

THE NEUROSCIENCE BEHIND HAPTIC EXPOSURE AND POSITIVE EMOTIONS IN MIXED REALITY ENVIRONMENTS

LA NEUROSCIENZA DIETRO L'ESPOSIZIONE APTICA E LE EMOZIONI POSITIVE IN AMBIENTI DI REALTÀ MISTA



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ABSTRACT

The study aims to identify the neuroscience behind haptics and positive emotions, and the impact of virtual environments' designs and implementation on shaping them. The neural circuitries of haptics and positive emotions overlap. MR design, the degree of multisensory immersion and the haptic stimulation pattern influence the outcome in favor of immersive active haptics. Future digital education research in virtual environments should rely on neuroscience findings to design more immersive and emotionally stimulating approaches.

Lo studio si propone di identificare la sovrapposizione tra i circuiti neurali dell'aptica e le emozioni positive, e l'impatto dell'implementazione di ambienti virtuali sulla loro modellazione. La progettazione della RM, il grado di immersione multisensoriale e il modello di stimolazione aptica influenzano il risultato a favore dell'aptica attiva immersiva. La futura ricerca sull'educazione in ambienti virtuali dovrebbe basarsi sui risultati delle neuroscienze per progettare approcci più coinvolgenti ed emotivamente stimolanti.

KEYWORDS

Haptics, happiness, surprise, virtual environments, medical education
Aptica, felicità, sorpresa, ambienti virtuali, educazione medica

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Introduction

The first invention of virtual reality (VR) technology dates to 1965 (Cipresso et al., 2018). While the first use was principally for gaming purposes, extended reality (XR) has expanded globally recently to include many aspects of life from gaming, to social media, research and education (Cipresso et al., 2018). Mixed reality (MR) and augmented reality (AR) are interactive XR technologies that allow to perceive at the same time real physical objects and virtual ones (Park et al., 2020). These tools rely on multisensory immersive aspects as a principal criterion in their design (Burin et al., 2022). Unlike visual and auditory stimuli, touch is a challenging sense often difficult to transmit to virtual reality due to the wide surface of sensory receptors within the whole body, its intricate association with voluntary movements, and the presence of different modalities of tactile perception (Hatwell et al., 2003). Research also identified an important role that haptics can play in motor learning, cognitive functions and emotions (Hatwell et al., 2003). Attempts of including haptics within MR have shown interesting results in learning performance, and emotional stimulation.

The aim of this study is to explain the neuroscientific theories underlying the relationship between haptics and positive emotions and how MR-based-haptics designs impact these emotions in learning context.

1. Methods

A narrative review of the literature is performed by identifying the neuroscientific basis of haptics, cognition and emotions and its different representations in mixed reality educational environments. The following keyword strings were used to conduct our research in Scopus and web of sciences:

Web of science: ((mixed AND reality OR Virtual AND reality) AND (haptic* OR touch* OR tactile) AND (emotion* OR happiness OR happy OR joy OR surprise) AND (education OR learn*)) (All Fields)

Scopus: (TITLE-ABS-KEY (mixed AND reality OR virtual AND reality) AND TITLE-ABS-KEY (haptic* OR touch* OR tactile) AND TITLE-ABS-KEY (emotion* OR happiness OR happy OR joy OR surprise) AND TITLE-ABS-KEY (education OR learn*))

Other papers were identified by manual research in specific medical education journals.

2. Discussion

This review first explains the neuroscience of haptic perception and positive emotions. Then identifies the advances in haptic technologies designs in MR environments. And finally describes the results of experimental research in terms of positive emotions generation through the use of haptics in MR and VR, and how they might be influenced by the different interventions and technological designs.

3. Neuroscience of haptics

The haptic system is defined as the system combining tactile perception and instrumental motor control in upper limbs within the shoulder arm hand system (Hatwell et al., 2003), or lower limbs (Schmitt et al., 2023). It allows the person to explore the holistically elements of the external environment through sensori-motor contingencies (Hatwell et al., 2003). Haptic function has two major components: a tactile component, and a motor component (Deo et al., 2021).

The tactile components of haptics include the perception of spatial cues (shape) and material properties (texture/hardness) (Hatwell et al., 2003). The neuroscientific basis of manual perception involves two major systems: the somesthetic sensory system, and the voluntary motor areas (Hatwell et al., 2003). The control of haptic perception is intra and interhemispheric (Hatwell et al., 2003). The neural circuitry of tactile cutaneous proprioceptive input can be passive (not including hand movements) or active (haptic) (Rodríguez et al., 2019). The first relay is the proprioceptive cutaneous by the stimulation of mecano-receptors: Merckel disc receptors for of spatial shape and texture, Meissner corpuscles for perception of movement (Hatwell et al., 2003), and Pacinian corpuscles and Ruffini endings for perception of temporal attributes (Hatwell et al., 2003). Muscular receptors on the other hand give information about the position or movement of limb segments (Hatwell et al., 2003). Sensory information travels through proprioceptive lemniscal ascending pathways in the dorsal column following a temporal and topographical organization to reach the ventral posterior nucleus of the thalamus and then the primary and secondary posterior parietal areas of the somatosensory cortex and the motor cortex (Hatwell et al., 2003). The primary somatosensory cortex (SI): Brodmann area 3b allows the perception of form and texture of objects, while areas 2 and 3a receive articular and muscular afferences (Hatwell et al., 2003). The primary motor cortex on the other hand, plays a major role in manual exploration and grasping precision: Brodmann's area 4p allows haptic tactile discrimination of objects and triggers movement through touch (Hatwell et al., 2003).

The motor component of haptics involves the motor cortex (Li et al., 2023). Premotor cortical areas and the cerebellum have a role in modulating and coordinating hand movements according to visuo-tactile stimuli (Hatwell et al., 2003). The supplementary motor area (Brodmann 6) has a role in temporal sequential exploratory manual movements and bimanual activities through its interaction with the basal ganglia (Hatwell et al., 2003). Associative motor areas interfere with movement coordination (posterior parietal cortex: Brodmann 5), bimodal visuo-tactile integration (Brodmann 7b), motion control (prefrontal cortex (PFC) and striatum), memorization (amygdala hippocampal complex), and motivation (limbic system) (Yavas et al., 2019). The interaction with the limbic system allows spatiotemporal memorization of tactile events (temporal lobe Brodmann 21, 22) (Hatwell et al., 2003). The neural circuitries of haptics' components are summarized in figure 1. Some of the regions involved in haptics like the prefrontal cortex, striatum, limbic system and amygdala are central regions for emotional regulation as well (Ahmed et al., 2015).

4. Psychology and neuroscience of positive emotions

There are 92 possible controversial definitions of emotions (Celeghin et al., 2017). Three principal theories tried to categorize emotions. The first are evolutionistic Darwinian approaches that recognize emotions as innate separate functions with basic neural correlates, identifying 6 primary emotions: disgust, sadness, fear, anger, joy and surprise (Celeghin et al., 2017). The second, is conceptual act theory that considers emotional meanings as a construction of attention, perception, and memory, influenceable by language and social factors (Celeghin et al., 2017). And the third is the social functional theory, that allowed through computational studies to identify three categories of emotions to which can be associated multiple states : 1- The attachment category with three possible states: desire, love and compassion, 2- The Power and status category with two possible states pride and triumph, and 3- The knowledge and social cultural practice category with as states amusement, awe, interest, contentment, joy and relief (Keltner & Cowen, 2021). Feelings differ from emotions by being conscious experiences that accompany body states and can be generated either by emotions and drives, or by sensory stimuli (hearing, vision, touch taste and smell) (Damasio & Carvalho, 2013). Valence and arousal can also induce positive emotions (Hoyt et al., 2015). Multiple tests help in the assessment of emotional states: 1- The Geneva emotion wheel that uses degrees of "pleasantness" and "control" as measurement factors (Scherer, 2005), 2- The Plutchik wheel of emotions that categorizes emotions according to their type

(positive , negative) (Semeraro et al., 2021), and 3- The atlas of emotions that combines the assessment of physical, and behavioral components (Coppini et al., 2023). Functional brain imaging studies identified a new challenge in considering emotions based on the difficulty of their triggering separately in neuropsychological assessments and the overlap in the activation of certain networks and brain regions in different emotional experiences (Celeghin et al., 2017; Gu et al., 2019). This review will address positive emotions only with a specific focus on two basic universal emotions: Happiness and surprise.

Happiness has two components ; hedonic and eudaimonic (Berridge & Kringelbach, 2011). While hedonic happiness is stimulated by physical and psychological pleasures, eudaimonic occurs through achievement of personal goals (Berridge & Kringelbach, 2011). The PFC and Orbitofrontal cortex (OFC) have been found to be activated in these kinds of experiences (Berridge & Kringelbach, 2011). The ventromedial PFC (vmPFC) , cingulate cortex (Murphy et al., 2003), ventral striatum are associated with hedonic states. Eudaimonic states on the other hand were associated with precuneus activation (Luo et al., 2017). The mesolimbic system as well plays a role through reward by releasing Dopamine from the ventral tegmental area in the locus coeruleus, PFC and anterior cingulate cortex to generate cognitive effects of joy (Gu et al., 2019) (Figure 1).

Surprise on the other hand, is defined as the neural response that generates an emotion that can be triggered by an unexpected or new stimulus (Modirshanechi et al., 2023). Surprise specifically requires a set of elements to be identified from the mere perception of novelty: belief, expectation, prediction, confidence, and familiarity (Modirshanechi et al., 2023). While novelty is principally a result of visual cortex activity to unfamiliar stimuli (Modirshanechi et al., 2023), surprise is triggered by unexpected stimuli and serves to focus attention and is modulated by the activity in the amygdala, striatum, vmPFC and cingulate cortex (Gu et al., 2019) (Figure 1).

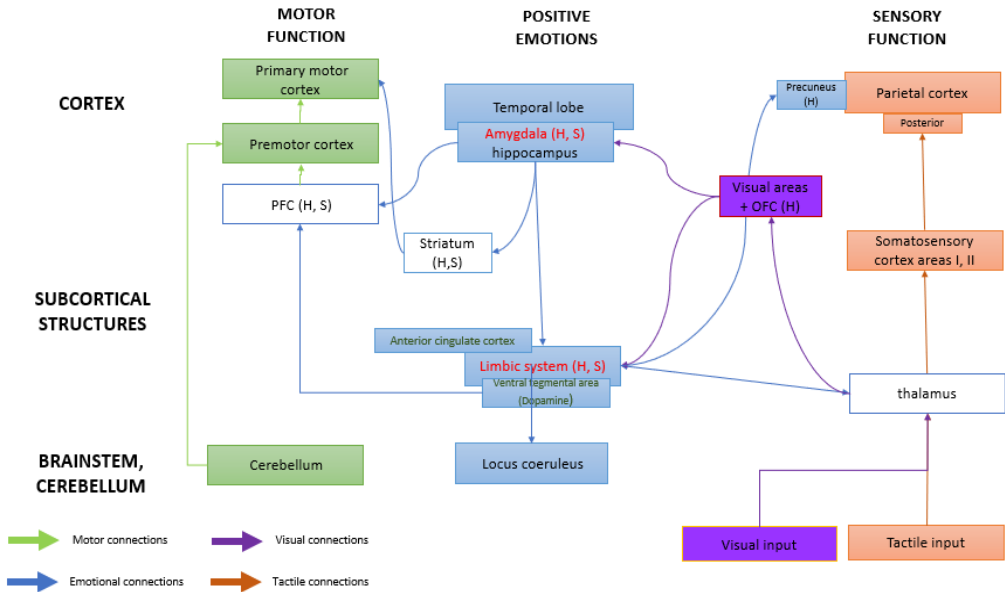


Figure 1 The neural circuitries of haptics and positive emotions and their different interaction pathways

H: Principal structures interfering with happiness

S: principal structures interfering with surprise

PFC: Prefrontal cortex, OFC: Orbitofrontal cortex

5. Mixed reality and haptic technologies designs

The term mixed reality lies under the umbrella term of extended reality that includes three main group of technologies: mixed reality (MR), augmented reality, and (AR) virtual reality (VR) (Stendal & Bernabe, 2024). While VR consists of an immersive experience within a totally virtual environment, AR and MR consists of a mixed perception of virtual and real-life elements (Stendal & Bernabe, 2024). On the other hand, MR offers a wider perspective for multisensory experiences including visual, auditory and other senses that are still not fully transferable technologically to the virtual world like touch, smell and taste (Long et al., 2023). The use of MR has spread widely recently to many fields including education (Silvero Isidre et al., 2023). MR is an experience that offers the best of both the physical real world and virtual environments (Evangelidis et al., 2021). And within its taxonomy it includes virtualized reality, augmented virtuality, mediated reality,

augmented reality, and amplified reality (Evangelidis et al., 2021). Mixed Reality can be implemented using devices such as smart headsets, glasses or AR displays, which allow virtual elements to be superimposed on users' physical environments in a dynamic and interactive way (Barteit et al., 2021). Within the field of education the use of mixed reality depends on five main research layers which are the user interface, the concept of MR, the architecture of MR systems, the middleware, and the application (Harjana et al., 2023). The concept and architecture of MR should reply to the user interface usability requirements and respond to the application need (Rokhsaritalemi et al., 2020). The middleware on the other hand should respond to software preferences that should respect the applicability and adaptability between the system and the network used (Rokhsaritalemi et al., 2020). The technical design of mixed reality should consider device recognition and calibration, space recognition through appropriate modeling of real and virtual worlds, object recognition, detectability and tracking, mapping, visual, and portable recognition (Rokhsaritalemi et al., 2020).

Another element to define is the hand object haptics taxonomy in virtual environments. They belong to two subgroups: the primitives and the implementation (Gonzalez-Franco et al., 2022). While the primitives can be contact (palpation), grasp (manipulation), and forces (kinetic) (Gonzalez-Franco et al., 2022), the implementation relies on more specific controller prototypes and can include physical and vibrotactile rendering and other more dexterity, movement and surface oriented procedures (Gonzalez-Franco et al., 2022). The interaction between the human and the environment through haptics can be active or passive (Srinivasan & Basdogan, 1997). This depends on whether or not the sensori-motor stimulation is actively exerted on the user's body or not (Dufresne et al., 2024). Within the educational sector Virtual Worlds and Tangible User Interfaces (TUIs) are commonly used MR technologies (Guerrero et al., 2016). Dickey showed the possibility of virtual worlds' use to improve learning while using a constructivist pedagogical approach (Dickey, 2003). Another similar outcome was identified through the design of an interaction between an avatar and the virtual environment (Shaer, 2009). Dede, also, was able to illustrate in depth how the use of virtual environments is beneficial to develop harmless real-world activities, allowing a bigger space for learning through virtual mistakes (Dede, 1995). This supports the fundamental principle of "learning by doing" (Marougkas et al., 2023). Moreover, Virtual worlds can increase active learning and engagement (Reigeluth, 2012). The engagement factor depends on many elements, among which the design of the virtual environment and the degree of integration of realistic elements, and immersion (Dwivedi et al., 2022). The use of MR in education concerns also TUIs

that permit a non-intrusive incorporation of digital information within physical objects, allowing users to interact with computers and other digital devices by using physical and manipulable objects that can be moved or touched (Shaer, 2009). It is important to underline that the design of MR technologies should take into consideration the alignment in terms of multisensory integration and motor activity during the didactic experience. Such a gap may cause many side effects like easy distraction, motion sickness, and sometimes even frustration (Weech et al., 2019). Another element is the distribution of attention and workload between the virtual and real environments that is often observed with visual displays underestimating and underusing the non-visual interaction channel (Yip & Saunders, 2023). This reliance on the visual display is problematic when used out of context distracting the users' visual attention from the MR application interface (Yip & Saunders, 2023). Some of the causing factors rely on unequal focus on an audio, tactile, or other interactive modes (Ren et al., 2018). This importance of homogeneity in sensorimotor integration can be explained by the embodiment theory that has proven its applications in many educational contexts like science, math and physics education (Kontra et al., 2015). The embodiment and sensorimotor integration highlight the important role of haptics in shaping cognition in virtual environments (McAnally & Wallis, 2022). This interaction concept-action can reduce the cognitive load, strengthen cognitive performance (Michalski et al., 2023), and increase the sense of presence (Slater et al., 2010).

Figure 2 summarizes the taxonomies and characteristics of MR technologies and their associated sensory experiences.

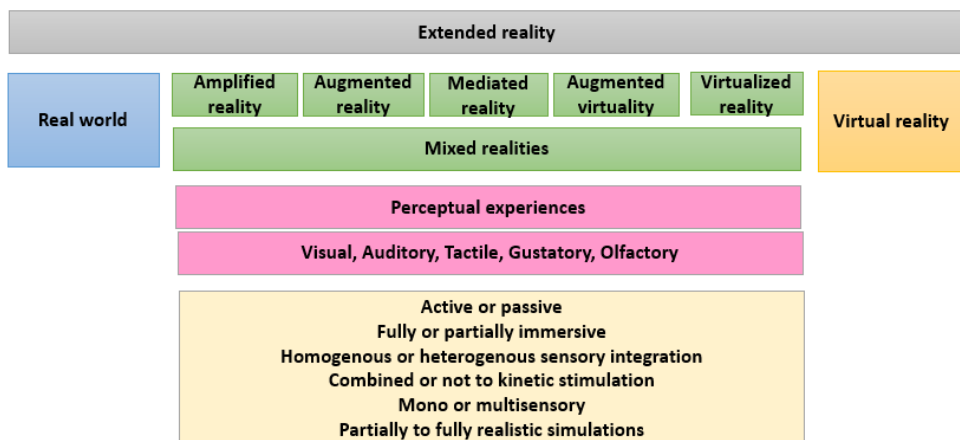


Figure 2 Taxonomy and particularities of mixed realities

6. How do mixed reality environments impact positive emotions?

Technology has become a reliable candidate for improving individuals' well-being leading to the concept of "positive technologies" that comes from positive psychology (Pavic et al., 2022). MR positive technological aspects are immersion and increasing the sense of presence (Botella et al., 2012). Recent studies demonstrated effects of MR on emotions and arousal (Pavic et al., 2023). In particular, mixed reality environments, due to their ability to merge elements of the physical and virtual world, can deeply affect positive emotions such as joy and happiness, and more complex emotions such as positive surprise (Pizzolante et al., 2024). An example of the application of MR positive technology is when the design focuses on engaging participants through interactivity and immediacy of control (Yang et al., 2023). These features increase the sense of presence and perceived enjoyment through the possibility to manipulate objects within the environment that increases the sense of agency and control (Yang et al., 2023). On the other hand, joy can be aroused through haptic based mixed reality environments that focus on tactile stimulation (Desnoyers-Stewart et al., 2024). Tactile stimulation in these environments could increase the sense of parasocial presence, social connection, tactile realism, and embodiment (Desnoyers-Stewart et al., 2024). Phantom tactile illusion integration through multisensory training in MR environments could induce surprise in multisensory conditions featuring the roles of phenomenological control and suggestibility on tactile perception (Pilacinski et al., 2023). Novelty also in immersive MR environments towards unexpected elements can generate reactions of wonder and surprise, and even modulate the negative elements of surprise (premonition) by integrating the other sensory perception and adapting the reaction to the nature of tactile stimulus (Truong et al., 2022). MR can also positively impact arousal and emotional valence (Tsalamlal et al., 2018). MR technologies impact positive emotions differently: Using a multimodal experience, and combining it to haptics and auditory stimulation in a virtual environment could reduce fear and pain and increase happiness during injections (Chin et al., 2021). Another virtual reality and mid-air ultrasound tactile stimulation was able to reduce painful perception by increasing valence and arousal linked to joy and excitement (Karafotias et al., 2018). Another situation showed an increase in pleasure-arousal by using an immersive virtual reality environment (iVR) with haptic feedback vests (Elor et al., 2021). Immersive and multisensory wheelchair simulators could also increase in pleasant and exciting emotions (Salgado et al., 2022). Many other studies in the medical education context were able to induce positive feelings like enjoyment, excitement, confidence, motivation, active engagement through MR based haptic technologies involving tactile active

interaction with 3D printed models, manikins and other kinetic interaction based software that were able to increase the sense of agency while learning practical clinical skills (Table 1). In addition, active-haptic-stimulation-designs are more likely to generate positive emotions than passive approaches (Dongye et al., 2023). The implementation of a modular haptic agent (MHA) system and haptic mapping was able to identify different responses between active and passive haptic interaction in favor of the active interaction, in terms of positive emotions' triggering (Dongye et al., 2023). Table 1 summarizes the existing MR educational technologies combining Haptic interfaces used in education and their impact on emotions.

Some of the methodological implications to consider for MR educational emotionally-inclusive-designs are: the scenario and environmental context of the MR haptic experience, the target group, the technology structuring of MR and haptics, the nature and degree of stimulation through the haptic interface (tactile or kinetic or gestural, active or passive, simple or complex), and the adopted associated educational approaches. Another factor to consider for future studies is the quantitative assessment emotions in these interventions. Many studies seemed to have a target objective to assess the usability of the different intervention, while the assessment of emotional responses was just a secondary result reported subjectively through questionnaires. This shows the importance of paying attention to the role of emotions as a primary trigger of cognitive processes through haptics and the importance of implementing quantitative measurable assessment tools for emotional responses in MR-Haptic environments.

Table 1 The existing MR educational technologies combining Haptic interfaces and their impact on positive emotions.

Author, Year, Country	Name of Technology or intervention	MR technology	Haptic interface	Educational strategy and context	Impact on positive emotions
(Kelliher et al., 2009), USA	SMALLabel (The Situated Multimedia Arts Learning Lab)	High-definition overhead projector Personal Computer SMALLab software	Foam floor mat (projection of educational content) Ultra-precise motion capture camera system	Gamification Group learning Embodied learning Semi-immersive setting.	N/A
(Müller & Nationale Agentur Bildung für Europa, 2005), Italy	The MARVEL project (Virtual Laboratory in Mechatronics: Access to Remote and Virtual E-learning)	Mixed Reality Web Service for mechatronics (deriveSERVER): online hyperbond technology.	Hybrid electro pneumatic circuits combining real and virtual components.	Engineering education Simulation	N/A
(Fiore et al., 2014), Italy	TIWE Linguistico	VR: 3D objects, virtual environments Web talk collaborative virtual environments TiweApp quizzes	Real objects recognisable through QR codes	English teaching Gamification Group Competition	N/A
(Le Jin & Zhigang Wen, 2001), Japan, USA, France	Magic Book	Handheld augmented reality display (HHD) Computer graphics workstation Physical book Computer vision-based head tracking system: InterSense InterTrax inertial tracker, color video camera on the front of the Glasstron display	Kinetic haptics (switch and pressure) in the handle: Pushing the pressure pad allows to fly. To return to the real world, users flick the switch again.	Embodied learning Role play (avatar)	N/A

(Mateu et al., 2015), Spain	Virtual Touch	RFID sensors/tags to detect the position of real objects and display it on LCD screen	A virtual world server and client Tangible interaction devices (Phidgets, Arduino and Microsoft Kinect)	Cubica: Gamification to facilitate teaching sorting algorithms Virtual Touch Eye: gamification to learn grammar in Catalan language	N/A
(Dongye et al., 2023), China	Modular Haptic Agent System with Encountered-Type Active Interaction	Virtual artificial intelligence-based agents combined to VR Unity 3D software	Modular haptic agent (MHA) prototype system: Tactile simulation, modular design and haptic mapping with virtual pet agents. Active and passive interaction through position tracking system	Social interaction Education	24 out of 30 people felt happy during the intervention
(Chin et al., 2021), USA	Multimodal Virtual Reality Experience on the Emotional Responses Related to Injections	Multimodal experience (haptics and audio in a virtual environment: experience of nature environment visuals, popping bubbles tactile feedback, and waterfall audio)	-Tactile stimulation: A syringe with a blunt needle tip -Tactile feedback Ultraleap STRATOS Explore development kit: ultrasound mid-air haptics array and a hand tracking sensor.	Simulation Medical education	Enjoyment; increase in happiness
(Elor et al., 2021), USA	bHaptics tactot vest	Immersive virtual reality (iVR) environment Vive HMD visors Vive hand controllers Unity 3D game engine	-Haptics Designer mobile app to design haptic patterns. The app allows for runtime actuation of the 40 vibrotactile vest positions on the front and back torso through touchscreen controls.	Emotional interaction Virtual museum	Increase in pleasure-arousal

			-bHaptics vest: tactile feedback. A total of 15 pictures are presented to the user with 45 haptic patterns		
(Karafotis et al., 2018), UAE	Mid-Air Tactile Stimulation for Pain Distraction	Virtual reality (VR): Oculus Rift. Unity 3D engine Hand avatars linked to LEAP motion tracker	-Tactile stimulation: Haptogram system; tactile sensations at the subject's hand palm through acoustic pressure	Serious game	Higher arousal, excitement and happiness.
(Salgado et al., 2022), Ireland	Immersive haptic-based VR wheelchair simulator	Unity game 3D Oculus Rift HMD 2D display screen Control interface (wheelchair joystick)	-The simulator provided multi-sensory feedback, visual, auditory and haptic (wheelchair joystick model VR2) - Emotions tracker: Empatica E4 watch	Healthcare Patient education Simulation	Increased pleasant, exciting emotions, and arousal
(Silvero Isidre et al., 2023), Germany	Mixed Reality as a Teaching Tool for Medical Students in Neurosurgery	Immersive VR headsets + 3D printed simulation model reconstructed from computed tomography MR viewer Magic Leap goggles	Printed 3D model from MRI data, then 5–10 min interaction with the model using immersive Magic Leap Inc Headsets and a controller to rotate the model.	Neurosurgery Medical education Simulation	Contentment compared to the conventional way. Enjoyment, higher satisfaction, and engagement
(Richards, 2023), USA	HoloLens Mixed-Reality Technology in Human Anatomy	HoloLens headset and HoloLens Anatomy software program Computer or Tablet with internet access	Only the motor component of Haptics: hand movement to perform the virtual dissection.	Team-based learning and case-based learning Gamification Simulation	Improved engagement, motivation,

	Laboratories			Medical education Anatomy	responsiveness, and curiosity.
(Guha et al., 2023), UK	N/A	Microsoft HoloLens 2 headset Microsoft dynamics 365 guide for live instructional video and simultaneous active written instructions and feedback	Real surgical instruments and practice set identifiable through 3D hologram Sensori-motor haptics	Medical education Simulation Teaching surgical skills Interactive learning	Increased confidence and enjoyment
(Lee et al., 2024), South Korea	MR based Major trauma care simulator	HoloLens 2 HMD Trauma Nursing XR training course training system Virtual patient Digital mentor to guide the steps of the virtual patient treatment	Virtual patient overlaid on prefixed mannequin Virtual and real examination instruments to access the state of the patient Tactile haptics through direct touch of the mannequin Kinetic Haptics through gestures assessment of the different examination procedures	Medical education Simulation	Enjoyment
(Coduri et al., 2023), Italy	RiNeo MR, a simulator for newborn life support training	VR headset Leap Motion tracker (user's hand) HTC Vive system to immerse in the virtual environment Real time feedback 2D and 3D modalities	A sensorized manikin to monitor in real time resuscitation skills: sensorized bag valve mask, and microcontrollers in the manikin to monitor head and mask positioning, force sensing resistor to assess pressure ventilation, and infrared obstacle	Medical education Simulation	Engagement and enjoyment

			detection sensor to detect chest compression Passive haptics		
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N/A: not available, 3D: 3 dimentional, 2D: 2 dimentional, HMD: Head mounted display, MR: mixed reality, XR: extended reality, VR: virtual reality

Strengths and limitations

This study has strengths and limitations that might open up perspectives for future studies. The strengths include the holistic approach in reviewing MR haptic based environments from a neuroscientific, technological, and educational perspective. This study also highlighted the role of positive emotions in triggering learning through haptics. It also showed the important role of active haptic features compared to passive features in modulating emotional responses. The limitations of this study lie in the lack of quantitative results regarding emotional assessment, and the complexity in the taxonomies used for classifying emotions, mixed reality technologies and haptics that might render some studies unavailable through research keywords due to potential confusion in terminology.

Conclusions

This paper summarizes the neuroscientific basis of haptics and positive emotions and their intersection. Then describes the classification of haptic based MR and their characteristics to finally conclude the impact of MR haptic based interventions on positive emotions and the different factors interfering with that. The first two sections showed the motor and sensory circuitries of haptics and their overlap with positive emotion regulation centers mainly the prefrontal cortex, striatum, limbic system and amygdala. The following section provided a summary on the structural taxonomy and classification MR according to the degree of virtuality or realism and of haptics according to their active or passive aspects and kinetic, palpation and manipulation characteristics. The last section provided a summary of MR haptic based interventions in research and educational context and their impact on positive emotions. The applications prevailed in the healthcare and medical education sectors. The results were promising and seemed to depend on multiple external and inner factors, as well as on the technological design of these interfaces and their active or passive haptic characteristics. Haptic perception is the new challenge in digital education research within MR environments. Future research should focus on the neuroscientific ground of haptics and emotions to move forward with the quality and outcome of education through more specific and emotionally inclusive pedagogical and technological designs.

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