyze the effects. These studies showed that touch via haptic played an important role in modulating the user's perception and overall experience while interacting with a virtual agent. Repeated measures ANOVAs were also used to analyze the physiological data during interaction with emotional virtual agents (Harjunen et al. 2017; Ravaja et al. 2017; Ahmed et al. 2020) and found the changes in signals that can even predict the corresponding event. For example, the happy agent reduces orienting responses related to touch (Harjunen et al. 2017), facial muscle activities of the users mirrored the perceived facial expressions of the agents making it able to predict the agent's emotion and the user's touch behavior (Ahmed et al. 2020), and brain-related activities showed affective modulations of touch-evoked

Table 4 Empirical studies on affective touch in different contexts

Context	Data	Independent variable	Dependent variable	Summary of the findings
Emotional expression (1,8,9,12,13,15,16,18,20,22,23)	**Ques**: Experience (VR[1,12,22,23], embodiment[23], touch[23], emotion[1,12,18]), Perception (emotion[8,9,12,13,18, 20], agent[15,23], touch[8,9,12,22,23]), User's personality[8,15], Emotion recognition[8,9,12,13,18, 20], **Bhv**: Pressure input[18]**Phy**: ECG[8,18], EDA[18], fEMG[18], EEG[9]	Touch (condition[22,23,26], feedback[1,13], intensity[8,9,12], technology[8,9,12]), Agent's (emotion[8,9,12,13,18, 20], type[15,22]), Time window[9], Electrode[9], User's (gender[1,8], personality[8,15]), Emotion (perception[18,20], experience[18])	Experience (VR[1,12,22,23], emotion[1,12,18]), Perception (emotion[8,9,12,13,18,20], touch[8,9,12,23,26], agent[15,23,26]), Touch expression[18], Emotion recognition[12,13,18, 20], HR[8,18], EDA[18], fEMG[18], SEPs[9]	**1)** Tactile feedback enhances hugging experience[1], and emotion recognition accuracy[13]. **2)** Tactile feedback affect the perception of an agent[15,22] **3)** Force feedback actuator provides better touch than vibrotactile[12]. **4)** Agent's emotion modulates touch perception[8,9] and expression[18], and emotional experience[9,12,2, 20]. **5)** Touch after emotional expression changes physiological responses (ECG[8,18], EEG[9], fEMG[18]).
Notification (3,4,10,11,14,28,30,31)	**Ques**: Agent likeability[3], Experience (VR[4,10,28,30,31], touch[4], emotion[10,30,31], game[10]), Emotion recognition[10], Language skill[11], Confidence[14] **Bhv**: Reaction time[3,30,31], Accelerometer[10], Voice reply[11], Click[14], Pose[28], Eye Gaze[30] **Phy**: ECG[10], EDA[4,10]	Touch (condition[4,28,30,31,] intensity[4]), Agent's (type[3,31], emotion[10]), Distance[3], Language skill level[11], Voice reply[11], Scenarios[11], Clicks[3,14]	Reaction time[3,30], Agent likeability[3], Experience (touch[4], emotion[10,30,31], VR[4,10,14,28,30,31]), Performance[10,11,28], Eye Gaze[30], Language skill[11], Social judgment[14], Empathy[14], Confidence[14], Scores[14], Co-regulation[14], Clicking accuracy[14], Movement[10], EDA[4,10], HR[10], SCR[10]	**1)** Tactile feedback enhances VR[4] and game[10] experience, sense of other's presence[3,14,28], realism[4,31], and learning[11]. **2)** Agent's emotion modulates game and emotional experience[10], and type modulates peripersonal space[3]. **3)** Physiological response changes after a touch (GSR[4]), agent's emotion (EDA[10]), and game events (EDA[10], SCR[10], and Movement[10]).
Changing behavior (2,6,19, 21, 24, 25, 27,29)	**Ques**: Agent perception[2,24,27,29], Experience (VR [2,24,25,27,29,32], Touch[24,29]), User's personality[2,6,21] **Bhv**:Movement (IMU)[29,32], Collisions[29,32], Shopping time[25], Money Spent[25], Compliance with request[24], Leadership[29], Persuasion[29], Offer acceptance[2,6,19] **Phy**: EDA[2,27], HR[27], ECG[2,6], fEMG[2], EEG[19]	Offer/Request (acceptance[2,24], fairness[6,19]), Agent's (configuration[32], social status[2], gender[6,21], body size[21], emotion[6,19], ethnicity[6]), Touch condition[2,6,19,24,25,27,29,32], User's (culture[2], gender[21], personality[6])	Agent perception[2,27], VR experience[2,24,25,27,29,32], Attitudes[2,21], Behavior[25,29,32], Offer/Request (value[2], acceptance[6,19,24], willingess[24]), Touch (Duration[21], Intensity[21]) Scores[2], SCR[2,27], HR[2,6,27], ERPs[19]	**1)** Agent's touch[2,6,25] or emotion[6,19] increases compliance with an offer[2,6,19], influences shopping behavior[25] and movement bahavior[29, 32] **2)** Physiological response changes after perception of offer's fairness (ECG[6], EEG[19]), agent's touch (EDA[2], EEG[19]), touching an agent (EDA[27]), or emotion (EEG[19]).

Ques = Questionnaire, Bhv = Behavioral, Phy = Physiological, Touch feedback (no touch, visual only, tactile,visuo-tactile), ECG = Electrocardiogram, EDA = Electrodermal activity, EEG = Electroencephalography, SCR = Skin conductance rate, GSR = Galvanic skin response, HR = Heart rate, fEMG = Facial electromyography, ERP = Event related potential

somatosensory potentials caused by agent's facial expression took place even within 25ms of touch onset (Ravaja et al. 2017).

In the *changing behavior* context, the common aim of the studies was to understand the effect of social touch and the appearance of the virtual agent on influencing users' behavior, such as their compliance with virtual other's offers (Harjunen et al. 2018; Spape et al. 2019; Świdrak et al. 2020), willingness to perform a potentially embarrassing task like singing in public (Bourdin et al. 2013), shopping behavior (Zhao et al. 2017), or reinforcing certain social dynamics such as attitudes toward body image and weight-related biases (Tremblay et al. 2016). Bourdin et al. (2013) investigated compliance to a request (singing in public) in a collaborative virtual environment in which participants (all male) embodied avatars and were touched by the experimenter represented as a female avatar. Vibrotactile feedback was provided to simulate the sensation of being touched when the experimenter's avatar touched the participants' avatars on the shoulders or forearms. The results showed that the touch condition did not significantly increase compliance, as all participants accepted singing regardless of whether they received the tactile feedback or not. The study also compared these results with a physical face-to-face setting, finding no significant differences in behavior between the virtual and physical environments. Zhao et al. (2017) performed a study in which participants shopped in two virtual stores, where in one store they were touched on the upper arm by a virtual shop assistant (using an armband with a small motor for haptic feedback), and in the other store, they were not touched, with the order of conditions being randomized. They found that artificial social touch in a virtual reality shopping environment can positively influence consumer behavior by increasing the time spent shopping, the amount of money spent, and the perceived quality of the shopping experience.

Interestingly, Koilias et al. (2020) and Berton et al. (2022) studied the effect of haptic feedback on walk and movement behavior in a crowded scenario. They measured behavioral data such as direction, walking speed, body motion, or collisions, collected through observation and data from Inertial Measurement Units (IMU). Berton et al. (2022) studied different crowd configurations, however the density of the crowd did not change in both studies. Results from the studies indicate that haptic feedback enhanced the overall realism of the interaction, prompting participants to actively avoid collisions. Participants with haptic feedback tended to adjust their movement patterns, such as changing speed and direction, to avoid collisions more effectively compared to those without haptic feedback (Kiolias et al. 2022). Additionally, a significant after-effect in participants' behavior was observed by Berton et al. (2022) when the haptic feedback was disabled.

In the studies on compliance with an offer, the behavioral data of offer acceptance (accept or reject) were collected during the experiment to measure the compliance effect. Harjunen et al. (2018) and Spape et al. (2019) employed virtual agents who had the ability to show emotional facial expressions and touch the user, whereas, Świdrak et al. (2020) employed virtual agents who appear to have low and high social status. Interestingly, these studies found that unfair offers were accepted less. However, users had a tendency to accept even an unfair offer if the agent smiled or touched them (Harjunen et al. 2018). Świdrak et al. (2020) showed that touch and social status both affected compliance, with culture modulating the overall effect. Overall, the expression of the agent and touch affected the offer acceptance rate. A brief touch (Świdrak et al. 2020; Harjunen et al. 2018) or happy facial expression (Harjunen et al. 2018) increased the compliance, whereas an angry face (Spapé et al. 2019) decreased it. The users' personality also affected the compliance, for example, users with low Justice Sensitivity (JS) or Behavioral Activation System (BAS) were more affected by the agent's touch and showed higher readiness to accept even an unfair offer (Harjunen et al. 2018), and the users to whom social status was important, accepted less offer from the virtual agents (Świdrak et al. 2020). These studies collected physiological data as well. The physiological signals were found to be changed after perception of the offer's fairness (Harjunen et al. 2018; Spapé et al. 2019), agent's touch (Świdrak et al. 2020; Spapé et al. 2019), or emotional facial expression (Spapé et al. 2019). An unfair offer produced longer interbeat intervals (Harjunen et al. 2018) and stronger negativity in the range of P3 (Spapé et al. 2019) than fair and generous offers, and a touch increased the skin conductance level (Świdrak et al. 2020). Świdrak et al. (2020) found that people tend to reject unfair offers more often regardless of the affective cue. However the emotional facial expression of the agent, together with receiving touch from the agent, increases compliance. Participants accepted unfair offers more likely when the agent smiled or touched the user (Harjunen et al. 2018), and rejected them more likely if the agent had an angry expression (Spapé et al. 2019). The user experiences the touch via a haptic glove which was equipped with a servo motor-based force feedback actuator and audio haptic exciter vibrotactile actuator (Ahmed et al. 2016). Harjunen et al. (2018) used both vibrotactile and force feedback actuators. Similarly, Spapé et al. (2019) also utilized these technologies.

The common aim of the studies in the context of *emotional expression* was to measure visual (agent) and tactile (touch) perceptions during interaction with virtual agents. Gaffary et al. (2015) evaluated emotional responses from touching agents in a desktop-based experimental setup, concluding that the selection of modality or multimodality relies on the specific emotion being conveyed to enhance the accuracy of perception. concluding that the emotional facial expression of a virtual agent affects touch perception as well as participants' emotion at a very early stage of neural processing. Harjunen et al. (2017) showed that the emotional facial expression of the agent influences the touch perception; touch from the happy, angry, and fearful agent was perceived more intensely than others (surprise, disgust, sadness, and neutral). In a study in which a participant interacted with two virtual agents in an immersive game (one of them touching the participant before and after the game), Huisman et al. (2014) showed that social touch via haptic feedback positively influences the perception of a virtual collaborator. Similarly, Hoppe et al. (2020) found that haptic social touch significantly increases the perceived human-likeness and social presence of virtual agents, enhancing user engagement and the emotional connection with the agent. Boucaud et al. (2023) found that the acceptability of agent-initiated social touch in virtual environments depends on factors like interaction context, touch coherence, and user rapport with the agent. Aligned with interpretations by Hoppe et al. (2020), the study suggests that users may learn to appreciate vibrotactile feedback over time, enhancing its acceptability in virtual interactions.

Conversely from the above-mentioned studies, in which users receive touch from the virtual agent, Ahmed et al. (2020) collected pressure inputs and physiological data (fEMG) to measure the user's touch behavior while interacting with an emotional agent. The facial expression of the agent was found to affect the user emotionally, and that a convincing empathic communication could be achieved between a human and an agent by using simulated social-touch through vibrations.

Five empirical studies investigated the effect of situational factors such as ethnicity, social status or gender of agents and participants on the effects of mediated social touch in the decision making or interpersonal communication. Harjunen et al. (2018) studied the effect of gender and ethnicity on compliance with the agents' offers, finding that ethnicity predicted compliance. Świdrak et al. (2020) investigated the interplay of social status of an agent and the cultural differences of participants in the context of economic decision-making. Based on their findings, culture has a moderating effect on the significance of social status on compliance. Cui et al. (2021) explored participants' experiences of tactile feedback patterns when hugging a virtual character, revealing that accurate tactile feedback enhances the realism of the interaction, particularly among female participants. Tremblay et al. (2016) found that gender differences influenced the duration and intensity of virtual touch, with male and female participants displaying distinct patterns of interaction based on the body size and gender of the virtual character, highlighting how anti-fat attitudes can significantly alter social interactions in a virtual setting. Additionally, Harjunen et al. (2017) also explored whether individual differences, such as personality and gender, influence affective touch perception. They used a behavioral inhibition system (BIS)[11] to measure individual differences, finding that males with high behavioral inhibition sensitivity perceived touch from virtual characters as more intense and less pleasant when accompanied by high-arousal emotional facial expressions of the agent. Self-reported touch intensity increased in correspondence with high-arousal approach-related (happiness, anger) and avoidance-related (fear) expressions. Happiness instead reduced the orienting response to touch. Harjunen et al. (2017) demonstrated that interpersonal differences in behavioral inhibition and gender play distinct roles and that perception depends on the *emotional expression* of the virtual agents.

In the notification context, six studies demonstrated the impact of haptic feedback as a sensory cue on user interactions with agents. Buck et al. (2020) analyzed the reaction time to measure the peripersonal space boundaries for different types of agents and found that vibrotactile notifications in response to agents crossing a user's peripersonal boundary influenced user behavior, particularly when interacting with human-like agents versus virtual monsters. Results from Buck et al. (2020) show that peripersonal space boundaries can be modulated and reactions to these boundaries can be varied based on salient features of objects and agents in those environments. Boundaries are malleable, and are responsive to an agent that is perceived in a negative light. Krogmeier et al. (2019) showed that haptic feedback via a tactile vest enhanced self-embodiment and interaction with virtual characters in a virtual city scenario. Both Krogmeier et al. (2019) and Venkatesan et al. (2023) showed that haptic feedback increased the perceived realism of the interaction with virtual characters. Additionally, Venkatesan et al. (2023) found that the combination of vibrotactile and torque feedback influenced participants' emotional responses when navigating through virtual crowds, with vibrotactile feedback amplifying negative emotions. Torque feedback was associated with a stronger perception of physical presence and realism. Ahmed et al. (2017) reported that different tactile feedback during a competitive game engaged users deeply, with game events affecting physiological responses. Froese et al. (2014) found that vibrotactile feedback during a game enhanced responsiveness and the perception of another player's presence. Venkatraj et al. (2024) further revealed that haptic feedback in co-embodiment tasks could lower the sense of agency in free-choice scenarios but increase it in targeted tasks, while also influencing co-presence, body ownership, and motion synchrony, highlighting the nuanced effects of haptic cues in shared virtual interactions. Lastly, Hassani et al. (2016) demonstrated that integrating multiple feedback modalities and interacting with intelligent agents in an immersive environment could enhance learning experiences in language learning.

Ahmed et al. (2017) analyzed the self-reported items, effect of agent's emotion, user's hand movement using accelerometer, and physiological data (ECG, EDA) to measure the user's game performance and experience. They found that game performance affected both movement and EDA signals losing increasing signal amplitudes. Hassani et al. (2016) collected self-reported items related to language skills and user's voice reply using the microphone to measure the language learning performance and changes in language skills. Interestingly, Froese et al. (2014) calculated a number of dependent variables including social judgment,

---

[11] The Behavioral Inhibition System (BIS), as described in reinforcement sensitivity theory, is a physiological mechanism controlling aversive motivation. Sensitive to signals of punishment and nonreward, it suppresses behavior that may lead to negative outcomes and inhibits goal-directed actions. The BIS is responsible for negative feelings such as fear, anxiety, frustration, and sadness in response to these signals, and a chronically active BIS is associated with introversion. This concept was described by British psychologist Jeffrey Alan Gray.

empathy, scores, clicking accuracy, co-regulation, using the mouse click data and self-reported items related to confidence for measuring the effect of presence in a co-regulated interaction.

Beyond the effect of the type of touch technology (e.g., vibrotactile versus force feedback) studied by Ahmed et al. (2016) and Venkatesan et al. (2023), only Krogmeier et al. (2019) measured the effect of qualities of tactile feedback, such as intensity or placement, on the experimental conditions. They considered self-reported items and EDA, concluding that physiological signals could help determine the optimal parameters for haptic feedback.

Considering Table 4, it would be important to be able to ensure that studies are comparable or replicable. This would require a better consideration for making technology setups comparable, allowing for benchmarking of tools and better support the sharing of data for replicability.

4 Discussion

We systematically reviewed articles from 2010 to 2024 that used haptics for social touch interaction in VR with virtual agents and avatars, excluding, for instance, other uses of haptic technology in VR, such as embodiment, presence and interaction with objects.We acknowledge that our focused approach, while providing a solid foundation for future research, imposes certain limitations on the generalizability and breadth of the findings. However, these can be complemented by findings from broader reviews on haptics and social touch (Olugbade et al. 2023) and technologies for haptic interaction in various forms of extended reality at large (Pacchierotti et al. 2024). In terms of technology to study haptic interaction in VR, the relatively small number of studies (32) might not fully represent the broad spectrum of implementations and it might overemphasize specific technologies, potentially overlooking emerging or less common approaches. For instance technological development such as a social haptic device for creating continuous lateral motion using sequential normal indentation (Culbertsome et al. 2018) and a soft pneumatic haptic wearable designed to create the illusion of human touch (Talhan et al. 2023) are promising. However, they have not yet been used (or developed) in the context of interaction with avatars or virtual agents, and thus have not been included in our review. Future research should consider a wider range of technologies and applications to ensure a more comprehensive understanding of the field.

In this section we first discuss our findings through the lens of our classification dimensions (contexts, technology and empirical studies), and then provide implications for future research.

4.1 Analyzing contexts, technology and empirical studies

The analysis for the first research question in Sect. 3.1 resulted in a classification of the reviewed articles into three categories based on the research contexts: (1) Emotional expression as exchange of emotions and intentions through mediated haptics representing hugs, handshakes, or other forms of tactile interaction, and understand its effect on social interaction; (2) Notification, as using haptics to provide tactile sensory cues to inform or notify individuals about certain events, and; (3) Changing behavior, as utilizing haptic feedback to understand the effect of social touch on users' actions or decisions during interactions with avatars or virtual agents, such as affecting compliance, altering decision-making processes or shaping social dynamics based on the tactile experiences provided. Not surprisingly, *emotional expression* communication was the category with most contributions as it can be considered to have the widest scope. It is notable that only in the case of *notification* dimension, no direct social touch either from the virtual agent/avatar or toward them was used.

In addition, we separately addressed VR technologies and haptics. VR technologies were characterized by common use of Unity as its accessible and flexible platform and a HMD (Meta Quest and HTC Vive). Several solutions of interaction devices were used in particular to track hands and body with the required fidelity. Haptic technologies include widespread use of vibration or force techniques and the stimulation was applied mainly to the hand and arm in the three contexts, but also to lips, neck and other more sensitive body parts in the *emotional expression* literature. The majority of the articles used vibrotactile actuation and force feedback, and the hand was the most used body location for receiving touch. Therefore, the studies and technologies were largely limited to hand-based interactions and traditional devices.

The empirical studies described in 3.3 primarily employed self-reported questionnaires, with some incorporating behavioral and physiological data. While most studies used full questionnaires, a few only provided partial sets. Various physiological data, such as GSR, EDA, ECG, and EEG, were collected alongside self-reported subjective experiences. All studies were conducted in controlled laboratory environments, with participants usually seated except in a few standing-position studies.

These studies frequently utilized experimental factorial designs with randomized trials and participants. The research explored diverse contexts, including emotional expression, decision-making, and VR interaction. Repeated measures ANOVAs were commonly employed to assess the effects of touch and haptic feedback on user experiences, revealing that such feedback significantly influenced perceptions, emotions, and behaviors in virtual environments.

The research indicated that haptic feedback enhances realism, modulates emotional responses, and influences behaviors like compliance, social interactions, and decision-making. Studies also explored the impact of situational factors, such as gender and ethnicity, on the effects of social touch in VR, and highlighted the importance of making experimental setups comparable for future research. Overall, the findings underscore the critical role of haptic feedback in shaping user experiences in virtual environments, emphasizing the need for standardized methodologies to ensure the comparability and replicability of results across studies.

Lastly, empirical findings from controlled experiments are congruent across studies in the three categories. In the case of *emotional expression*, the unfolding of the conversation and social context are key beyond individual responses to stimuli. Such conversational and social context can be best studied in-the-wild in actual social VR platforms.

4.2 Implications

We discuss the implications for future research based on themes that emerged from our literature analysis. These include the need to consider in-the-wild studies and address emerging issues in social virtual worlds, such as harassment. Additionally, we emphasize the importance of understanding the implications of simulating actual social touch and using VR to study human social interactions. There is also a need to broaden the spectrum of participants in evaluations of haptic technologies to include neurodivergent and disabled individuals. Finally, we highlight the importance of developing tools to support exploration and expand research in this field.

4.2.1 Studying mediated social touch

Existing haptic stimuli have been unable to effectively convey their intended meaning or establish a connection to real touch. Although there is preliminary support for the idea that mediated social touch can produce effects comparable to real-life situations, other studies have not been able to establish the same findings. VR experiments, for instance, have not consistently confirmed the presence of the “Midas touch effect” (Świdrak et al. 2020, 2021). Mediated social touch, as experienced through current technology, is often seen as different from physical touch without technology (Askari et al. 2020). The lack of consistent positive results could be attributed to the intricate nature of specific tactile social interactions, which involve integrating multiple signals that are challenging to replicate using simple devices (Schirmer et al. 2016) as well as considering contextual factors (Askari et al. 2020). This distinction may arise due to the limitations of current haptic technology in realistically reproducing the sensation of human touch and a limited understanding of the broader context in which mediated social touch occurs. Therefore, further investigation is necessary to explore technological advancements and various social, perceptual, and other influences.

Jaron Lanier views VR as an instrumentation to explore motor cortex intelligence and nervous systems adaptations, as VR offers ways to simulate reality (Lanier 2017), so that there are parallels between social touch through haptic technology and actual social touch. Some VR research in psychology is aimed at simulating what happens in physical reality (Pan and Hamilton 2018), benefiting from providing control of variables during experiments. Conversely studying mediated social touch can also be used to understand interaction in emergent social VR platforms(Chen et al. 2025a, Chen et al. 2024b). As an example, harassment in social VR has been documented as being a graver problem than in social media and deserving more research for studying it and mitigating it (Chen et al. 2024c, Chen et al. 2025b, Freeman et al. 2022). A novel topic called phantom touch sensation has emerged (Chen et al. 2024a), which refers to a touch sensation occurring in social VR by just visual stimuli (Alexdottir and Yang 2022). Recent views criticize limits of prevailing social cognition approaches to transfer to everyday situations advocating the application of interaction theory (Huisman 2022). Mediated social touch research should address these emerging themes suggested and informed by social VR platforms, to increase its social relevance.

4.2.2 Accessibility and inclusive design

Longitudinal to the context of use, the systematic analysis reveals that haptics for social touch in VR are largely studied and developed without critical examination of existing biases towards normalized body standards, thus neglecting individual variability in touch perception and haptic affordances. The need to include more diverse perspectives has been also acknowledged by previous reviews on the broader area of affective haptic systems (Vyas et al. 2023) and the intersection of embodied interaction and VR at large (Gerling and Spiel 2021). For instance, people with disabilities regularly face barriers in accessing various forms of technology, and these barriers are particularly problematic in the development of haptic-augmented social VR technologies that often involve nuanced and context-specific forms of touch that are difficult to replicate with standard interfaces. Most of the reviewed haptic technologies target hands or forearms without full consideration of the wearability of the device for different body configurations (e.g., amputees), nor obstacles for operation or sensation. For example, people with limited upper body mobility would likely face difficulty operating force feedback devices such as the Falcon, while haptic feedback perception may be inaccessible to people with sensory impairments related to conditions such as cerebral palsy (Wingert et al. 2008) or Parkinson's disease (Sathian et al. 1997). This not only limits their ability to interact in a virtual environment, but also excludes them from the social benefits that these novel interaction possibilities can provide.

The empirical studies we reviewed are affected by sampling biases and narrow perspectives on diversity. Beyond considering situational factors such as gender or social status (Świdrak et al. 2020; Ravaja et al. 2017), they do not take into account the experience of people with disabilities towards different modalities of social touch. For instance, in the case of interpersonal interaction, expressing emotion by the combination of touch and a visual stimulus, such as the facial expression of the virtual agent, would not be an accessible modality for people with visual impairments. These results are also unlikely to extend towards populations with impairments in discriminating emotional expressions (Harms 2010; Della Longa et al. 2022). Social interactions in virtual environments are increasingly becoming a substitute for physical interactions for people with disabilities (Zhang et al. 2022) and have shown potential to support new forms of communication beyond the verbal channel (Maloney et al. 2020). Exclusion in these contexts can result in a lack of social engagement, reduced opportunities for emotional expression, and an overall diminished sense of belonging and inclusion.

Empirical studies are needed to understand how neurodivergent conditions and special needs affect the perception of touch, both independently and in the context of affective agents. People have different sensory and cognitive needs, and haptics for social VR interactions with agents or avatars can be tailored to these differences. The reviewed studies show that the use of haptic feedback significantly influences user perception, interaction experience and behavior when engaging with virtual agents in various social contexts. Interestingly, this includes the potential to learn to appreciate vibrotactile feedback (Hoppe et al. 2020; Boucaud et al. 2023). However, it is unclear if these effects translate to neurodivergent users. Including neurodivergent participants in empirical studies could reveal different perceptions, emotional response and acceptance of more intimate social touches (e.g., hug) from virtual agents compared to neurotypical populations.

Mediated touch interactions with emotional agents could have numerous applications for individuals on the autism spectrum. Providing suitable feedback through multiple sensory channels, such as tactile and visual, when touched by a virtual agent could be used in therapeutic settings to enhance body awareness or increase comfort to social touch, potentially reducing social touch inhibition (Della Longa et al. 2022). However, both opportunities and challenges exist. While enriching affective interactions with haptics signals may improve social communication by strengthening the multimodal emotional representation (Lerner et al. 2013), without clear guidelines, these signals may add complexity. Due to the highly personalized nature of social touch and interaction, iIt is therefore imperative that future research must directly involve neurodivergent populations and people with disabilities in the design process, so they can benefit from multimodal VR systems rather than be marginalized by their use.

4.2.3 Support exploration and broaden research

Vibrotactile and force feedback technologies have been widely adopted in easy-to-deploy setups to study the effect of haptic feedback in different contexts. While rudimentary setups have allowed researchers to conduct empirical studies uncovering findings on the role of social touch in the interaction with virtual agents or avatars, technology alone, or the lack of technology, should not set the limit to realize digital touch and it is crucial for the research community to investigate the factors that play a role in attributing a haptic sensation to another social actor, particularly in the context of multisensory experiences and concurrent haptic stimulation with social cues. Jewitt et al. (2022) recently put forward a manifesto emphasizing the importance of delving into the depth and significance of social haptics while promoting interdisciplinary approaches to touch design that go beyond solely technology-driven advancements. The current experience primarily revolves around individual sensations or altered perceptual experience, with a notable absence of emotional cues from agents or avatars. There is a need to explore the diverse dimensions of mediated touch and enhance the digital touch experience, providing more nuanced and immersive sensations in digital interactions beyond the simple replication of human behaviors as well as encourage the exploration of meaningful touch experiences to accommodate different individual preferences and thresholds for tactile sensations, thus promoting inclusivity and customization in mediated touch communication with virtual characters.

One primary obstacle that hinders exploration is the inherent complexity and cost of creating haptic feedback (Schneider et al. 2017). Toolkits with configurable hardware modules of different actuator setups, including new technologies such as shape-memory alloys for haptic skin deformation (Messerschmidt et al. 2022), can help palliate the implementation effort and, thus, support iterative design and the exploration of the perception of touch modalities and expressive touch metaphors in different contexts. Such tools, moreover, should support designers in the selection of touch characteristics (e.g., velocity, amplitude, force or type), agents or avatars configurations (e.g., gender or ethnicity), as well as customizable support to research methods suggesting, for instance, placement (e.g., arm, hand, torso), emotions and measures. In the context of VR interaction, in which wearable technology is continuously evolving as the result of an academic and industry effort, the exploration of technology placement covers a particular interest, and support tools can be a valuable help to identify the appropriate actuation technologies and methods that can be effectively integrated into wearable devices and materials to provide haptic feedback, as well as socially acceptable areas of the body for remote touch experiences in various contexts, considering cultural and social factors and designing haptic stimuli for wearables that can convey emotional expressions, thereby enhancing the emotional richness of haptic experiences with virtual characters.

Another venue for future research is how to effectively integrate and use existing social VR software and platforms in studies of haptic-mediated touch in social settings to go beyond the context and situations of limited setups as well as to support in-the-wild studies. Recent work puts forward the need to understand mediated social touch not only in terms of individual physiological responses in a simplified sender-receiver scenario, but more significantly how it unfolds and is created in relation to the presence of others (Olugbade et al. 2023), including how participants perceive co-presence and the social context of the interaction (Huisman 2022). Depending on the research context, social virtual worlds could provide the user population, the virtual environment and the network infrastructure to study social touch in a wide range of configurations, such as in-the-wild studies of multi-user collaboration or emerging scenarios such as meditation (Salminen et al 2023) or empathy (Salminen te al 2019, Järvelä et al. 2021). However, their integration with custom or do-it-yourself haptic technology could be hindered by the lack of mechanisms to program and extend the social platform itself in order to render the haptic feedback over networked remote users. Recent technological trends show promising developments in this direction. For instance VRChat, a widespread social virtual world, provides an SDK and a visual dataflow language, Udon[12], to extend the social platform and implement custom behaviors. Other open-source, web-based social VR platforms, such as Overte[13] or the Hubs ecosystem[14], enable users to create and host their own virtual worlds, offering extensive customization capabilities through scripting API and creation tools, thus facilitating the inclusion of new content and the design of customized avatars and interactions. Furthemore, an example of research efforts in this direction is the work of Fermoselle et al. (2020), that provides a software framework and network infrastructure to add haptic feedback to user communication in a web-based social VR environment.

5 Summary and conclusion

The aim of this work was to review the last decade of research on haptics and virtual reality technologies investigating social touch behavior between human avatars as well as humans and non-human virtual agents. We collected articles from WoS informed by a systematic review checklist selecting 32 articles. We were guided by three main dimensions of inquiry set forth by three research questions around the context of the research, the technology used, and findings from empirical studies. In addition the first dimension (contexts) served as a lens to analyze technologies and findings.

We identified three categories of context of mediated touch —emotional expression, notification and changing behavior— that were useful to group studies, highlight differences in technology setups, and in considering what variables have been used, outcome measures and congruence of findings from empirical studies. We discussed how mediated social touch research relates to actual physical touch and to emerging issues and trends in social VR platforms. We also discussed how to consider human touch perception for people with different physical and cognitive abilities. We identified as obstacles for the research the lack of development tools to broaden the exploration of advanced technological setups.

We believe it is an exciting time to renew the research agenda of mediated social touch because of the growing importance of social VR platforms and for the rapid development of embodied conversational agents and their possible deployment, considering open and community wide development tools and sharing of data for replicability.

Author contributions GJ, AB did most of the work in particular in the revision of the manuscript. GJ, AB and IA contributed to various aspects of defining the search queries, and defining exclusion and inclusion criteria. AB in particular, was responsible for the methodology and its documentation. IA extracted the information from the first set of articles, producing the first versions of tables and content. AB and GJ handled new papers in the revision, AB and GJ derived key im-

---

[12] https://creators.vrchat.com/worlds/udon/.

[13] https://overte.org/.

[14] https://hubsfoundation.org/.

plications in the discussion. MS, VH, NR, and GJ, contributed to the analysis and discussion.

Funding A.B. was supported by Ayudas para la recualificación del sistema universitario español para 2021–2023, Universidad Carlos III de Madrid, Spanish Ministry of University, https://www.boe.es/eli/es/o/2021/05/26/uni551/dof/spa/pdf. G.J. and I.A. were supported by the Research Council of Finland Project MyModel 357270 and by the EU FET Horizon project VirtualTimes 824128.
Open Access funding provided by University of Helsinki (including Helsinki University Central Hospital).

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors have no conflicts of interest to disclose.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Ahmed, I, Harjunen, V, Jacucci, G, Hoggan, E, Ravaja, N, Spapé, MM (2016) Reach out and touch me: effects of four distinct haptic technologies on affective touch in virtual reality. In: Proceedings ofthe 18th ACM International Conference on Multimodal Interaction. https://doi.org/10.1145/2993148.2993171.

Ahmed I, Harjunen V, Jacucci G, et al (2017) Total Immersion: Designing for Affective Symbiosis in a Virtual Reality Game with Haptics, Biosensors, and Emotive Agents. In: Jacucci G, Blankertz B, Freeman J (eds) Symbiotic Interaction. Springer International Publishing, Cham, pp 23–37

Ahmed I, Harjunen VJ, Jacucci G, et al (2020) Touching Virtual Humans: Haptic Responses Reveal the Emotional Impact of Affective Agents. IEEE Trans Affective Comput 14:331–342. https://doi.org/10.1109/TAFFC.2020.3038137

Alexdottir S, Yang X (2022) Phantom Touch phenomenon as a manifestation of the Visual-Auditory-Tactile Synaesthesia and its impact on the users in virtual reality. In: 2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct). https://doi.org/10.1109/ISMAR-Adjunct57072.2022.00218

Askari SI, Haans A, Bos P, et al (2020) Context Matters: The Effect of Textual Tone on the Evaluation of Mediated Social Touch. In: Nisky I, Hartcher-O'Brien J, Wiertlewski M, Smeets J (eds) Haptics: Science, Technology, Applications. Springer International Publishing, Cham, pp 131–139. https://doi.org/10.1007/978-3-030-58147-3_15

Berton F, Grzeskowiak F, Bonneau A, et al (2022) Crowd Navigation in VR: Exploring Haptic Rendering of Collisions. IEEE Trans Visual Comput Graphics 28:2589–2601. https://doi.org/10.1109/TVCG.2020.3041341

Boucaud F, Tafiani Q, Pelachaud C, Thouvenin I (2019) Social Touch in Human-agent Interactions in an Immersive Virtual Environment. In: Proceedings of the 14th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications. https://doi.org/10.5220/0007397001290136

Boucaud F, Pelachaud C, Thouvenin I (2023) "It patted my arm": Investigating Social Touch from a Virtual Agent. In: Proceedings of the 11th International Conference on Human-Agent Interaction. https://doi.org/10.1145/3623809.3623853

Bourdin P, Sanahuja JM, Moya CC, Haggard P, Slater M (2013) Persuading people in a remote destination to sing by beaming there. In: Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology. https://doi.org/10.1145/2503713.2503724

Buck LE, Park S, Bodenheimer B (2020) Determining Peripersonal Space Boundaries and Their Plasticity in Relation to Object and Agent Characteristics in an Immersive Virtual Environment. In: 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR). https://doi.org/10.1109/VR46266.2020.00053

Chen Q, Spapé MM, Jacucci G (2024a) Understanding Phantom Tactile Sensation on Commercially Available Social Virtual Reality Platforms. Proceedings of the ACM on Human-Computer Interaction 8(CSCW1):1–22. https://doi.org/10.1145/3637418

Chen Q, Bellucci A, Jacucci G (2025a) Mirror Dwellers in Social VR: Investigating Reasons and Perception of Mirror Watching. Proceedings of the ACM on Human-Computer Interaction 9(CSCW1): 1–22

Chen Q, Mousavi M, Riccardi G, Jacucci G (2025b) Investigating the Use and Perception of Blocking Feature in Social Virtual Reality Spaces. Proceedings of the ACM on Human-Computer Interaction 9(CSCW1)

Chen Q, Bellucci A, Jacucci G (2024b) "I'd rather drink in VRChat": Understanding Drinking in Social Virtual Reality. In: Proceedings of the CHI Conference on Human Factors in Computing Systems. https://doi.org/10.1145/3613904.3642405

Chen Q, Cai J, Jacucci G (2024c) "People are Way too Obsessed with Rank": Trust System in Social Virtual Reality. Computer Supported Cooperative Work (CSCW) 4:1-33.https://doi.org/10.1007/s10606-024-09498-7

Cui D, Kao D, Mousas C (2021) Toward understanding embodied human-virtual character interaction through virtual and tactile hugging. Comput Anim Virtual Worlds 32(3-4):e2009. https://doi.org/10.1002/cav.2009

Della Longa L, Valori I, Farroni T (2022) Interpersonal Affective Touch in a Virtual World: Feeling the Social Presence of Others to Overcome Loneliness. Front Psychol 2:795283. https://doi.org/10.3389/fpsyg.2021.795283

Dzardanova E, Vlasios K (2022) First Impressions Matter! IVR Haptic Feedback Effect on User Perception Towards Non-Player Characters. In: Proceedings of the 17th International Conference on the Foundations of Digital Games. https://doi.org/10.1145/3555858.3555911

Fermoselle L, Gunkel S, ter Haar FT, Dijkstra-Soudarissanane S, Toet A, Niamut O, van der Stap NV (2020) Let's get in touch! adding haptics to social vr. In: Proceedings of the 2020 ACM International Conference on Interactive Media Experiences, pp 174–179

Freeman G, Zamanifard S, Maloney D, Acena D (2022). Disturbing the peace: Experiencing and mitigating emerging harassment in social virtual reality. Proceedings of the ACM on Human-Computer Interaction, 6(CSCW1):1-30. https://doi.org/10.1145/3512932

Froese T, Iizuka H, Ikegami T (2014) Embodied social interaction constitutes social cognition in pairs of humans: A minimalist virtual reality experiment. Sci Rep 4:3672. https://doi.org/10.1038/srep03672

Gaffary Y, Martin J-C, Ammi M (2015) Perception of congruent facial and kinesthetic expressions of emotions. In: 2015 International Conference on Affective Computing and Intelligent Interaction (ACII). https://doi.org/10.1109/ACII.2015.7344697

Gerling K, Spiel K (2021) A Critical Examination of Virtual Reality Technology in the Context of the Minority Body. In: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems. https://doi.org/10.1145/3411764.3445196

Haans A, IJsselsteijn W (2006) Mediated social touch: a review of current research and future directions. Virtual Reality 9:149–159. https://doi.org/10.1007/s10055-005-0014-2

Harjunen VJ, Spapé M, Ahmed I, Jacucci G, Ravaja N (2017) Individual differences in affective touch: Behavioral inhibition and gender define how an interpersonal touch is perceived. Personality and Individual Differences 107:88–95. https://doi.org/10.1016/j.paid.2016.11.047

Harjunen VJ, Spapé M, Ahmed I, Jacucci G, Ravaja N (2018) Persuaded by the machine: The effect of virtual nonverbal cues and individual differences on compliance in economic bargaining. Computers in Human Behavior 87:384–394. https://doi.org/10.1016/j.chb.2018.06.012

Harms MB, Martin A, Wallace GL (2010) Facial emotion recognition in autism spectrum disorders: a review of behavioral and neuroimaging studies. Neuropsychol Rev. 20:290–322. https://doi.org/10.1007/s11065-010-9138-6

Hassani K, Nahvi A, Ahmadi A (2016) Design and implementation of an intelligent virtual environment for improving speaking and listening skills. Interactive Learning Environments 24:252–271. https://doi.org/10.1080/10494820.2013.846265

Hecquard J, Saint-Aubert J, Argelaguet F, Pacchierotti C, Lécuyer A, Macé M (2023) Fostering empathy in social Virtual Reality through physiologically based affective haptic feedback. In: 2023 IEEE World Haptics Conference (WHC).https://doi.org/10.1109/WHC56415.2023.10224380

Hoppe M, Rossmy B, Neumann DP, Streuber S, Schmidt A, Machulla TK(2020) A human touch: Social touch increases the perceived human-likeness of agents in virtual reality. In: Proceedings of the 2020 CHI conference on human factors in computing systems (CHI '20) pp 1–11. https://doi.org/10.1145/3313831.3376719

Huisman G (2017) Social Touch Technology: A Survey of Haptic Technology for Social Touch. IEEE Trans Haptics 10:391–408. https://doi.org/10.1109/TOH.2017.2650221

Huisman G (2022) An Interaction Theory Account of (Mediated) Social Touch. Front Psychol 13:830193. https://doi.org/10.3389/fpsyg.2022.830193

Huisman G, Kolkmeier J, Heylen D (2014) Simulated Social Touch in a Collaborative Game. In: Auvray M, Duriez C (eds) Haptics: Neuroscience, Devices, Modeling, and Applications. EuroHaptics 2014. Lecture Notes in Computer Science(), vol 8618. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-44193-032

Järvelä S, Cowley B, Salminen M, Jacucci G, Hamari J, Ravaja N (2021) Augmented virtual reality meditation: Shared dyadic biofeedback increases social presence via respiratory synchrony. ACM Transactions on Social Computing 4(2):1-9. https://doi.org/10.1145/3449358

Jewitt C, Price S, Steimle J, Huisman G, Golmohammadi L, Pourjafarian N, Frier W, Howard T, Ipakchian Askari S, Ornati M, Paneels S (2022) A provocative call to engage with social and sensory aspects of touch. Multimodality & Society 2:261–264. https://doi.org/10.1177/26349795221115463

Koilias A, Mousas C, Anagnostopoulos C (2020) I feel a moving crowd surrounds me: Exploring tactile feedback during immersive walking in a virtual crowd. Computer Animation & Virtual 31:e1963. https://doi.org/10.1002/cav.1963

Krogmeier C, Mousas C, Whittinghill D (2019) Human–virtual character interaction: Toward understanding the influence of haptic feedback. Comput Anim Virtual Worlds 30. https://doi.org/10.1002/cav.1883

Lanier, J (2017). Dawn of the new everything: Encounters with reality and virtual reality. Henry Holt and Company.

Lee J-T, Rajapakse RPCJ, Hung Y-P, Tokuyama Y (2018) The Development of a Virtual Doll Companion for Haptic Interaction. In: 2018 Nicograph International (NicoInt). https://doi.org/10.1109/NICOINT.2018.00038

Lerner MD, McPartland JC, Morris JP (2013) Multimodal emotion processing in autism spectrum disorders: an event-related potential study. Developmental cognitive euroscience 3:11-21. https://doi.org/10.1016/j.dcn.2012.08.005

Maloney D, Freeman G, Wohn DY (2020) " Talking without a Voice" Understanding Non-verbal Communication in Social Virtual Reality. Proceedings of the ACM on Human-Computer Interaction 4(CSCW 2):1–25. https://doi.org/10.1145/3415246

Maunsbach M, Hornbæk K, Seifi H (2023) Mediated Social Touching: Haptic Feedback Affects Social Experience of Touch Initiators. In: 2023 IEEE World Haptics Conference (WHC). IEEE, pp 93–100. https://doi.org/10.1109/WHC56415.2023.10224506

McGlone F, Wessberg J, Olausson H (2014) Discriminative and affective touch: sensing and feeling. Neuron. 82:737-755

Messerschmidt MA, Muthukumarana S, Hamdan NA, Wagner A, Zhang H, Borchers J, Nanayakkara SC (2022) ANISMA: A Prototyping Toolkit to Explore Haptic Skin Deformation Applications Using Shape-Memory Alloys. ACM Trans Comput-Hum Interact 29:1–34. https://doi.org/10.1145/3490497

Olugbade T, He L, Maiolino P, Heylen D, Bianchi-Berthouze N (2023) Touch Technology in Affective Human–, Robot–, and Virtual–Human Interactions: A Survey. Proc IEEE 1–22. https://doi.org/10.1109/JPROC.2023.3272780

Pacchierotti C, Chinello F, Koumaditis K, Di Luca M, Ofek E, Georgiou O (2024) Haptics in the Metaverse: Haptic feedback for Virtual, Augmented, Mixed, and eXtended Realities. IEEE Transactions on Haptics 17(2):122–128. https://doi.org/10.1109/TOH.2024.3369192

Page MJ, Moher D, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R (2021) PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. BMJ n160. https://doi.org/10.1136/bmj.n160

Pan X, Hamilton AF (2018). Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape. British Journal of Psychology, 109(3):395-417. https://doi.org/10.1111/bjop.12290

Rahman AS, El Saddik A (2011) HKiss: Real world based haptic interaction with virtual 3D avatars. In: 2011 IEEE International Conference on Multimedia and Expo.https://doi.org/10.1109/ICME.2011.6012223

Ravaja N, Harjunen V, Ahmed I, Jacucci G, Spapé MM (2017) Feeling Touched: Emotional Modulation of Somatosensory Potentials to Interpersonal Touch. Sci Rep 7:40504.https://doi.org/10.1038/srep40504

Saarinen A, Harjunen V, Jasinskaja-Lahti I, Jääskeläinen IP, Ravaja N (2021) Social touch experience in different contexts: A review. Neuroscience & Biobehavioral Reviews 131:360–372. https://doi.org/10.1016/j.neubiorev.2021.09.027

Salminen M, Järvelä S, Ruonala A, Harjunen VJ, Hamari J, Jacucci G, Ravaja N (2021) Evoking physiological synchrony and empathy using social VR with biofeedback. IEEE Transactions on

Affective Computing 13(2):746–755. https://doi.org/10.1109/TAFFC.2019.2958657

Salminen M, Järvelä S, Kosunen I, Ruonala A, Hamari J, Ravaja N, Jacucci G (2023) Meditating in a neurofeedback virtual reality: effects on sense of presence, meditation depth and brain oscillations. Behaviour & Information Technology 16:1–5.https://doi.org/10.1080/0144929X.2023.2258231

Sathian K, Zangaladze A, Green J, Vitek JL, DeLong MR (1997) Tactile spatial acuity and roughness discrimination: Impairments due to aging and Parkinson's disease. Neurology Jul 1997, 49: 168-177. https://doi.org/10.1212/WNL.49.1.168

Schirmer A, Wijaya MT, Liu S (2016) The Midas Effect: How Somatosensory Impressions Shape Affect and Other-Concern. In: Olausson H, Wessberg J, Morrison I, McGlone F (eds) Affective Touch and the Neurophysiology of CT Afferents. Springer New York, New York, NY, pp 283–299. https://doi.org/10.1007/978-1-4939-6418-5_17

Schneider O, MacLean K, Swindells C, Booth K (2017) Haptic experience design: What hapticians do and where they need help. International Journal of Human-Computer Studies 107:5–21. https://doi.org/10.1016/j.ijhcs.2017.04.004

Sinclair M, Ofek E, Gonzalez-Franco M, Holz C (2019) CapstanCrunch: A Haptic VR Controller with User-supplied Force Feedback. In: Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology. https://doi.org/10.1145/3332165.3347891

Spapé, MM, Hoggan, EE, Jacucci, G, Ravaja, N (2015) The meaning of the virtual Midas touch: An ERP study in economic decision making. Psychophysiology, 52(3):378-387. https://doi.org/10.1111/psyp.12361

Spapé M, Harjunen V, Ahmed I, Jacucci G, Ravaja N (2019) The semiotics of the message and the messenger: How nonverbal communication affects fairness perception. Cogn Affect Behav Neurosci 19:1259–1272. https://doi.org/10.3758/s13415-019-00738-8

Świdrak J, Pochwatko G, Navarro X, et al (2020) The joint influence of social status and personal attitudes in a contact and open versus a noncontact and homophobic culture on the virtual Midas touch. Virtual Reality 24:619–633. https://doi.org/10.1007/s10055-019-00423-8

Świdrak J, Pochwatko G, Insabato A (2021) Does an agent's touch always matter? Study on virtual Midas touch, masculinity, social status, and compliance in Polish men. J Multimodal User Interfaces 15:163–174. https://doi.org/10.1007/s12193-020-00351-x

Talhan A, Yoo Y, Cooperstock JR (2023) Soft pneumatic haptic wearable to create the illusion of human touch. IEEE Transactions on Haptics 17(2):177–190. https://doi.org/10.1109/TOH.2023.3305495

Tani Y, Fujisawa S, Hagiwara T, Ikei Y, Kitazaki M (2019) Bidirectional Infection Experiences in a Virtual Environment. In: 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR). https://doi.org/10.1109/VR.2019.8797761

Tremblay L, Roy-Vaillancourt M, Chebbi B, Bouchard S, Daoust M, Dénommée J, Thorpe M (2016) Body image and anti-fat attitudes: an experimental study using a haptic virtual reality environment to replicate human touch. Cyberpsychology, behavior, and social networking 19(2):100-6. https://doi.org/10.1089/cyber.2015.0226

Tsetserukou D, Neviarouskaya A (2012) Emotion Telepresence: Emotion Augmentation through Affective Haptics and Visual Stimuli. J Phys: Conf Ser 352:012045. https://doi.org/10.1088/1742-6596/352/1/012045

Vallbo AB, Johansson RS (1984) Properties of cutaneous mechanoreceptors in the human hand related to touch sensation. Hum neurobiol 3:3-14.

Van Eck NJ, Waltman L (2010) VOSViewer: Visualizing Scientific Landscapes. 1.6.15 ed

Van Erp JBF, Toet A (2015) Social Touch in Human-Computer Interaction. Front Digit Humanit. https://doi.org/10.3389/fdigh.2015.00002

Venkatesan RK, Banakou D, Slater M (2023) Haptic feedback in a virtual crowd scenario improves the emotional response. Front Virtual Real 4:1242587. https://doi.org/10.3389/frvir.2023.1242587

Venkatraj KP, Meijer W, Perusquía-Hernández M, Huisman G, El Ali A (2024) ShareYourReality: Investigating Haptic Feedback and Agency in Virtual Avatar Co-embodiment. In: Proceedings of the CHI Conference on Human Factors in Computing Systems. https://doi.org/10.1145/3613904.3642425

Vyas P, Desai UM, Yamakawa K, Maclean K (2023) A Descriptive Analysis of a Formative Decade of Research in Affective Haptic System Design. In: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems. https://doi.org/10.1145/3544548.3580735

Wingert JR, Burton H, Sinclair RJ, Brunstrom JE, Damiano DL (2008) Tactile sensory abilities in cerebral palsy: deficits in roughness and object discrimination. Dev Med Child Neurol. 50(11):832-838. https://doi.org/10.1111/j.1469-8749.2008.03105.x

Wohlin C (2014) Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering. https://doi.org/10.1145/2601248.2601268

Zhang K, Deldari E, Lu Z, Yao Y, Zhao Y (2022) "it's just part of me:" understanding avatar diversity and self-presentation of people with disabilities in social virtual reality. In: Proceedings of the 24th international ACM SIGACCESS conference on computers and accessibility. https://doi.org/10.1145/3517428.3544829

Zhao Y, Ham J, van der Vlist J (2018) Persuasive virtual touch: The effect of artificial social touch on shopping behavior in virtual reality. In: In: Ham, J., Spagnolli, A., Blankertz, B., Gamberini, L., Jacucci, G. (eds) Symbiotic Interaction. Symbiotic 2017. Lecture Notes in Computer Science(), vol 10727. Springer, Cham. https://doi.org/10.1007/978-3-319-91593-7_11

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.