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## INTRODUCTION

This paper brings multimodality into methodological dialogue with experiential methods from sensory ethnography to explore what 'counts' as virtual touch and how touch is used to make meaning in virtual reality (VR) environments. It points to continuities and changes in the past, present and futures of touch, and how these are brought to the fore by VR experiences.

Touch is both socially grounded and expressive, it is connected to social and individual tactile trajectories, emotions and histories a complex space for touch technology to mediate. Technological innovation has a long history of trying to bring touch into the digital realm (Parisi, 2017), and touch is increasingly central to the futures imagined for VR within Human Computer Interaction (HCI). However, there is little research on how people experience or make sense of virtual touch. We take an extended view of touch, this moves beyond a notion of touch as direct physical contact to encompasses a wider range of sensorial and social aspects of touch including attending to proprioception, notions of remote touch, touch norms and practices, and touch metaphors (Jewitt et al, 2020).

VR is a computer-generated simulation in which a person can interact within an immersive artificial three-dimensional environment using devices such as a headset with a screen and hand-held controller fitted with sensors. For the purposes of this paper our notion of virtual touch focuses on immersive gesture based VR interfaces, rather than mid-air haptics and 'touchless' interactive spaces. The paper discusses a study of two immersive commercially available VR experiences (a virtual museum, and climbing-rock face environment) using a VR headset and two hand-held controllers to support touch interaction. Virtual touch is explored through a qualitative study with sixteen participants who first interact with the VR experiences, followed by a sensory interview. Participant interactions (including on-screen VR actions) were video recorded. Multimodal and multisensory perspectives were combined to analyse virtual touch as realised through the dynamic interaction between semiotic meaning making resources (e.g. sound effect, images and touch) and participants' experiential sensorial experiences.

This paper contributes to the descriptive (and analytical) work of mapping virtual touch and the semiotic continuities and changes at stake. It points to the challenges of researching touch and shows how multimodality might help us to engage with touch in VR.

## BACKGROUND

Touch is central to human experience and interaction with a vital role in forming and maintaining intimate social bonds and well-being (Bull et al, 2006). The action of touching another (which also involves being touched) and meaning making through touch are constructed in interaction with others, in cultural contexts and governed by social conventions, with many factors (power, gender, culture, generation etc.) in play in the complex space of touch interaction.

Touch is increasingly central to future imaginations of the digital landscape. Historically VR's technically driven emphasis has been on the visual and the aural, bringing challenges to designers and developers in how to integrate touch. Despite being unable to fully replicate the cutaneous and kinesthetic properties of physical touch, advances in haptic technologies enable new ways to remotely communicate a feeling of touch (van Erp & Toet, 2015; Huisman, et al, 2017). The digital remediation of touch is of significant interest to VR developers as it is seen to herald new possibilities, notably enhancing a sense of presence (Campbell et al. 2018) and immersion (Muthukumarana et al. 2019). Touch is seen to make VR tangible in ways that vision cannot (Paterson 2007), to create a physical link between users and virtual experiences (see Parisi 2018), and a felt sense of reality (Spence and Gallace 2013). However, integrating touch into VR is in its early stages of development.

Within both the field of design and VR research, touch is understood as both a physical and 'imagined' experience, in which perceptual gaps are supported through the provision of appropriate multisensory stimuli (Biocca, Kim & Choi 2001). Current research focuses on the development of digital artefacts such as gloves, vibrotactile controllers, mid-air haptics to generate tactile sensations in VR, linked to our understanding of neurophysiological touch mechanisms, as well as extending work on the notion of 're-creating touch' or 'touch illusions' (Muthukumarana et al. 2019), which rely on visuals and sound mapped to movement of the hand or body. The focus of touch is differently conceptualised as replication or illusion (Price et al., 2021), shaping the design process. Given the current state-of-the art, touch in VR cannot deliver a 'realistic' physical sensation of touch (Stone 2019) and is constrained in the ways that bodies are captured and represented. Nonetheless, research shows that VR can "feel real" even when the physical experience of vibrotactile feedback offered by controllers is degraded (Parisi, 2019, who offers an extensive historical analysis of vibrotactile feedback). Although not focusing on touch, Hollett et al (201), demonstrated that our 'feeling histories', that is, embodied ways of sensing, feeling and moving within and outside technology shape the way we experience VR.

The relationship between notions of the 'virtual' and 'real' is complex. A multimodal approach problematises 'reality' by emphasizing representation, mediation, and interpretation as central to its construction. It rejects a straightforward dichotomy between the virtual and 'the real', and instead takes representations as reflections of reality and questions whose realities are represented, how and why (Chandler, 2017). That is, 'reality' always involves representation and the concept of virtuality is thus central to the process of meaning making itself (Barricelli et al., 2016). In VR, the notion of similarity and mimesis are key for the capacity of immersivity to locate the user in a specific world. Making the artificial world feel credible or believable is thus essential for the active interaction of a user who in turn makes meaning (Marini, 2011).

Against this backdrop it is important to note that
when any new technology enters the 'Technoscape' (Appadurai, 1990), societies reach a con sensus over time and develop a set of norms for its use, and this shapes the ways we communicate and interact. From a multimodal perspective, changing the medium and the material form of a signifier influences the potential meanings which readers can make of the 'same' content (Kress and van Leewuen, 1996:231), hence a concern with 'the materials of representation and the materiality of the processes of representation' (Kress and van Leewen, 2021:170). Indeed, how materiality is taken up as a semiotic resource - the meanings that cultures attach to materials, is a vital aspect of meaning making. Multimodal attention to the material characteristics of communication and the processes of meaning making, point to the

dynamic ways in which semiotic resources and technology shape one another (Kress, 2010). This paper explores the shaping of touch through the introduction of touch controllers with haptic feedback (see fig. 1) to the standard (audio-visual) VR headset. In doing so, it builds on previous multimodal studies that have mapped the meaning-making potential of specific modes, and shown how these are expanded or reconfigured through the digital, for instance, as image moves from page to screen (Jewitt, 2002),, or the gains and losses involved in visual representation of tactile surface texture in PowerPoint (Djonov & Van Leeuwen (2011). (A mode refers to a set of socially and culturally shaped semiotic resources for making meaning with well-acknowledged regularities/principles of use (Kress, 2014).) In addition, studies have examined multimodal orchestration and analytical principles (e.g. modality, framing, etc.) that operate across different semiotic resources – both modes and media, and practices (Kress & Van Leeuwen, 2001). A few recent multimodal studies have explored conceptual tools towards mapping the emerging resources of touch (Jewitt, 2017) and how these may be digitally remediated (Crescenzi, Price and Jewitt, 2014; Jewitt et al, 2020). Such studies show that new configurations of modes always exist in relation to past and present meaning making resources, knowledge, and practices: a constant process of continuity and change in which the new connects with, slips and slides over, the old.

Researching touch is particularly challenging. Qualitative methods for touch, including within multimodal and sensory methods, are under-developed. People tend to have low awareness of their touch and find it difficult to articulate touch experiences (Jewitt and Price, 2019). This is compounded by the limited tactile vocabulary and metaphors available to lay people, restricting the insights provided by talk-based methods (e.g. interviews) (Obrist, Seah and Subramanian, 2013). While observational methods can provide some insight on touch practices and interaction, they do not capture the felt, sensorial, and affective dimensions of touch which are central to understanding touch. The digital-mediation of touch and future-facing touch technologies further amplify the methodological challenges of researching touch 'in flux'. Given the significance of touch in general, and recognition of the value of touch in mediating experiences in VR design and technology more widely, little research has explored touch, and/or touch-based VR experiences.

The paper explores the potential of VR technology to shape touch continuities and changes, at a societal level, in turn reshaping touch as a 'semiotic resource', wider discourses of touch, and meaning making through touch, as VR becomes a more central feature of the technoscape. Here the term semiotic resource refers to the actions, materials and artefacts that are used for communication, produced with the human body and/or a variety of technologies (van Leeuwen, 2005). Semiotic resources have meaning potentials, grounded in their prior use – or provenance (origins), and a set of affordances based on what is recognised (by a sign maker the according to their interests) as the properties and potential uses of a resource (Kress and van Leeuwen, 2021). Touch in VR is emergent and in flux (Jewitt, 2017), and in response, we approach it as a resource at the intersection of the semiotic and the sensorial-experiential (Jewitt and Leder Mackley, 2019). Engaging and reflecting on the experiential and the semiotic in the context of touch poses a challenge for multimodality - as the senses and the sensory are not within its analytical frame; however, it helps to open multimodality up to conceptualizations of touch that can contribute to theorizing the semiotic resources of touch, and bring the experiential and the representational more clearly into view.

## METHODOLOGY

The study design consists of two interconnected parts, designed in response to the challenge of researching touch noted above. Participants first interacted with two purposefully selected VR experiences and were then interviewed on their experience using sensory objects to support exploration of touch.

The study used the commercially available Oculus Rift Headset and Touch Controllers kit (see Fig 1). The headset covers the user's eyes and ears, cutting them off from their physical environment, to provide an immersive audio-visual experience. The controllers are held in each hand (Fig 1 b) and used to orientate the user's virtual hands - displayed to them on the headset - to interact with the VR objects and environments; they provide haptic feedback (via a rumble motor) – the sensation of a gentle vibration, which is activated when performing specific touch actions (e.g. grasping or holding) with particular objects or aspects of the landscape. When wearing the VR kit the user's distance mobility is constrained by the VR interaction space (edges only visible through the headset when physically near them) and a long cable connected to a computer.

Figure 1: a) Oculus Rift Headset and Touch Controllers; b) the VR equipment in use

This paper is concerned with the process of meaning making. Recognising the importance of the multimodal resources made available through the two VR experiences, but due to the constraints of space we provide an overview of these the rather than an in depth multimodal analysis.

The two VR experiences used in the study were selected because touch is a central feature of both, the focus is 'real-world' touch experiences (handling objects, climbing) and a range of touch actions (e.g. gripping, rotating, stretching). They are single-player experiences (the norm in VR) so do not involve interaction with other social actors, which is why we explore their sociality in relation to the touch experiences, practices, imaginations and memories that participants bring to them. The user's whole-body is not represented in either VR experience, only their hands are depicted: in the form of a thin-line outline of hands in *Hold the World* (fig.2 a) and a fuller, more 'naturalistic' representation of hands in *The Climb* (fig.3). It is significant to note that throughout both experiences participants were largely static, and body movement was limited to upper-torso or arm movement when reaching to touch, hand positions were fixed in a grip by holding the two controllers. Participants stretched and moved their arms more vigorously in *The Climb*, with several commenting on sweating, increased heart-rate, and experiencing vertigo. Participants' faces were partially covered (by the headset) and were generally inexpressive and immersed in concentration.

*Hold the World* (2018) is based 'in' the Natural History Museum (NHM), London, drawing on objects and exhibits present in the museum not usually available for tactile forms of exploration. It was designed by VR developers (Factory 42, Dream Reality Interactive and Talesmith) in conjunction with the NHM and the SKY Media group with the aim to communicate and educate visitors by providing new interactive access to the Museum collection. *Hold the World* offers the user an opportunity to go 'behind the scenes' of the NHM. We preselected the Conservation Centre for the study where users are invited to explore two items (different in natural size, texture and form) a butterfly and a dinosaur. In this experience, the user can open a drawer on a virtual display table, take out an object, and place it (in circular markers) on the virtual table which triggers a virtual representation of David Attenborough who offers spoken information about the objects. While the object becomes suspended in mid-air, the user is invited to pick it up and they can grasp it, pull it towards them, manipulate it – enlarge and shrink it. Clicking on specific locations on the object enables the user to get more information about it, in the form of a monologue by Attenborough and initiates an animation of the butterfly or dinosaur to enable them to experience it moving in the VR space and to hear the sounds that makes (the flapping butterfly wings or the stomping dinosaur feet). Other sounds include the sound effect of doors and drawers opening and objects touching the table. While the user presses triggers on the controller to interact, their hand is represented in the virtual world with an outline sketch of a hand (Figure 2). Synced to specific touch interactions, users receive (digitally mediated/produced) feedback in the form of vibrotactile stimulation provided by touch controllers, sounds and visual cues of touch from the headset. The VR experience lasted between 15 to 20 minutes per participant.

Figure 2: *Hold the World*:a) Butterfly grasped by the outline hand representation; b) Stegosaurus; c) Dinosaur when animated
https://www.youtube.com/watch?v=kFasefT-zrY&t=83s

*The Climb* (2016) is a popular commercial VR game experience developed by Crytek for the Oculus Quest platform. It simulates the physical activity of rock climbing routes in a variety of settings. A headset provides a dynamic visualisation of the climbing environment - that allows the player to look around 360 degrees and up and down (Figure 3a). Sound includes clicks when the player grabs onto the rock grips, sound of panting while climbing, a voice that goes '*Ahhhh*' when the player loses their grip on the rock and falls, and ambient background sound (e.g. birds and bugs). Players chalked their hands throughout the game - by shaking their hand: visual feedback indicated when chalking was needed – the virtual hands reddening and or the stamina/energy bar changing from blue to red (Figure 3b) if the player did not chalk their hands regularly or maintained a grip maintained for too long. One controller is held in each hand, using the trigger with the forefinger to make a grasping/ holding action with the virtual hands. Vibrotactile feedback is provided when users make initial (correct) contact with the wall and again if their 'energy' bar (Figure 3b) runs low. The study began with a 5 minute tutorial to familiarise participants with key actions (i.e. hand-chalking, gaining stamina) (Figure 3b). This was followed by an opportunity to take the Tourist track in 'Zen Bay' (described as a relaxing climbing route), where they can climb in a 'realistic' environment, with visual texture of a rock, insects, plants). The experience lasted between 15 and 20 minutes per participant.

Figure 3: *The Climb* a) the climbing environment; b) hands and energy bar
https://www.youtube.com/watch?v=er1aUDbyUXo

**Participant recruitment and selection**
In response to the context of the two experiences, participants were sought with knowledge or experience of museums and/or digital games, and were recruited from two related MA programs at a British university. Sixteen participants were recruited, with a mix of experience

of gaming (10), climbing (11), museums (9), and digital games (5). Participants had a range of experience levels, rated from none, novice or expert.

**Data collection**

***The VR experience session*** included a five-minute introduction to the two VR experiences, to provide safety information (i.e. to stop if dizzy or uncomfortable), to seek and obtain consent from participants, and to collect participant information (e.g. level of gaming experience etc.). Participants were introduced to *Hold the world* first as it provides an easy entry point into VR, followed by *The Climb*. Each participant total session was between 30 to 40 mins in duration divided equally between the two experiences. Throughout the session the researcher responded to participants' technical/usage questions and ensured their safety (e.g. trip risks) but did not prompt or ask questions in an effort to capture the participants 'natural' interaction with the environment.

The VR experiences were video recorded using a fixed camera at the front-side of the participant to capture their whole body interaction and screen capture software (OBS studio) to record their multimodal interaction *in* the virtual experience. The two video recordings of each participant were combined using *Lightworks*, a non-linear editing system for editing and mastering digital video to produce a time-stamped composite video which enabled us to see the link between participant actions and reactions with their in-VR actions. This captured participants interaction from differing perspectives and facilitated a multimodal and sensorial analysis. A total of just over eight-hours of composite video data (16 x average of 30 mins) was collected.

An ***interview*** was conducted with each participant following their VR session to explore their experiences of the two virtual environments with attention to touch. In response to the challenges of researching touch (outlined earlier), we used an open topic guide alongside sensory 'touch' objects (e.g. climbing chalking-ball and grip, a model dinosaur) as tactile probes to help participants recall, 'flesh out', and 'reconnect' with touch. Participants were also invited to move and touch with the objects to demonstrate or re-enact their VR touch experiences. This experiential method is designed to generate a sensorial empathetic research encounter with a participant's sensory world, and hone in on participants' experiential experiences with perception at its centre, a focus on memory, imagination, and affect (Leder Mackley and Pink, 2013). The interviews explored if and how participants felt they were touching an object in VR, their tactile sensations, their relationship to the virtual hands represented, how other modalities shaped their touch experience, and what if anything was 'missing' for them, and how they knew how to touch. The interviews provided in-depth data on participants' reflections on touch to supplement the observations of touch interaction. Individual interviews were selected, rather than group interviews, to build the rapport necessary to explore touch in depth, including personal memories, and discomfort with touch. This was important as discussing touch is often taboo, intimate, and people generally find it challenging to recall or articulate touch experiences. They were video recorded using a single fixed camera and were between 21 to 49 minutes, an average of 35 minutes (a total of just over 9 hours of interview data).

**Analytical framework and process**

The over-arching analytical frame for the study brings multimodal and experiential perspectives into methodological dialogue (Jewitt, and Leder Mackley, 2018) through a simultaneous concern with semiotic resources and sensorial aspects of touch. Table 1

summarises this frame and the analytical dimensions of touch in VR that it brings into focus towards exploring continuities and change. Touch in VR is emergent and in flux (Jewitt, 2017), and in response, we argue for the benefits of approaching it as a resource at the intersection of the semiotic and the sensorial-experiential (Jewitt and Leder Mackley, 2019).

Table 1: Summary of the descriptive analytical dimensions of touch in VR

| **Analytical focus** | **Descriptive analytical dimensions of touch in VR** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Prior touch experiences (memory)** | **Provenance & Associations** | **Touch Practices** | **Multimodal Orchestration & Multisensory relations** | **Breakdowns & Disruptions** | **Emotional Affective Responses** | |
| **MULTIMODAL SEMIOTIC** | | | | | | | **CONTINUTIES & CHANGE** |
| **EXPERIENTIAL SENSORIAL** | | | | | | | |

Multimodality is concerned with how participants select and use the most 'apt' semiotic resources available to them in a given social interaction to make meaning (Kress, 2010; Jewitt, Bezemer, O'Halloran, 2016). People's agency is key both at the level of a sign-maker's resource selection (always socially located), and at a societal level as resources are shaped from the material, representational (audio-visual) and social expectations of a specific context as well as the resources it makes available. As a result of this shaping, modes (i.e. sets of semiotic resources with principles of use that fulfil a community's social purposes) are taken up and used in distinct ways. In other words, choice of mode is a central aspect of meaning making. Our analytical emphasis is on the place of touch and its distinct meaning making potentials in VR, nonetheless we discuss its relationship with other (visual and audio) modes and acknowledge that it is part of a broader multimodal ensemble (Jewitt, 2017). Alongside the multimodal, we attend to the sensorial, experiential character of touch, with attention to participants' first-person perspective on the sensing touching body, the technological and the material constraints that shape virtual touch experiences, including affect, memory and imagination (Pink, 2015). Engaging and reflecting on the experiential and the semiotic in the context of touch poses a challenge for multimodality - as the senses and the sensory are not within its analytical frame. We are not suggesting that touch is not always semiotic, rather we use an experiential sensorial approach to open multimodality up to conceptualizations of touch that can contribute to theorizing the semiotic resources of touch, and bring both the experiential and the representational more clearly into conversation.

We viewed the video data of each participant's VR experience guided by the concepts of semiotic resource, materiality, and the affordances and provenances of these, to generate a descriptive account of their multimodal interaction including bodily reactions to touching in VR environment (e.g. changing bodily position or posture), breakdowns and frustrations raised by trying to touch, types of touch, touch actions, touch practices and what is touched. Throughout the VR experiences, however, participants' body posture was largely static and

limited to upper-torso or arm movement when reaching to touch, hand positions were fixed by the controllers, and faces were partially covered (by the headset) and generally unexpressive (in immersed concentration). While the video observations provided some analytical openings and directions, the interview data was essential to make meaning of the participants' experiences, and provides the rationale for the weight given to the two sets of data in this paper. The analysis explores findings from across the two VR environments to explore the range of touch experiences afforded by commercial VR, and integrates data from the VR experience and interviews. While it is challenging to undertake a thematic analysis of two different types of data, the strong connection between the data enabled the analysis to iteratively follow themes across them. Themes were first developed from the observational data, second explored and expanded through the interview data, and third used to revisit and review the video observational data: this iterative analytical process was valuable as it brought participants' semiotic actions, their reflections, and experiential experiences into an intimate analytical dialogue. Two themes - touch resources, and touch practices, are brought into focus in this paper to examine meaning making through touch in VR, and address what 'counts' as touch for the study participants. Touch resources includes data on the participants' touch expectations, prior experiences, imaginations and norms. Touch practices includes data on participants' their handling and movement of touch controllers, virtual hands and (absent) bodies, interpreting audio-visual resources to bridge to touch, and multimodal orchestration.

## MEANING MAKING THROUGH TOUCH IN VR: WHAT 'COUNTS' AS TOUCH

In this section we describe the touch resources and the touch practices that participants' drew on. These two themes, and the data collected around them, are entangled through the rich connections between resource and practice, and more generally, between body, technology, and environment.

### Touch resources

#### *Touch expectations, prior experiences, imaginations and norms*

In VR touch is directed to specific objects and activated in particular forms, that is, only certain 'touches' are enabled for a sub-set of the different objects encountered. At times these selections were at odds with the participants' expectations of touch, real-world (prior) experience of touch, and everyday touch norms. In *Hold the World*, for instance, a drawer on the desk can be opened, and a static dinosaur or butterfly can be picked up, rotated or enlarged but once animated it cannot, the desk cannot be moved and the chair cannot be sat on. Participants repeatedly reached out their virtual hands as the butterfly flew around hoping for it to land on their hand. In, *The Climb*, designated climb points can be gripped but other objects or parts of the environment cannot, including a climbing-grip hanging from the cliff, vegetation and holes in the rock face. This design shaped participant touch experience: what and how to touch in each of the virtual experiences.

> *I wanted to be able to touch more things, like things I would do in real life, pull out a chair, pick up a pencil, open doors… have more freedom to touch things……. I didn't really know when I could touch things, or how I could touch things. … I had to explore myself… like when the dinosaur was moving I was trying to touch it… I wish I could grab things that were grabbable in real life instead of just the ledges that were designed in the game* [P6]

The possibility for touch raised participant touch expectations of the experience, raising a challenge for designers in deciding the amount and place of touch and creating tactile touch cues.

The ability to interpret the virtual landscape – notably the visual (e.g. use of lighting, colour) and tactile (e.g. vibration feedback) conventions that signal an object is interactive, were central to (newly) learning to touch. This is illustrated by the following description of one participant's experience of *The Climb* (drawn from the video data and the interview data). Participant [P5] is trying to assess what aspects of *The Climb* environment she can hold onto. She reaches and grasps at different elements, she tries to hold onto a shrub on the cliff-face, reaching her arm with the controller forward, pressing the buttons, "*Can I hold this now? I think I can hold the forest*". The virtual hand will not close around the shrub. "*No*". She reaches out her arm to hold onto the rocks rather than the designated climbing edge. "*No*". The VR environment enforces climbing *advice* not to hold onto shrubbery or loose rocks. In her interview, P5 notes that her touch exploration enabled her to understand what could and could not be held. She noted that while she "*Could only touch what the game gave*", she "*was curious about everything and I wanted to touch everything*," and commented that the lack of verbal instruction gave her "*a sense of experience and adventure*".

This exploratory process generated awareness of the constraints and possibilities for virtual touch and exposed participants' expectations of virtual touch. Several participants, however, continued in their belief that an object *was* touchable when it was not: "*I couldn't grasp the climbing clip – I didn't know the right way to touch it*." [P13]. The activation of the climbing clip, however, depended on proximity (it responded if they were close) rather than touch. This highlights the persistence and strength of participants' touch expectations and the challenge of reconciling a mis-match between prior touch experiences and the virtual possibilities of touch. It also points to future 'physical touch expectations' and 'VR touch expectations'.

Participants experienced *how* they could touch as constrained, describing the range of touch actions available to them including gripping, grasping, holding, pulling, stretching, banging, poking, opening or rotating, as '*functional*' or '*instrumental*' touch - *"very much focusing on skill and just the hands"* [P3]. While most participants found virtual touch limited, they also found it recognisable and '*realistic*' in that it set out to mimic or replicate physical touch and or touch practices '*in the real world*', albeit lacking in '*nuance*' and '*affect*'.

> *I could feel pressure, but not control. Grabbing a handle was same as grabbing object. Which is not true in real life – visualisation of finger movement would be important in grabbing objects. Generally a 'mono-touch' – my hand didn't change. Felt very stiff.* [P4]

This reductive touch was compounded by a focus on the hands (the only part of the body represented) in these VR experience "*I didn't use my legs in the climb – felt like just swimming with your hands*" [P11]. The fragmenting or '*loss*' of the body (an issue we return to later) impacted on participants' sense of a tactile experience:

> *It was very weird that I was rock climbing but I was not feeling that I have to use my body. I was only focused where to put my hand. In the beginning that was strange but then it was fine* [P15]

Alongside a virtual flattening of the richness of embodiment, offering standardised caricatures of a grip sensation, participants commented on a perceived 'felt' lack of texture, temperature, weight, fragility or robustness of an object.

> *It was like touching air.* [P12]

> [Objects were] *floating in air, object with no weight, I can't feel sharpness*. [P2]

> *Round and smooth was hard to sense*. [P6]

Participants drew on their tactile memories and imaginations to make meaning of (and with) virtual touch, including their personal touch histories. Participants used tactile memories to smooth over the cracks in their expectations between physical and virtual touch notably in relation to texture.

> *This experience lacks… You don't feel the texture. So your mind has to create the texture…* [I] *imagined the texture and it felt like it was that part of the climbing. It was almost the same. I am trying to think how rocks felt. There were moments that I actually felt it. Because it reminded me of our holiday house. There is a place like that on the rocks. And I felt it. So, that memory instinctively attached to what I was feeling at that moment.* (P15)

This appeared to be more successful in relation to hard textures, perhaps due to the hard-feel of the controllers they held in their hands.

> *The butterfly* [in Hold the World] *wing I imagine it must be soft but holding it I don't feel soft. It seemed brittle, not like a butterfly, which is delicate, fragile. It is easier to sense the hard bone* [of the dinosaur] *than a furry skin.* [P13]

Participants' tactile memories and imaginations were an orchestrating force for the multimodal resources (outlined in this paper) through which virtual touch was realized.

> *When I used the shaking function* [i.e. the chalking function] *and some powder* [visually] *appeared* [she rubs her two hands together]*, it feels like there is some powder. It's a dry, smooth feeling. It's basically imagination in that moment* [gestures the powder dispersing]. [P3]

These experiential resources were often, though not exclusively, mobilised around the sensorial lacks that participants expressed feeling, particularly in relation to texture, and have, we suggest, an emotional affective quality.

While virtual touch confounded the expectation that touching can provide information about an object (person or environment), it continued to meet their expectation of touch to create a bond between them and virtual objects:

> *I get closer to the objects, emotionally. It is not something separate from my life. Because I can touch it. I can establish a relationship between us*. [P5].

> *Touching is important between me and the object* [P10]

For two participants, illustrated by the quote below, their experience was just not touch:

> *I am not sure I felt that I* ***touched*** *the objects. It was a brilliant experience, but I am not sure that was the same as I am touching objects. Something else was missing… Temperature, texture, and all those things were missing. I don't think that I was thinking about that as an object handling experience, but that didn't detract from the experience. Maybe it would harden the experience if I had something in my hand?* [P16]

For others, the social norms of touch persisted to shape both the possibilities for virtual touch and their sense of professional identity:

> *My professional mindset* [as a museum educator] *wouldn't allow me to just bang it, just to be able to hold it and to enlarge it… I felt slightly clumsy at times. In reality I am much more dexterous.* [P3]

For some, the possibilities of virtual touch created as an exploratory space where they could play with the usual rules of touch:

> *Sometimes you can do things* you wouldn't normally be able to do *in the real world*, for example, *in the museum you would behave more reticently – not touch things or go there, but in this space it feels like you can do what you want – a bit like a child - break the rules, test the boundaries, test the limitations, making it [the objects] large or small. There are some limitations on how you could do this, though* I *felt like I could throw it – you could let go and it would float in mid-air.* [P2]

## Touch Practices

### *Touch controllers, virtual hands and (absent) bodies*

Participants' touch practices with controllers, notably the pressure of their grip, the act of holding one in each hand, also contributed significantly to building a sense of connection between the physical and virtual environment and a part of generating their feelings of touching. All participants grasped the controllers at moments during their interaction (Figure 3), directing touch at the virtual objects they were engaged with, rather than the controller itself.

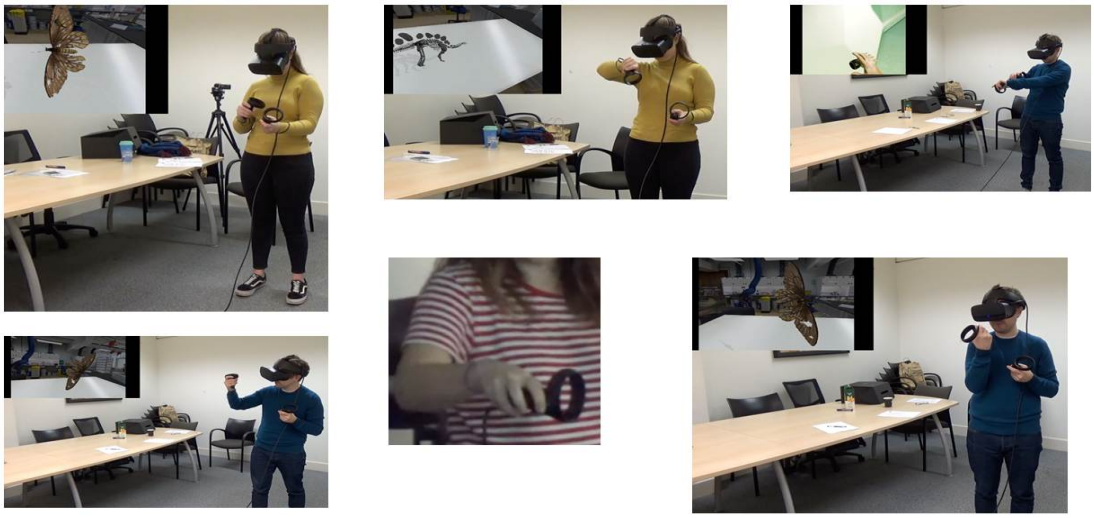

Figure 3: Participants holding and directing the touch controller

For most, the controller gave a physical sensation that mirrored the felt act of grasping, gripping or releasing objects with the weight of the controller itself taking on significance.

> *It felt like I was holding it* [butterfly in *Hold the World*] *in my hands. I don't know why, maybe because you hold the hand device. That was the sensation as well. It did actually feel very much that there was a link between you two. It felt like I was holding it in my hand, even when manipulating, but then the controllers also require a grip so there is a mapping between the two – so there was a physical sensation*. [P1]

For one participant, in contrast, the physicality of the controllers was an '*interference*' resulting in them experiencing their hand as a tool and touch feeling 'too functional', a kind of non-human mechanical type of touch.

> *It feels like an alien…Unreal. It doesn't quite feel human. It just feels very clunky. Your hand is not your hand it's just a thing that presses objects.* [P2]

This suggests a desire for a finer-grained replication of touch in order for it to feel natural and to draw meaning from virtual touch in similar ways as they would outside of VR.

Participants' virtual bodies, were visualised through the hands in both experiences (Figures 1 and 2). Participants described the *Hold the World* depiction of hands as '*just outlines*' or '*lines*', however, they also considered them '*enough*' to create a point of connection between the technology, body and environment. Being able to see 'their hands' when interacting in VR promoted, and to some extent instructed, participants to touch. This was especially effective when a participant could map their physical hand to 'their' virtual hand through image, movement and sound.

> *There was no difference between VR hands and my physical one. They just came together. Hands during climbing look like physical hands but in Museum experience there is no hand, it's just a line, outline of the hand. When VR and physical hands came together - physically it felt easier to climb.* [P5]

Seeing moving virtual hands on the screen also prompted touch. In *Hold the World*, for example, one participant started to use her hands to manipulate and stretch the butterfly. In their explorations of objects participants rotated their wrists, reached or stretched their arms to manipulate and position objects or understand how the virtual hands related to their body and bodily space. The VR experiences (notably *The Climb*) brought the participants' awareness to their bodies, beyond a focus on their hands to stretch and fully engage their upper body to move more fluidly and via their felt muscular tension, bodily signs of physical exertion (e.g. *sweating, tiredness, adrenaline,* feeling *dizzy*) as well as emotional states (*fear, joy, happiness*). In the case of physical exertion and at points of being affected (e.g. scared), the participants' lived bodies returned to their embodied awareness to generate an experience which is lived in the whole physical body. This exposes a gap between the disembodied representation provided in the virtual world (i.e. reduction to hands) with the felt sensory experiences of the participants. Such experiences therefore reveal discontinuities in touch as it relates to a wider sense of embodiment (and presence/immersion) through VR experiences. To reconcile such gaps, participants used both audio-visual resources and social imaginaries.

***Bridging to touch: interpreting audio-visual resources***

Participants' multimodal integration of the virtual visual resources with their physical touch experience was central to shaping their virtual touch experience. The visual resources of VR provided participants with a 'bridge to touch'. They served to 'heighten' participants' sense of touching, providing a context for touching:

> *The Museum set up was like a conservation lab… Materials and surroundings of museum were very familiar and realistic.* [P11]

> *I didn't feel it* [the dinosaur] *like* ***physically****, tactile, but visually and mentally definitely because once I picked it up and let go, it just stayed in the air, so I definitely felt a sense of agency in that I could mould and manipulate it.* [P7]

The visual guided participants' touch explorations, signalling both how and where to touch, including drawing (Figure 4c) on the visual touch-screen gesture of enlargement.

> *I felt that it* [visuals] *kind-a guided me like how I should touch, like what I am supposed to touch… I kept trying to touch one of the rocks but it wouldn't let me grab it.* [P6]

Figure 4: a) picking up the dinosaur in *Hold the World*; b) turning to reach and ring the bell in *The Climb*; c) enlarging the butterfly in *Hold the World*

Participants relied on the visual for information they would often glean from touch, notably texture, and again this contributed to a sense of feeling in VR.

> *I zoomed in and out and grabbed the object to me. I could see the texture. It felt like I was really holding it…when I see the texture of the bones* [dinosaur skeleton] *I can sense the feeling of touching it – all your senses are integrated so when you see it you can feel it.* [P13]

The visual contributed to participants feeling in touch with the virtual environment. In *The Climb*, for example, participants responded emotionally (e.g. stress, fear, excitement) to the visually displayed information about their stamina and energy levels (i.e. changes in the colouring (reddening) of the virtual hands and the energy-stamina wrist 'bracelets'). They experienced the physiological sensations that they felt in response to their emotional state (e.g. sweat, adrenaline, increased heart-rate) as part of a sense of touch:

> *The VR hands were quite similar to physical hands in terms of the energy limits…Virtual energy present in the climbing experience conveyed a sense of using energy – I felt the energy. It helped to feel touch.* [P6]

> *In climbing saw my hands becoming sweaty, bloody. I was afraid that was real. So, I was trying to shake it right away. The hands were hurting.* [P13]

The visual could also disrupt (puncture) a sense of virtual touch. As previously mentioned, several participants interpreted visual elements of the environment as touchable based on their expectations linked to prior experience. For example, the hanging climbing grip or the bell (Figure 4 b) in *The Climb* which they read as a *"place of safety",* or in *Hold the World* the table and chair in the lab, or the flying butterfly. When they realised they were unable to touch these objects, the mismatch that they experienced '*interrupted*' their sense of touch.

The virtual soundscape was another integral resource used by participants' to '*reinforce*' their sense of virtual touching. For example, the sound of a drawer being opened or the 'weight' of

an object landing on the desk in the *Hold the World* experience, and the sound of a hand landing on a rock in *The Climb*.

> *When you put it on the table you can hear the sound 'click'... and that makes it more realistic. I felt touch more during the climbing experience… I feel like the sound really helped. 'Cos when I grabbed onto the rock there's a kind of "ZZZT" and I felt like that really resonated with when I am touching.* [P6]

> *Feels like I can hear sounds of touching rock like in real life.* [P13]

Indeed for some sound was felt as a more powerful resource than the visual as it was "*more immediately interpretable"* and involved the "*sensory integration through association to feel the touch*… [e.g. the sound of a ] "*successful grip*" [P9].

***The multimodal orchestration of virtual touch***

Participants mobilised and orchestrated the range of multimodal touch resources and practices described above to make meaning of (and through) virtual touch. Expectations of touch, prior touch experiences and social touch norms were central to participants virtual encounters. While all participants, albeit to different degrees, experienced 'virtual touch' as restricted and reduced, it was sometimes felt as familiar. Prior expectations, experiences and norms drew participants' attention to the gaps in virtual touch (e.g. a missed sensation of texture), they also, paradoxically, enabled participants to smooth over gaps and to glean a felt sense of touch. Most participants identified virtual touch as, and felt it to be, a resource for meaning making: albeit a complex, ambiguous one, with meaning potentials in an emergent state of flux.

The physicality of the environment provided an initial pathway into virtual touch. This included the tactility (weight, shape) of the VR controllers held in each hand and the VR vibrotactile feedback these provided; the physicality of participants' movement or touching of their own body and the immediate physical environment. This dynamic collision of semiotic and experiential sensory resources enabled most participants to make meaning of (and through) virtual touch, although for a few the initial touch experience fell too far short of their expectation and dissipated.

It is significant that in isolation none of these resources was sufficient to make meaning of virtual touch, rather meaning was realised through the dynamic social and sensorial encounter between body, technology, and environment. In short, making meaning of virtual touch was an integrated multimodal and multisensory accomplishment rather than either a wholly technical or sensory-physical endeavour.

While expectations of continuity between virtual and non-digital touch were key to participants' experiencing and making meaning of (and with) virtual touch, a few felt the lure of new possibilities such as painless or effortless touch, touching in new ways or things that we cannot touch 'in real-life'. Participants brought virtual touch into the 'real' by reconciling their experiences of virtual touch with those from their lived touch trajectories. However, for some the cracks and gaps between their expectations and actual experience of virtual touch were too deep or wide to smooth over. The extent to which participants generated a sense of virtual touch thus differed; some felt it as weak, others as a partial kind-of-touch, others a different kind of touch, and for some, in some moments, a realistic '*like in real-life*' touch.

## CONTINUITY AND CHANGE

This section discusses how participants experiences translated into discourses of touch continuities and change in VR.

### From meaning to discourses: virtual touch

Given the emergent state of VR technology, it is unsurprising that study participants found the material basis of their virtual touch experiences lacking. What *is* surprising, however, is that against the backdrop of tactile limitation (outlined above), the majority of participants reported experiencing a sense of touch in VR (albeit to different degrees). These individual experiences also articulate broader discourses including simulation, illusion and replication (Price et al, 2021), sensorial ambiguity and multimodal sensory integration and wider discourses of touch and technology (Price et al, under review). As virtual touch (increasingly) becomes a central feature of the technoscape, the continuities and changes discussed throughout the paper at an individual level, that is, participants tactile experiences, work to articulate more social continuities and changes. Below we present illustrations of how participants described touch as a meaning making resource either as a recreation of a familiar touch (continuity) or as a divergence of touch (change).

#### *Touch continuities*

Discourses of continuity elaborated on familiar touch, disciplinary knowledges of touch and illusions of touch. Some participants considered their touch experience to be a form of tactile illusion linked to the controller. Others considered their experience of virtual touch to be prompted by a kind of simulation of physical touch practices, in which the virtual environment required them to move their arms or hands in recognised touch gestures. More so than the vibrotactile stimulation these connections to recognisable gestures led to a 'feeling of touching'.

> *Pressing trigger on controller is fairly similar to making a pincer grip when picking up e.g. butterfly….it's* [handling the virtual objects] *not that sensory, so I can't say it really* ***feels*** *like touch, but it is 'how' it is, is pretty much like how you touch it, how you roll the object that way, that* ***is really like touch in reality****, how you* ***'do'*** *on that object.* [P8]

For some participants these familiar actions of manipulating objects (e.g. gripping or grabbing) even transferred into more surreal scenarios.

> *It* ***felt*** *like I was touching it when I* ***grabbed*** *it – especially the dinosaur* [P 13]

Additionally, disciplinary discourses of touch, such as from neuroscience, were also reflected in participants' articulations of their experiences.

> *I'd thought that I won't feel physicality but then I saw how my body was literally putting the effort into that. My muscles where tense… I've finished sweaty… Obviously, it's not the same amount of energy as in a real-time scenario but it was quite interesting to see how my muscles were still compressed while doing the movements... I think we do have mirror neurons and potentially* [the] *simulations triggered them. And it is quite interesting to see how involuntary that is.* [P4]

Such continuities of touch experience were critical in bringing some meaningful touch experiences to the (physically or materially) constrained, restricted or reduced VR touch experience.

***Divergences of touch***

Discourses of change or the divergence of touch speak of the possibilities of the reconfiguration or transgression of the tactile within VR. These concerned participant commentaries on the ambiguities and partialities of touch as well as an imagination of the possibilities of touching differently. Some participants engaged with felt ambiguities of touch, with one comparing her sensation of touching in VR with the slightly removed sense of touching brought about by wearing thick rubber gloves.

> *I felt like I had, you know, when you put those heavy gloves on like when you could do some cleaning or when you are picking up rubbish in the garden, it felt more like that, and you can't actually feel the plant … it felt like I was holding something but it was very protected*. [P3]

A couple of study participants considered their virtual touch experiences too partial, functional or machinic to warrant naming them touch.

> *"I felt like it [the object] was close, …you feel close to it and like you are interacting with it, but I wouldn't say you could actually touch it"* [P11]

> *"It felt like clasping, grabbing, rotating, moving rather than touching. Didn't really feel like touching. Not a* ***sensitivity*** *to it…. I was controlling objects, not feeling them*. [P2]

These quotes suggest that while material encounters with virtual touch were often partial or ambiguous for some, they could still feel a sense of closeness or control.

In contrast to doing familiar movements, some participants interpreted the environments as making "*explicit that you have to move differently in order to 'touch' in the same way* [as in real life]" [P4]. That is, the process of touching is organised differently. For several others, this opened up consideration of new possibilities for virtual touch.

> *Being able to touch differently, like not my hand but my hand inside the VR world, maybe I could touch something I wouldn't dare to touch in real life, something I wouldn't want to touch – a worm!...or like reaching higher, like in the climbing world the fact that I was able to reach further than in real life, that type of touch felt good. [P6]*

The terms in which participants articulated their VR touch experiences situate virtual touch within the discourses of the continuities and change afforded by evolving technoscapes (Appadurai, 1990). These disparate and nuanced discourses reflect touch in VR as a space of extremes, tension and flux, at a moment when virtual touch is on the brink of domestication and about to more fully enter the technoscape. As individual experiences solidify into felt cumulative discourses, virtual touch is situated through notions of continuity and/or change (new possibilities). We argue that these discourses are significant as they will contribute to the design and (re)shaping of touch - virtual and physical, as a semiotic resource for meaning making.

**A multimodal sensory perspective on touch in VR**

The descriptive map of virtual touch presented in this paper offers insight into the possibilities and challenges participants experienced in orchestrating semiotic and experiential resources to make meaning through touch. Through their selection of the most apt resources available to them in their interaction within VR, participants brought their different 'interests', touch trajectories and histories to the process of meaning making and in doing so they created different routes to touchy engagement with the future possibilities of this complex environment. We have explored the continuities across the functions of touch in daily life, its role in exploration and engagement with our environments, and our efforts to express agentive curiosity, to connect and control virtual touch. We have also pointed to the ways in which the physicality of touch and the body, albeit differently configured, are entangled with and essential to the realisation of virtual touch, pointing to the tactile continuities across the virtual and the 'real' to blur and reconstruct the boundaries between these two concepts. We have mapped the ways in which touch is reconfigured through its digital remediation in VR , on the one hand to strip-back touch in ways that lose its nuance, individuality, and affect; and on the other, to open up possibilities for painless or effortless touch, enable touching in new ways or with things or environments that we cannot usually touch in the physical world, to provide new kinds of proximity and interactions to objects and experiences, as well as altering the consequences for breaking touch norms. In this way we have argued that the potentials for virtual touch experience are both supported by *and* constrained by prior 'real-world' experiences to re-imagine touching.

This paper makes a methodological contribution to researching touch and the application of multimodality. First, it illustrates the potential of a multimodal approach to unpack how virtual touch is orchestrated and the connections across a diverse set of semiotic and experiential resources for meaning-making. Using a multimodal approach, this paper provides empirical evidence on emergent digital touch as a multimodal resource for meaning making, notably its relationship to visual and audio resources. Second, the paper contributes to multimodality by demonstrating how it can be brought into a methodologically productive dialogue with sensory methods to engage with first and second person perspectives in contexts such as VR. The paper has highlighted the difficulty of describing and observing touch experiences from multimodal observation alone, as well as the challenges of accessing tactile sensations with language, and shown that combining multimodal observation with sensory interviews can help to address these challenges to offer a holistic view of touch that accesses the richness of participant experiences. Third, the paper shows how an exploratory methodological lens can attune to continuities and change and explore participants' past and present relationships to touch as well as their imagined futures of virtual touch. Adding to existing multimodal literature on how technologies and modes shape one another. In short, the paper demonstrates that multimodality has much to contribute to our understanding of touch as a semiotic resource and how it is reshaped through virtual technologies. This lens emphasises and reshapes touch by pointing beyond touch as a *solely* physical experience to an extended experience shaped through social, cultural, historical and technological factors.

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