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Evaluating the Quality of Experience (QoE) in Cinematic Experiences

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Résumé

L'intégration rapide de l'intelligence artificielle (IA) dans la création de contenu ouvre de nouvelles perspectives pour automatiser des processus exigeants en main-d'œuvre dans les médias immersifs. Cependant, la capacité des retours haptiques générés par l'IA à égaler la Qualité d'Expérience (QoE) produite par des retours haptiques conçus par des humains reste une question ouverte, notamment dans des contextes nécessitant une fidélité élevée et un fort engagement utilisateur. Cette étude vise à évaluer l'efficacité des retours haptiques encodés par l'IA dans un environnement cinématographique en les comparant à ceux encodés par des humains sur des métriques de QoE. En combinant des mesures auto-rapportées et des réponses physiologiques, l'étude a examiné des variables clés telles que l'absorption cognitive, l'éveil, la valence et la satisfaction. Les résultats ont montré que les retours haptiques humains génèrent un niveau d'éveil physiologique plus élevé comparé au retour haptiques encodés par l'IA. Cependant, ces deux produisent des résultats comparables en termes de perception de la QoE. Ces résultats suggèrent que les retours haptiques générés par l'IA peuvent reproduire une grande partie de l'expérience perçue par l'utilisateur, mais peuvent manquer de la profondeur d'engagement physiologique associée aux retours haptiques encodés par des humains. Cette recherche met en lumière le potentiel de l'IA en tant que solution évolutive dans les médias haptiques, tout en soulignant la nécessité d'explorations supplémentaires pour comprendre pleinement sa place aux côtés de l'artisanat humain dans la création d'expériences immersives.

Mots clés: Intelligence artificielle, retour haptique, qualité de l'expérience (QoE), immersion, absorption cognitive, éveil physiologique, engagement de l'utilisateur, expériences cinématographiques, interaction homme-machine.

Méthodes de recherche: Cette étude a utilisé une approche mixte pour comparer le feedback haptique codé par l'IA et par l'homme dans une expérience cinématographique. Une expérience de laboratoire intra-sujets a été mené avec 29 participants. Les participants ont regardé six clips de film - trois avec un retour haptique codé par l'homme et trois avec un retour haptique codé par l'IA - délivrés par un siège vibro-cinétique haute-fidélité (HFVK). À la suite de chaque clip, les participants ont rempli des questionnaires auto-rapportés mesurant l'absorption cognitive, l'engagement émotionnel (éveil et valence), la satisfaction et les intentions comportementales de

revivre et de recommander l'expérience. Simultanément, des données physiologiques, notamment l'activité électrodermale (EDA) et la variabilité du rythme cardiaque (HRV), ont été enregistrées pour évaluer les réactions émotionnelles physiologiques. Cette méthodologie a fourni une base solide pour l'évaluation de la qualité de l'expérience (QoE) suscitée par chaque méthode d'encodage haptique.

Abstract

The rapid integration of Artificial Intelligence (AI) in content creation has opened new avenues for automating labor-intensive processes in immersive media. However, whether AI-generated haptic feedback can match the Quality of Experience (QoE) produced by human-crafted haptics remains an open question, particularly in settings that demand high fidelity and user engagement. This study aims to evaluate the effectiveness of AI-encoded haptic feedback in a cinematic environment by comparing it to human-encoded haptics on QoE metrics. Utilizing a combination of self-reported measures and physiological responses, the study examined key variables including cognitive absorption, arousal, valence, and satisfaction. Findings revealed that while AI and human-encoded haptics yielded comparable results in perceived QoE measures, human-encoded feedback elicited a higher level of physiological arousal. These results suggest that AI-generated haptics can replicate much of the user-perceived experience yet may lack the depth of physiological engagement associated with human-encoded feedback. This research highlights AI's potential as a scalable solution in haptic media, with continued exploration needed to fully understand its place alongside human artistry in delivering immersive experiences.

Keywords: Artificial Intelligence, haptic feedback, Quality of Experience (QoE), immersion, cognitive absorption, physiological arousal, user engagement, AI in creative industries, cinematic experiences, human-computer interaction.

Research methods: This study employed a mixed-methods approach to compare AI- and human-encoded haptic feedback in a cinematic experience. A within-subject laboratory experimental design was conducted with 29 participants who experienced six movie clips – three with human-encoded haptic feedback and three with AI-encoded haptic feedback – delivered through a high-fidelity vibro-kinetic (HFVK) seat. After each clip, participants completed self-reported questionnaires measuring cognitive absorption, emotional engagement (arousal & valence), satisfaction and behavioral intentions to relive and recommend the experience. Simultaneously, physiological data, including electrodermal activity (EDA) and heart rate variability (HRV), were recorded to assess physiological emotional reactions. This methodology provided a robust foundation for evaluating the Quality of Experience (QoE) elicited by each haptic encoding method.

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List of abbreviations and acronyms

AI: Artificial Intelligencee

CA: Cognitive Absorption

DL: Deep Learning

EDA: Electrodermal Activity

EEG: Electroencephalogram

HAV: Haptic-audiovisual

HRV: Heart Rate Variability

HCI: Human-Computer Interaction

HFVK: High-Fidelity Vibro-Kinetic

ML: Machine Learning

SDNN HRV: Standard Deviation of Normal-to-Normal Heart Rate Variability

QoE: Quality of Experience

UX: User Experience

VR: Virtual Reality

Preface

The present work was completed as part of the student's Masters in User Experience at HEC Montreal. This thesis has been the object of evaluation and approval by the administrative management of the M.Sc. program at HEC Montreal. To ensure compliance with requirements outlined in the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans, all phases of research performed as part of this thesis went through an extensive ethical review prior to beginning data collection. Approval was granted by the Research Ethics Board at HEC Montreal under the certificate number 2024-5896. Accordingly, all stages of research involving humans as participants were completed ethically, with informed written consent obtained from all participants. Additionally, the authorization to write this thesis in the form of articles, in English, was provided by the program director (see Appendix A). Hence, this thesis encompasses 4 chapters. While the first and last chapters introduce the topic and reiterate important research takeaways, respectively, middlemost chapters present a scientific article and a managerial article.

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The past year and a half have been foundational for both my personal and professional growth. This journey reinforced my favorite verse, which has repeatedly affirmed its importance in my life: "I can do all things through Christ who strengthens me." This master's thesis stands as a hundred-page testament to that belief, reminding me never to underestimate myself. My sincere gratitude to everyone who has contributed to this accomplishment, even whether through a smile or laughter.

Chapter 1: Introduction

In today's digital entertainment landscape, the demand for immersive experiences is at an all-time high, with advancements in technology reshaping the way audiences interact with media. Immersive technologies, such as Virtual Reality (VR) and augmented reality (AR), enable users to engage more deeply with content, creating sensory experiences that go beyond traditional interactions (Danieau et al., 2014). Within this context, haptic technology – derived from the Greek term "haptesthai" meaning "to touch" – has emerged as a powerful tool for amplifying user engagement, transmitting information through the sense of touch by simulating tactile feedback through synchronized vibrations, forces, and motion (Hannaford & Okamura, 2008). The sense of touch serves as the primary means by which people interact with their environment. It is one of the most important senses in the human body. Touch is deeply rooted within people's everyday lives, from something as mundane and simple as turning on the lights to driving a car to work, nearly every interaction can be broken down to touch. Due to its pervasive influence, much attention and research has been devoted to understanding and replicating the sense of touch through technology.

The global immersive entertainment market size is expected to reach USD 426.77 billion by 2030, growing at a CAGR of 24.6% from 2024 to 2030. With audiences now becoming more sophisticated and technologically savvy, they expect a more innovative narrative that exceeds traditional cinematic expectations (Gibbs et al., 2022). Therefore, companies are continually working to improve the movie-viewing experience, with the aim of offering audiences unique advances and innovations (Eid & Al Osman, 2016). This allows the filmmaker to rethink, respond to and capture the attention of viewers with new expectations. The application of haptic feedback in cinema offers a unique opportunity to increase immersion by engaging the senses of touch and movement, creating a richer, multi-sensory experience for viewers (Eldeeb et al., 2020). Through technologies like high-fidelity vibro-kinetic (HFVK) seats, developed by DBOX Technologies (Longueuil, QC), audiences can experience the thrill of an explosion or the subtle sway of motion in tandem with on-screen visuals. This aligns with theories emphasizing the role of synchronized multi-sensory stimuli in heightening cognitive and emotional engagement (Giroux et al., 2019; Lemmens et al., 2009). Such sensory alignment ultimately greatly enhances the viewer's Quality of Experience (QoE), a concept referring to the degree of satisfaction or annoyance that users derive from an application or service, influenced by the fulfillment of their expectations related to utility or enjoyment (Brunnström et al., 2013). QoE has become a central metric for evaluating the user experience in multimedia applications, offering a holistic perspective that incorporates both system performance and user satisfaction (Hamam et al., 2014; Waltl et al., 2010; T. Zhao et al., 2017).

However, creating high-quality haptic feedback that produces a high QoE is a complex, labor-intensive process requiring precise synchronization with audiovisual content. This production process typically involves three stages: production (creating haptic effects), distribution (broadcasting the effects over networks), and rendering (delivering feedback to users via haptic devices) (Danieau et al., 2013). The production phase presents significant challenges, as manually designing haptic effects is time-intensive, demanding both technical expertise and artistic intuition to ensure each sensation enhances the overall experience. Traditional manual authoring requires hundreds of hours of labor per project, making the process costly and ultimately limiting scalability (D-BOX, 2022).

Interestingly, recent advancements in Artificial Intelligence (AI), particularly in machine learning (ML) and deep learning (DL), suggest potential pathways for addressing and automating complex processes such as haptic feedback generation. AI's ability to recognize patterns within audiovisual content can enable it to detect events, such as explosions, and generate the corresponding haptic effects, potentially reducing both labor and production time (LeCun et al., 2015; Mahesh, 2020). AI has shown promise to enhance productivity and efficiency by automating repetitive tasks, however its ability to fully replace human creativity is still debated in research (Bakhshi et al., 2015; Boden, 2016; Frey & Osborne, 2017; Z. Wu et al., 2021). Despite AI's promising developments, it remains unclear whether AI-generated haptic feedback can match the nuanced, context-sensitive QoE of human-encoding of haptic feedback.

1.1.1 Research Question, Objectives and Potential Contributions

This research addresses an underexplored area in understanding and comparing the impacts of AI and human-encoded haptic feedback on the QoE in immersive experiences, specifically within HFVK cinematic setting. While prior studies have acknowledged haptic feedback's role in enhancing immersion and emotional engagement (Eid & Al Osman, 2016; Gardé, Léger, Sénécal, et al., 2018), there is limited knowledge on whether AI-generated haptic feedback can replicate or even surpass human artistry in delivering a comparable user experience. This question gains relevance in the context of recent AI advancements and its rapid integration across applications and industries aimed at improving productivity and efficiency. Furthermore, it aligns with the growing interest in user-centered AI, which seeks to enhance human experiences through thoughtful AI design. Therefore, we aim to understand the following research questions:

1. **To what extent does the method of haptic feedback encoding (AI vs. human artists) of audiovisual content in a high-fidelity vibro-kinetic (HFVK) seat influence the QoE of viewers?**
2. **To what extent does the method of haptic feedback encoding (AI vs. human artist) of audiovisual content in a high-fidelity vibro-kinetic (HFVK) seat impact the viewers' intention to relive the experience and recommend to others?**

To answer this, this study employs a mixed-methods approach, integrating both perceptual and physiological measures to capture the nuanced effects of the different haptic encoding methods on key QoE metrics and users' subsequent behavioral intentions. This interdisciplinary research aims to contribute to the field of AI, haptic technology, and user experience (UX) by offering insights into the capabilities and limitations of AI in creating effective haptic feedback without compromising user experience. The study's findings may have practical implication for managers, content creators, developers, designers and UX professionals – particularly in gaming, VR, and cinematic and immersive media sectors. These insights can guide managers in resource optimization and scalability efforts, ensuring high-quality immersive experiences that define high-fidelity experiences.

1.1.2 Theoretical and Methodological Approach

We adopt immersion as a theoretical lens to understand the haptic experience and apply QoE as a framework to effectively operationalize it. Immersion has been defined as the sensation of becoming deeply absorbed in a virtual or narrative world, where attention is disengaged from external reality and fully focused on the experience at hand (Agrawal et al., 2019; Salselas et al., 2021). In cinematic contexts, immersive experiences are typically enhanced by aligning audiovisual stimuli with users' sensory feedback, which strengthens their emotional engagement and cognitive focus (Pauna et al., 2018). Moreover, haptic technology has the potential to amplify this immersion by adding tactile sensations that reinforce the narrative's emotional impact and realism (Gardé, Léger, Sénécal, et al., 2018). HFVK systems provide this tactile feedback through vibrations and kinetic stimuli, which are closely synchronized with the audiovisual elements to create a holistic and engaging sensory experience (Giroux et al., 2019).

The QoE framework aids in providing a comprehensive way to operationalize users' subjective and physiological responses to immersive media, encompassing metrics such as cognitive absorption, emotional state – arousal and valence, and overall satisfaction (Hamam et al., 2014; Tasaka, 2016). In this study, the focus on QoE is critical, as it reflects how effectively AI-generated haptic feedback can replicate or diverge from human-encoded experiences. Prior research suggests that synchronized haptic feedback can positively influence QoE by enhancing the sense of presence and emotional engagement (Eid & Al Osman, 2016; Hammond et al., 2023).

Therefore, to create an immersive experience, participants watched a series of movie clips from various genres while sitting in a HFVK seat, allowing for the integration of synchronized haptic feedback with audiovisual stimuli. By comparing AI- and human-encoded haptic responses across different movie genres, the study evaluates how each encoding method influences user engagement, emotional arousal, and intention to relive and recommend the experience. Recognizing that different genres elicit varied emotional intensities, the study also investigates the moderating effects of movie genres to provide a comprehensive understanding of these factors.

To evaluate the impacts of AI and human-encoded haptic feedback on QoE, this study adopted a mixed-methods approach, combining perceptual and physiological measures. Specifically, the psychometric assessments comprised of perceived cognitive absorption, emotional arousal, valence, and satisfaction to capture the subjective dimensions of QoE (Waltl et al., 2010; Yuan et al., 2014a). In parallel, physiological responses, including electrodermal activity (EDA) and heart rate variability (HRV), were measured to assess objective arousal levels, providing insight into the subconscious aspects of the experience that may not be fully captured through self-reporting (Riedl & Léger, 2016). Using both self-reported and physiological data not only enriches the assessment by capturing both conscious and unconscious reactions, but also mitigates the biases inherent in self-reports. This guarantees a comprehensive evaluation of emotional engagement and arousal across conditions (Bell et al., 2018; Ciuk et al., 2015; Rosenman et al., 2011).

This thesis addresses the overarching theme of creating high-quality immersive haptic experiences, focusing specifically on whether AI can deliver a level of QoE comparable to that of human designers in haptic feedback production. This inquiry is progressively explored throughout the subsequent chapters. Structured into four chapters, the thesis systematically examines the comparative impact of AI- and human-encoded haptic feedback on QoE in cinematic contexts, offering insights into their respective roles in shaping immersive experiences.

1.1.3 A Collective Endeavor: Outlining the Author's Contributions

Since this thesis was conducted within Tech3Lab, where multiple collaborators contributed at various stages, Table 1 below delineates my personal intellectual involvement in each aspect of the research. As per laboratory standards, a minimum contribution level of 50% is expected from the student. For areas where my contributions exceed this threshold, it reflects my leadership and ownership over those phases.

Table 1

Author's Contributions

Research Process	Student Contribution
Literature Review	**100% Literature Review:** Read over 50 scientific articles on previous research related to haptics, cinematic experiences, quality of experience and immersion to assess successful methodologies, select appropriate validated psychometric scales, detect emerging trends and identify the current gap in literature.
Research Question	**60% Research question formulation:** Formulate a novel yet pragmatic research question in response to the identified gap & problematic in literature.
Experimental Design	**50% Ethics approval:** Prepare the required documentation for the REB. Help was provided for a final review of the application. **50% Stimuli selection:** Select different movie genres for audiovisual stimuli and final selection was decided by the partner per the available haptic encoded movie clips. **70% Questionnaires:** Develop online Qualtrics questionnaires and formulate interview questions. Help was provided by Tech3Lab operations.
Recruitment	**50% Participants recruitment:** Provide important criteria for participant recruitment. The operation team at Tech3lab oversaw and applied my guidelines on the HEC panel and were also in charge of distributing the compensation.
Data Collection	**60% Data Collection:** Moderate the experiment and conduct user interviews after the experiment. Help research assistants with physiological signals calibration, stimuli launch and technical setup.
Statistical Analysis	**70% Psychometric & physiological data analysis:** Performed statistical tests using SAS and SPSS to test hypotheses. Formatting the data file for the analysis statistics was done by the Tech3lab statistician.
Thesis Writing	**100% Thesis writing:** Write the thesis detailing all phases and implications of this project. Guidance, review and feedback were provided by research directors and supervisors throughout the process.

1.2 Literature review

1.2.1 Haptic Technology

Haptics refers to the process by which information is conveyed through touch (Hannaford & Okamura, 2016; Kern et al., 2023; See et al., 2022). Haptic technology enhances the sensory experience of users by simulating physical sensations through various forms of stimulation, including tactile feedback, vibrations and motion (Petersen, 2019). This technology employs actuators to replicate sensations such as movement, vibration and force, allowing users to interact with digital content in a way that mimics real-world experiences (Danieau et al., 2013; Muender et al., 2022). As a result, haptic technology enables users to engage with digital content through physical sensations offering a more authentic and immersive experience to the user (E. Kim & Schneider, 2020).

Haptic feedback can be categorized into two primary types: tactile feedback and kinesthetic feedback. Tactile feedback involves the perception of textures and surfaces, providing sensory information through the sense of touch (Danieau et al., 2013; Iosifyan & Korolkova, 2019; Israr et al., 2014). Kinesthetic feedback, on the other hand, informs users about movement, position and orientation, enabling them to maintain spatial awareness without relying solely on visual cues (Angelaki et al., 2009; Poeschl et al., 2013). Previous research has shown that haptic feedback, such as motion, vibration and force, enhance the overall sensory experience by engaging multiple senses, deepening the level of immersion (Gavazzi et al., 2013; Hwang & Hwang, 2011). This increased immersion is closely linked to heightened attention, as viewers focus more cognitive resources on the content, resulting in greater engagement (Hammond et al., 2023; Lim et al., 2019).

HFVK technology, which provides precise vibro-tactile as well as kinetic stimulation through cinema seats, has garnered significant attention from researchers (Boasen et al., 2020). Studies have demonstrated that HFVK has the potential to enhance immersion and subjective enjoyment in various audiovisual experiences, including movies (Pauna et al., 2018) and VR environments (Gardé, Léger, Senecal, et al., 2018). For instance, in films with high-intensity action scenes, haptic feedback, such as vibrations, motions and force, can simulate the physical impact of explosions or car chases, pulling viewers deeper into the narrative (Boasen et al., 2020). This integration of haptic feedback with visual and auditory stimuli creates “haptic-audiovisual” (HAV) content, fully engaging multiple sensory channels (El Saddik et al., 2011; Maggioni et al., 2017). Such multisensory coordination enhances immersion by increasing emotional engagement and cognitive focus. Research further shows that synchronized haptic stimulation amplifies emotional and physiological responses, enriching the overall QoE by allowing users to perceive and experience a more realistic interaction with the media (Timmerer et al., 2014; Waltl et al., 2010; Yuan et al., 2014a).

Haptic technology has significantly evolved since its introduction in the 1970s, transforming industries such as gaming, medicine, teleoperation, aviation and everyday digital interactions. In gaming, it enhances immersion and enjoyment by providing tactile responses that stimulate in-game events, such as rumbling of a shot (Danieau et al., 2013). Beyond entertainment, haptics has been instrumental in fields like teleoperations, where it allows operators to control robotic arms with precision, and in telemedicine, where surgeons perform life-saving remote procedures with tactile feedback (Chaudhari et al., 2014). In aviation, haptics improves pilot training by replicating flight conditions and enhancing safety through tactile alerts. Additionally, haptic feedback is integrated into devices like smartphones and car interfaces to improve the overall user experience by enhancing usability and intuitiveness (Gaffary & Lécuyer, 2018). As technology continues to expand, particularly with the rise of immersive environments like the Metaverse, researching haptics is critical for understanding its broad and impactful applications and future potential. We explore the concept of immersion in the following section.

1.2.2 Immersion

Immersion is a multifaceted concept, encompassing psychophysiological, neurophysiological and perceptual dimensions (Agrawal et al., 2019). It generally refers to the ability of a narrative or environment to fully engage individuals, transporting them into a fictional or virtual realm (V. Visch et al., 2010). Immersion is closely linked to realism, naturalness, and presence, reflecting a state in which individuals dissociate from their immediate surroundings and focus their attention entirely on the content or environment they are engaging with (Agrawal et al., 2019). Immersion is typically divided into mental and physical dimensions. Mental immersion involves deep cognitive engagement with the narrative or environment, while physical immersion arises when users process sensory cues to navigate a synthetic environment (Agrawal et al., 2019; Nilsson et al., 2016; Suh & Prophet, 2018). Conceptualized as a psychological process, immersion has been shown to enhance flow and presence, often leading to positive emotions such as enjoyment and satisfaction (C. Zhang, 2020; C. Zhang et al., 2017). In hedonic contexts, immersion heightens the user's emotional and cognitive engagement, amplifying the pleasure derived from the experience (Jennett et al., 2008; Karafotias et al., 2017; Magalhães et al., 2023). In cinematic experiences, immersion can significantly influence perceptions of time, cognition and emotion (Subramaniam et al., 2022; V. Visch et al., 2010).

Immersion serves as the theoretical basis for analyzing the depth of user engagement with haptic-enhanced cinematic experiences, including comparisons of AI and human artists haptic encoding methods. The following section explored QoE as a framework for operationalizing these interactions.

1.2.3 Quality of Experience (QoE)

QoE can be defined as the degree of satisfaction or annoyance that users derive from an application or service, shaped by how well it meets expectations for utility or enjoyment (Brunnström et al., 2013). QoE has become a key metric for evaluating user experience in multimedia applications, providing a holistic evaluation that incorporates both system performance and user satisfaction (Hamam et al., 2014; Rodrigues et al., 2022; Skorin-Kapov et al., 2018; Timmerer et al., 2014; Waltl et al., 2010). Unlike the earlier focus on Quality of Service (QoS), QoE adopts a user-centered perspective, emphasizing the role of human and contextual factors in line with a broader trend in Human-Computer Interaction (HCI) and multimedia research (Wechsung & De Moor, 2014). Previous research indicated that integrating haptic feedback enhances audiovisual experiences, resulting in higher QoE compared to when it is absent (Danieau et al., 2014).

To help evaluate these experiences, frameworks have been proposed to assess QoE across multiple dimensions. Hamam et al. (2013) proposed a framework that evaluates QoE based on QoS and UX (El Saddik et al., 2011; Hamam et al., 2014). QoE assessments encompass user-centered measures rooted in perception, physiology, and psychology. Perception-based measures use subjective assessments through questionnaires and validated scales to evaluate user engagement and enjoyment (Hamam et al., 2008, 2014). Psychological measures focus on the mental and emotional states, while physiological measures, including heart rate variability (HRV) or EDA, objectively capture unconscious emotional and cognitive reactions that may not be reflected in self-reported data (Ciuk et al., 2015; Hammond et al., 2023; Pauna et al., 2018; Walla, 2018).The next section explores the construct of cognitive absorption (CA) and its relationship to immersion in hedonic contexts.

1.2.4 Cognitive Absorption (CA)

Immersion has been shown to heighten the user's emotional and cognitive engagement, amplifying the pleasure derived from the experience in hedonic contexts (Weniger & Loebbecke, 2011). Within the framework of QoE, engagement is a central component under the perception measures. To better understand and operationalize engagement, we employ the construct of CA. CA has been defined as a "state of deep involvement with software" (Agarwal & Karahanna, 2000), encompassing cognitive and affective dimensions that shape user engagement and perceptions of technology. CA is theoretically rooted in the concepts of absorption (Tellegen & Atkinson, 1974), flow (Csikszentmihalyi, 1990), and cognitive engagement (Webster & Ho, 1997). A cognitively absorbed user is intrinsically motivated and fully focused, with their attention entirely consumed by the interaction (Saadé & Bahli, 2005).

According to the flow theory (Csikszentmihalyi, 1990), this state is described as one of intense concentration, where individuals lose track of time and become completely immersed. Building on this, Agarwal et al. (2000) conceptualized CA as a multi-dimensional construct with five dimensions: Temporal dissociation, Focused Immersion, Heightened Enjoyment, Control, and Curiosity (Agarwal & Karahanna, 2000). These dimensions align with elements of immersion as they break down the experience into specific dimensions (D. J. Kim & Zhang, 2011; Salselas et al., 2021; V. Visch et al., 2010). Furthermore, CA is especially relevant in a hedonic context, such as haptic enhanced cinematic experiences, as it is a multidimensional construct reflecting various aspects of intrinsic motivation (van der Heijden, 2004). Intrinsic motivation refers to actions driven by the inherent satisfaction and enjoyment of the activity itself (Deci & Ryan, 1985; Vallerand, 1997). Users exhibiting elevated levels of cognitive absorption tend to experience more positive emotions, higher arousal, and deeper cognitive involvement, especially in vibro-kinetic environments, therby enhancing QoE (Agarwal & Karahanna, 2000; Pauna et al., 2018). Consequently, CA plays a significant role in impacting users' satisfaction and, in turn, their intentions about a given technology. Building on this, the following section examines how the movie genre might interact with these factors to impact QoE.

1.2.5 Movie Genre

While haptic effects are central to enhancing immersion in audiovisual content, other factors, such as movie genre, can also potentially influence QoE. Different genres evoke varying levels of engagement, with elements such as action versus non-action scenes, and high- versus low-intensity sequences shaping to the audience's experience (Carpio et al., 2023; Israr et al., 2014; Rooney et al., 2012; V. T. Visch & Tan, 2009; Zwiky et al., 2024).

Action genres have the potential to heighten immersion through dynamic visuals, intense sound design, and adrenaline-driven narratives. These elements, amplified by haptic feedback, allow viewers to physically feel the action, enhancing physiological engagement with increased heart rate and emotional arousal during high-intensity scenes (Alma et al., 2021; Hammond et al., 2023). However, overly intense haptic effects may disrupt rather than enhance immersion. Conversely, low-intensity genres foster engagement on emotional and cognitive levels, relying less on physical stimulation. Given the potential moderating role of movie genre, it is valuable to examine how genre shapes the viewer's experience by influencing CA, arousal, and valence. These factors, in turn, play a role in determining satisfaction and its subsequent impact on user intentions, which are further explored in the next section.

1.2.6 Satisfaction & Intentions

Satisfaction is a key perceptual measure within the QoE framework, reflecting how positively users perceive their interaction with a system or technology. Elevated satisfaction levels are widely recognized in the literature as an indicator of a system's or an experience's success in delivering a positive experience (Halstead & Jr, 2022). Satisfaction is shaped by various factors, including CA and emotional states– specifically arousal and valence, components of QoE under psychological measures. According to Russell's circumplex model of affect, emotional states can be presented along two dimensions: valence, which measures emotional positivity or negativity, and arousal, which reflects the intensity of the emotional experience (Russell, 1980).

Building on the QoE framework's three user-centered measures—perceptual, psychological, and physiological—research suggests that higher levels of CA, arousal, and valence lead to greater satisfaction. As users become more cognitively and emotionally immersed in an experience, they are more likely to derive enjoyment and feel satisfied. This satisfaction, in turn, serves as a critical mediator, influencing users' likelihood to revisit the experience and recommend it to others (Dewi & Giantari, 2022; Halstead & Jr, 2022). However, achieving high-quality QoE in a haptic-enhanced cinematic context requires meticulous synchronization of haptic feedback with audiovisual content. Furthermore, creating these haptic effects is a complex and labor-intensive process, which is further explored in the following section.

1.2.7 Labor Intensive Nature of Haptic Feedback Creation

The process of adding haptic effects to audiovisual content involves three key stages: production, distribution, and rendering (Danieau et al., 2013). The term "haptic effect" is to designate the use of a haptic feedback in audiovisual content (a generalization of the term employed in the specific context of video viewing (Danieau et al., 2013; Lemmens et al., 2009). Firstly, production focuses on creating haptic effects to enhance audiovisual content. Then, distribution ensures synchronized transmission, or "haptic broadcasting," over networks. Finally, rendering involves delivering these effects on devices such as wearables, handhelds, desktops, or seats, where users experience them (El Saddik et al., 2011; Hannaford & Okamura, 2008; Kern et al., 2023; E. Kim & Schneider, 2020).

The three main techniques for producing haptic effects are: sensor-based data capture, automatic extraction from audiovisual components, and manual authoring. Manual authoring, a traditional and highly flexible method, requires designers to carefully synchronize tactile sensations, such as vibrations or forces, with audiovisual cues. While effective, this approach is extremely labor-intensive, taking over 100 hours per movie (D-BOX, 2022) and demanding both technical expertise and creative precision. Sensor-based data capture, using devices like accelerometers, provides realistic physical sensations but involves extensive processing to align data with audiovisual content. Automated extraction, which derives effects directly from audiovisual components, offers potential for reducing labor but is still constrained by the complexity of translating audiovisual cues into meaningful haptic feedback (Kern et al., 2023; Muender et al., 2022; Sreelakshmi & Subash, 2017). Despite advancements, the creation of haptic effects—whether through manual, sensor-based, or automated methods—remains labor-intensive. This highlights the need for efficient, scalable solutions that preserve high QoE for users, a potential approach to which is explored in the following section.

1.2.8 AI Adoption

Advancements in AI, particularly in Machine Learning (ML) and Deep Learning (DL), offer promising solutions to labor-intensive processes. These innovations enable systems to detect patterns and make predictions without explicit programming (Mahesh, 2020). ML focuses on identifying patterns in data, while DL, through multilayered neural networks inspired by the human brain, excels in processing complex, high-dimensional datasets (LeCun et al., 2015). This has allowed DL to outperform traditional approaches in numerous applications, spanning industries such as healthcare, finance, and autonomous systems (Feuerriegel et al., 2024; Sharifani & Amini, 2023).

In addition, generative AI, a subset of DL, has further expanded AI's capabilities by creating realistic content, including images, music, text, and 3D models (Fui-Hoon Nah et al., 2023; L. Zhao et al., 2023; W. X. Zhao et al., 2024). Widely used in arts and media, generative AI automates creative processes, enabling the production of highly complex and lifelike outputs (Epstein et al., 2023; Ko et al., 2018; Oppenlaender, 2023; E. Zhou & Lee, 2023). While these advancements have streamlined workflows and personalized media experiences, skepticism is evident in research about AI's ability to replicate the nuance and creativity inherent in human work, especially in subjective and creative fields (Anantrasirichai & Bull, 2022; Bakhshi et al., 2015; Boden, 2016).

Nonetheless, AI excels at automating repetitive and predictable tasks, enhancing efficiency in complex workflows (Z. Wu et al., 2021). However, it struggles with tasks requiring flexibility, strategic thinking, and intuitive understanding of emotional and social cues—areas where humans excel (Srivastava et al., 2023). In fact, AI has shown promise in enhancing productivity and efficiency; however, its ability to fully replace human creativity is still debated (Frey & Osborne, 2017). This limitation is particularly relevant in fields where subtle emotional and contextual nuances are critical, such as creating immersive haptic feedback.

Finally, AI's potential to automate haptic feedback creation could address the labor-intensive nature of the process. However, the extent to which AI-generated haptic effects can replicate or even surpass human-generated feedback in delivering high-quality immersive experiences remains an open question. Effectively modulating haptic stimuli – ensuring effects enhance rather than disrupt immersion – is crucial to optimizing user experience (Gaffary & Lécuyer, 2018). Machine learning models, constrained by predefined parameters, often struggle to adapt intuitively to emotional or contextual nuances, which can lead to overwhelming or ineffective haptic stimuli (Schneider et al., 2017). To our knowledge, no prior research has investigated the comparative impact of AI- and human-generated haptic feedback on both subjective and objective dimensions of QoE in cinematic contexts. The following section outlines the structure of this thesis, detailing how each chapter contributes to addressing this question.

1.3 Thesis Outline

This thesis is organized as follows: Chapter 2 presents the core research article providing a condensed literature review, theoretical foundation, and experimental methodology used to explore users' perceptual and physiological responses to AI- and human-encoded haptic feedback. Through rigorous data analysis, the study's findings and insights are discussed, highlighting key contributions to both haptic technology and user-centered AI research.

Chapter 3 offers a managerial perspective on the implications of AI adoption in haptic feedback creation in various industries. This chapter contextualizes the results from Chapter 2 within industry and professional applications, exploring how AI could optimize workflows, enhance scalability, and support innovation in entertainment, gaming, and VR. Practical insights are provided for managers, content creators, and designers, with emphasis on the role of AI in maintaining high QoE standards while reducing labor demands.

Chapter 4 concludes the thesis with a synthesis of the research findings, discussing the theoretical and practical implications, limitations, and future research directions. By summarizing contributions to haptic technology, user experience, and AI, this chapter reinforces the study's significance and identifies pathways for further exploration in AI-generated haptics and immersive media experiences.

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Chapter 2

Evaluating the Quality of Experience (QoE) in Cinematic Experiences: A Comparative Study of AI and Human-Encoded Haptic Feedback with Audiovisual Media[1]

Abstract

The rapid integration of Artificial Intelligence (AI) in content creation has opened new avenues for automating labor-intensive processes in immersive media. However, whether AI-generated haptic feedback can match the Quality of Experience (QoE) produced by human-crafted haptics remains an open question, particularly in settings that demand high fidelity and user engagement. This study aimed to evaluate the effectiveness of AI-encoded haptic feedback in a cinematic environment by comparing it to human-encoded haptics on QoE metrics. Utilizing a combination of self-reported measures and physiological responses, the study examined key variables including cognitive absorption, arousal, valence, and satisfaction. Findings revealed that while AI and human-encoded haptics yielded comparable results in perceived QoE measures, human-encoded feedback elicited a higher level of physiological arousal. These results suggest that AI-generated haptics can replicate much of the user-perceived experience yet may lack the depth of physiological engagement associated with human-encoded feedback. This research highlights AI's potential as a scalable solution in haptic media, with continued exploration needed to fully understand its place alongside human artistry in delivering immersive experiences.

Keywords: Artificial Intelligence, haptic feedback, Quality of Experience (QoE), immersion, cognitive absorption, physiological arousal, user engagement, AI in creative industries, cinematic experiences, human-computer interaction.

2.1 Introduction

From stepping into a Van Gogh masterpiece to feeling the rumble and suspense of an intense car chase scene at home, today's immersive experiences engage the users 'senses in unprecedented

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ways, driven by technologies that blur the lines between fiction and reality. These experiences are increasingly in demand, fueled by advancements in immersive technologies that deepen engagement and redefine entertainment. The global immersive entertainment market size is expected to reach USD 426.77 billion by 2030, growing at a CAGR of 24.6% from 2024 to 2030. The primary driver propelling the growth of the market is the widespread adoption of immersive technology in a wide range of entertainment industries, including gaming, movies, music, sports, and live events (Grand View Research, 2024).

Among the technologies driving this shift is haptic feedback, intensifying experiences by delivering tactile and kinetic feedback that mirror physical real-world sensations (Danieau et al., 2013; Muender et al., 2022). Through precisely synchronized vibrations, forces, and motions, haptic feedback enriches the QoE by creating immersive and emotionally engaging experiences (Boasen et al., 2020; E. Kim & Schneider, 2020). Its multisensory coordination strengthens immersion by increasing emotional engagement and cognitive focus (Gardé, Léger, Sénécal, et al., 2018; Pauna et al., 2018). However, achieving high-quality QoE depends heavily on the expertise of skilled designers. Additionally, the production of haptic feedback involves meticulous manual encoding, a labor-intensive and time-consuming process that limits the scalability of haptic-enhanced content (Danieau et al., 2013).

Recently, AI has shown promise as tool for automating complex and resource-intensive processes enhancing efficiency across various industries (Feuerriegel et al., 2024; LeCun et al., 2015; Mahesh, 2020; Sharifani & Amini, 2023). By streamlining the haptic feedback production, AI offers a potential solution to the challenges of scalability and efficiency in haptic feedback production. However, while AI may reduce the time and effort required for the creation of haptic feedback, a critical question remains: can AI-generated haptic feedback deliver a QoE comparable to human-encoded haptic feedback?

As such, this study investigated:

RQ1: To what extent does the method of haptic feedback encoding (AI vs. human artists) of audiovisual content, presented through a HFVK seat, influences the QoE of viewers.

RQ2: To what extent does the method of haptic feedback encoding (AI vs. human artist) of audiovisual content in a high-fidelity vibro-kinetic (HFVK) seat impact the viewers' intention to relive the experience and recommend to others?

Specifically, the research it explores whether AI-encoded feedback can elicit levels of cognitive & emotional engagement and satisfaction – key factors in QoE and immersion – and behavioral intentions towards the experience comparable to those elicited by human-encoded feedback.

This paper outlines the motivation and hypotheses for an experimental study examining the effects of AI versus human-encoded haptic feedback on QoE in an HFVK setting. The subsequent sections are organized as follows: the next subsections provide an in-depth literature review. Section 2 describes the methodology, detailing the experimental design and measures used. Section 3 presents the results, while Section 4 discusses the findings, explaining their theoretical and methodological contributions, practical implications, limitations and directions for future research. Finally, Section 5 concludes the paper by summarizing the study's contributions. This work aims to evaluate and compare AI- and human- encoded haptic feedback. Hopefully this work can offer foundational insights for content creators, designers, developers and researchers, enabling the development of scalable, user-centered AI solutions that expand the possibilities of immersive experiences across various domains.

2.1.1 Haptic Technology

Haptics involves conveying information through touch, enhancing sensory experiences by simulating physical sensations (Hannaford & Okamura, 2016; Kern et al., 2023; Petersen, 2019; See et al., 2022). Using actuators, haptic feedback replicates sensations such as movement, vibration, and force, enabling interactions with digital content that closely mimic real-world experiences (Danieau et al., 2013; Muender et al., 2022). By enabling multiple senses, this haptic feedback has the potential to deepen immersion, offering a more authentic and immersive experience to the user (Gavazzi et al., 2013; Hwang & Hwang, 2011; Maggioni et al., 2017). This enhanced immersion has been shown to increase attention, as viewers allocate more cognitive resources on the content, resulting in heighten engagement (Hammond et al., 2023; Lim et al., 2019).

Among the cutting-edge advancement in haptic technology, HFVK technology has emerged as a notable innovation. HFVK integrates precise vibro-tactile as well as kinetic stimulation through cinema seats, delivering an immersive sensory experience that has garnered significant interest from researchers (Boasen et al., 2020). This technology has been shown to enhance immersion and enjoyment across various audiovisual contexts, such as movies (Pauna et al., 2018) and Virtual Reality (VR) environments (Gardé, Léger, Senecal, et al., 2018). A key feature of HFVK is its ability to synchronize vibrations, motions and forces with on-screen visuals. For instance, in films with high-intensity action scenes, haptic feedback can simulate the physical sensations of explosions or car chases, thereby pulling viewers deeper into the narrative. This synergy between haptic feedback and visual and auditory stimuli forms what is referred to as "haptic-audiovisual" (HAV) content, which engages multiple sensory channels simultaneously (El Saddik et al., 2011). Further research demonstrates that synchronized haptic stimulation amplifies emotional and physiological responses, enriching the overall QoE and, in turn, immersion by enabling users to perceive and experience a more realistic interaction with the media (E. Kim & Schneider, 2020; Timmerer et al., 2014; Waltl et al., 2010; Yuan et al., 2014a).

2.1.2 Immersion & QoE

Immersion, much like the sensation of being enveloped by water, evokes a feeling of complete submersion in an alternate reality. Just as diving into the ocean captivates our entire sensory awareness, a psychologically immersive experience envelops the user, drawing their attention entirely into a new and compelling environment (Murray, 2017). This concept captures the psychological state of being fully engulfed in an environment or narrative, enabling users to dissociate from their immediate surroundings and redirect their attention entirely toward the content or environment they are interacting with (Agrawal et al., 2019; Nilsson et al., 2016; C. Zhang et al., 2017). This concept is broad enough to encompass gaming, films, virtual environments, and can apply to both real-world and technologically facilitated experiences (Cummings & Bailenson, 2016; Jennett et al., 2008).

Immersion can be broadly categorized into two dimensions: mental and physical. Mental immersion is characterized by deep cognitive engagement with the environment or narrative, where users lose track of time and external distractions fade away. While physical immersion relied on interpreting sensory cues – such as visual, auditory, and haptic stimuli – to navigate a synthetic environment (Agrawal et al., 2019; Nilsson et al., 2016; Suh & Prophet, 2018). Together, these dimensions heighten the user's emotional and cognitive engagement, amplifying the pleasure derived from the experience in hedonic immersive contexts (Karafotias et al., 2017; Magalhães et al., 2023; C. Zhang, 2020; C. Zhang et al., 2017). Moreover, in cinematic settings, immersive experiences can have a significant impact on various aspects of perception which includes time, cognitive and emotional perception (Subramaniam et al., 2022; V. Visch et al., 2010).

The concept of immersion is positioned as the theoretical basis for this research due to its relevance in understanding how deeply users become engaged with the haptic enhanced cinema experiences, comparing AI and human artist haptic encoding methods. Building on this foundation, the QoE framework is utilized to operationalize not only the perceived user engagement but also the emotional, cognitive and physiological responses elicited by multisensory experience such as haptic feedback (Agrewal et al., 2021; Kannegieser et al., 2021).

QoE has been defined as the degree of satisfaction or annoyance that users derive from an application or service, influenced by the fulfillment of their expectations related to utility or enjoyment (Brunnström et al., 2013). QoE serves as the primary metric for evaluating user experience in multimedia applications, offering a holistic perspective that considers both system performance and user satisfaction (Hamam et al., 2014; Timmerer et al., 2014; Waltl et al., 2010; C. Zhang, 2020). Reflecting a shift away from the older concept of solely evaluating Quality of Service (QoS), focusing mainly on technical performance metrics like communication delays or resolution, QoE adopts a user-centered approach. As multimedia content continues to proliferate, the need to assess QoE has been increasingly important in telecommunications and multimedia research to further inform designers, and content creators how to enhance the user experience.

Therefore, several frameworks have been developed to evaluate QoE across multiple dimensions. Hamam et al. (2013) proposed a model that extends beyond technical performance, integrating both system quality and the user-centered measures (El Saddik et al., 2011; Hamam et al., 2014). For a detailed taxonomy of QoE, refer to Appendix B. The user experience component of QoE is further categorized into three primary measures: perceptual, psychological, and physiological. Perception measures rely on subjective assessments obtained through questionnaires and validated scales focusing on user engagement, immersion, and enjoyment (Hamam et al., 2008, 2014). Psychological measures assess mental and emotional states, while physiological measures provide objective insights into the user's biological responses during interaction, such as heart rate variability (HRV) or electrodermal activity (EDA) to measure physiological arousal. These physiological signals are particularly valuable for capturing subconscious emotional and cognitive reactions that may not be reflected in self-reported data (Ciuk et al., 2015; Hammond et al., 2023; Kannegieser et al., 2021; Pauna et al., 2018; Walla, 2018).

2.1.3 Cognitive Absorption

As a component of QoE, particularly under perception measures, engagement plays a crucial role in evaluating immersive experiences As immersion heightens the user's cognitive engagement, amplifying the pleasure derived from the experience in hedonic contexts (Weniger & Loebbecke, 2011). The term Cognitive absorption (CA) is defined as a "state of deep involvement with software" (Agarwal & Karahanna, 2000), encapsulating both cognitive and affective components that influence user engagement and their subsequent beliefs about a given technology. Theoretical underpinnings of CA draw from the concepts of absorption (Tellegen & Atkinson, 1974), flow (Csikszentmihalyi, 1990), and cognitive engagement (Webster & Ho, 1997). A cognitively absorbed user is conceived to be intrinsically motivated and in a state of deep attention that consumes all this individual's resources (Saadé & Bahli, 2005). According to the theory of flow (Csikszentmihalyi, 1990), individuals experiencing this state are so engrossed in the interaction that they lose awareness of time and external distractions, experiencing a heightened sense of immersion and, therefore, immersion.

CA has been conceptualized by Agarwal et al. (2000) as a multi-dimensional construct with five dimensions: Temporal dissociation (the ability to register the passage of time while engaged in interaction); Focused immersion (the experience of total engagement where other attentional demands are ignored); Heightened enjoyment (the pleasurable aspects of the interaction); Control (the user's perception of being in charge of the interaction); and Curiosity (the extent to which the experience arouses an individual's sensory and cognitive curiosity) (Agarwal & Karahanna, 2000). CA's dimensions align closely and build upon the concept of immersion as the construct breaks down the experience of immersion. Offering a nuanced perspective, these dimensions map into immersion’s core elements by addressing attentional focus and loss of awareness of time or surroundings as well as the user’s enjoyment (D. J. Kim & Zhang, 2011; Salselas et al., 2021; V. Visch et al., 2010).

Furthermore, CA is particularly relevant in hedonic contexts such as haptic enhanced cinematic experiences due to its reflection of various aspects of intrinsic motivation, which refers to actions driven by the inherent satisfaction and enjoyment of the activity itself (Deci & Ryan, 1985; Vallerand, 1997; van der Heijden, 2004). This intrinsic motivation is central to the experience as users exhibiting high levels of cognitive absorption tend to experience more positive emotions especially in vibro-kinetic environments (Agarwal et al., 2000; Pauna et al., 2018). As a result, CA influences user’s satisfaction, which in turn shape their behavioral intentions regarding a given technology. Consequently, the quality of haptic interactions is vital for shaping both cognitive and affective responses, ultimately enhancing QoE.

2.1.4 Labor Intensive Nature of Haptic Feedback Creation

To achieve a highly rated QoE, haptic feedback must be meticulously synchronized with audiovisual content. However, creating high-quality and highly precise haptic effects is a complex and labor-intensive process. The workflow of adding haptic effects to audiovisual content is composed of three main stages: production, distribution, and rendering (Danieau et al., 2013). Production is the task of creating haptic effects to enhance audiovisual content. The second stage addresses the distribution of haptic effects, emphasizing the need for synchronized transmission, or "haptic broadcasting," to ensure haptic effects can be distributed over networks. The final stage involves rendering the encoded haptic effects on various devices, such as wearables, handhelds, desktops, or seats, where users experience the effects (El Saddik et al., 2011; Hannaford & Okamura, 2008; Kern et al., 2023; E. Kim & Schneider, 2020).

Three techniques in the process of production emerge from the literature: the capture and processing of data acquired from sensors, automatic extraction from a component of the audiovisual content (image, audio or annotations) and manual authoring of haptic effects. The term “haptic effect” is to designate the use of a haptic feedback in audiovisual content a generalization of the term employed in the specific context of video viewing, (Danieau et al., 2013; Lemmens et al., 2009).

One of the most traditional methods for creating haptic effects is manual authoring, where designers meticulously synchronize vibrations, forces and other tactile sensations with audiovisual cues like explosions or sudden movements. While this approach offers flexibility and creative control, it is highly labor-intensive, requiring both technical expertise and significant time of 100 plus hours per movie (D-BOX, 2022), to ensure the haptic effects enhance the experience without overwhelming the user (Kern et al., 2023; Muender et al., 2022; Sreelakshmi & Subash, 2017). Similarly, capturing real-world haptic data using sensors, such as accelerometers attached to actors or objects, provides a more realistic representation of physical sensations but remains cumbersome due to its extensive processing required to align the data with audiovisual content.

Efforts to automate haptic feedback generation, such as extracting effects directly from audiovisual content, show promise in reducing labor involved in the process. However, this method is still limited by the complexity of translating audiovisual cues into meaningful haptic effects. Despite advancements, the creation of haptic effects – whether through manual authoring, sensor-based data capture, or automation – remains labor-intensive, highlighting the need for a more efficient, scalable solution that does not compromise the QoE of users.

2.1.5 AI Adoption

Recent advancements in AI offer promising solutions to complex and labor-intensive processes. At the core of AI's capabilities are Machine Learning (ML) and Deep Learning (DL), which enable systems to detect patterns and make predictions without explicit programming (Mahesh, 2020). While ML focuses on identifying patterns within data, DL leverages multilayered neural networks inspired by the human brain to learn complex representations from high-dimensional datasets (LeCun et al., 2015). This has allowed DL to outperform traditional approaches in numerous applications, spanning industries such as healthcare, finance, and autonomous systems (Feuerriegel et al., 2024; Sharifani & Amini, 2023).

Among the advancements in AI is the development of generative AI, a subset of deep learning that learns underlying patterns in data to create new content. Generative AI models can produce images, music, text, and even 3D models that closely resemble human-created works (Fui-Hoon Nah et al., 2023; L. Zhao et al., 2023; W. X. Zhao et al., 2024). This capability has seen broad application in the arts and media, where generative AI automates creative processes, from digital art and visual effects to personalized media experiences. These tools are used to generate content with levels of complexity and realism that mirror human creativity (Epstein et al., 2023; Ko et al., 2018; Oppenlaender, 2023; E. Zhou & Lee, 2023). However, skepticism remains about AI's ability to replicate the nuance and imagination characteristic of human creativity, especially in highly subjective and creative fields (Anantrasirichai & Bull, 2022; Bakhshi et al., 2015; Boden, 2016).

While AI excels in repetitive, predictable workflows and managing complexity in multitasking environments (Z. Wu et al., 2021), it struggles with tasks requiring flexibility, strategic thinking, and generalization (Srivastava et al., 2023). Humans excel in this area as they can intuitively understand and adapt to nuanced emotional and social cues. AI has shown promise in enhancing productivity and efficiency by automating repetitive tasks, however its ability to fully replace human creativity is still debated in research (Frey & Osborne, 2017).

AI's potential to automate haptic feedback creation could address the labor-intensive nature of the process. For example, D-BOX traditionally relied on human artists to synchronize haptic effects with audiovisual content, a time-consuming process. In collaboration with Mila Institute, D-BOX explored AI-driven solutions to detect key events, such as explosions, and automatically generate the corresponding haptic effects in the D-BOX seat (Mila, 2024). This approach, from a bird's eye view appeared to have reduced the time-consuming and labor-intensive process allowing for the scalability of more haptic enhanced content. However, the extent to which AI-generated haptic effects can replicate or even surpass human-generated feedback in delivering high-quality immersive experiences remains an open question. To our knowledge, no prior research has investigated this in the context of haptic-enhanced cinematic experiences, evaluating both subjective and objective aspects of users' QoE. This prompts the exploration of the question:

While AI may streamline routine tasks, the intricacies of modulating haptic stimuli – ensuring effects enhance rather than disrupt immersion – are critical to user experience (Gaffary & Lécuyer, 2018). Machine learning models, constrained by predefined parameters, may lack the ability to intuitively adjust feedback based on emotional or contextual nuances, potentially resulting in overwhelming or ineffective haptic stimuli (Schneider et al., 2017). Given this skepticism in research, we hypothesize that in cinematic experiences, human-encoded haptic feedback will outperform AI-encoded feedback in delivering higher levels of Cognitive Absorption, Arousal, Valence, as well as stronger intentions to relive and recommend the experience. Thus, we propose the following hypotheses:

- **H1a:** Human-encoded haptic feedback will result in higher levels of Cognitive Absorption compared to AI-encoded haptic feedback.
- **H1b:** Human-encoded haptic feedback will elicit higher levels of Arousal compared to AI-encoded haptic feedback.
- **H1c:** Human-encoded haptic feedback will produce higher Valence levels compared to AI-encoded haptic feedback.

2.1.6 Movie Genre

While haptic effects play a crucial role in enhancing immersion in audiovisual content viewing, other factors, such as movie genre, may also significantly impact the QoE of viewers. Different genres elicit varying levels of engagement, with specific elements liked action versus non-action scenes, and high- versus low-intensity sequences contributing to the audiences' QoE (Carpio et al., 2023; Israr et al., 2014; Rooney et al., 2012; V. T. Visch & Tan, 2009; Zwiky et al., 2024).

Action genres are known to heighten immersion through dynamic visual, auditory, and haptic effects. Fast-paces scenes, intense sound design, and adrenaline-inducing narratives are often significantly enhanced by haptic feedback allowing the audience to physically feel the action (Alma et al., 2021). This combination can deepen physiological engagement, resulting in increased heart rate and emotional arousal during action sequences (Hammond et al., 2023). In some cases, overly intense haptic effects could also disrupt immersion rather than enhance it. Conversely, low-intensity genres engage viewers on an emotional and cognitive level. Given the potential moderating effect of movie genre on the QoE, this study hypothesizes that movie genre may influence how the haptic encoding methods (AI & human artists) affect cognitive absorption, arousal, and valence. Therefore, the following hypotheses are proposed:

- **H2a:** There is a significant difference in the level of Cognitive Absorption elicited by the Haptic Encoding Method as a function of the Movie Genre being encoded.
- **H2b:** There is a significant difference in the level of Arousal elicited by the Haptic Encoding Method as a function of the Movie Genre being encoded.

- **H2c:** There is a significant difference in the level of Valence elicited by the Haptic Encoding Method as a function of the Movie Genre being encoded.

2.1.7 Satisfaction & Intentions

Satisfaction is another crucial perceptual measure within the framework of QoE. It is well established in the literature that high levels of satisfaction indicate the success of a system or technology in delivering a positive experience (Halstead & Jr, 2022). Satisfaction reflects how positively users perceive their interaction, making it a significant indicator of the overall quality of their experience with a system or technology.

Moreover, satisfaction is influenced by multiple factors, including CA which has been consistently linked to positive experiences in information systems and technologies. CA enhances user enjoyment and engagement, leading to higher satisfaction (Agarwal & Karahanna, 2000). Thus, we hypothesize the following:

- **H3:** The higher the Cognitive Absorption, the higher the Satisfaction.

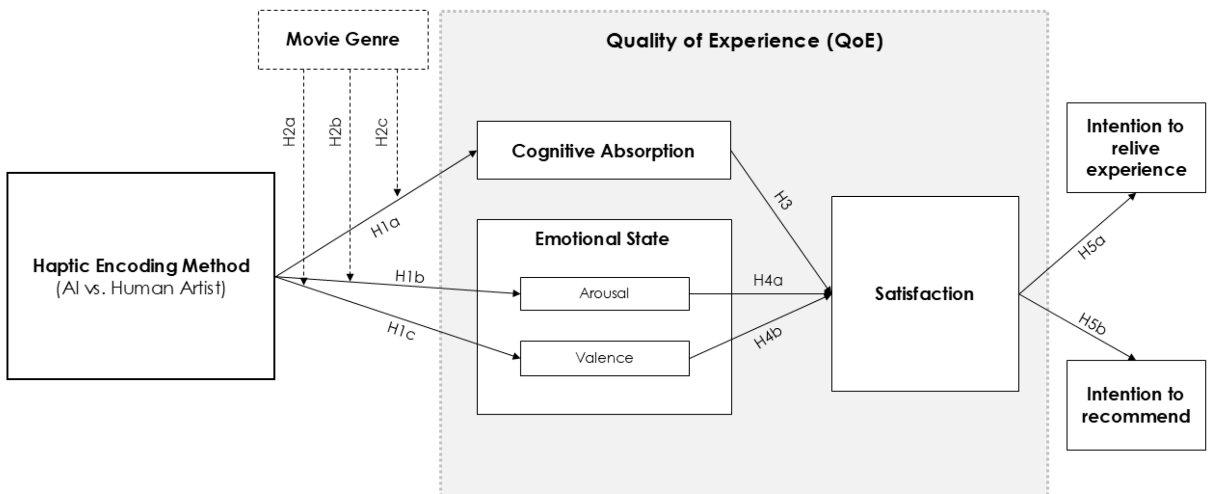
Additionally, users' emotional states – such as arousal and valence, components of QoE under psychological measures – influence satisfaction. According to Russell's "circumplex model of affect" (1980), emotional states can be mapped along two axes: valence, which measures the positivity or negativity of emotions, and arousal, which indicates the intensity of the emotional experience (Russell, 1980). We further hypothesize that:

- **H4a:** The higher the Arousal, the higher the Satisfaction.
- **H4b:** The higher the Valence, the higher the Satisfaction.

By applying the QoE model's three user-centered measures – perceptual, psychological and physiological – along with established literature, we hypothesize that higher levels of CA, arousal and valence will result in greater satisfaction. Drawing from the concept of immersion, as users become more cognitively and emotionally engaged with an experience, they are more likely to derive enjoyment and feel satisfied. This satisfaction, in turn, acts as a critical mediator, influencing users' intentions to relive the experience and recommend it to others (Dewi & Giantari, 2022; Halstead & Jr, 2022). Therefore, based on these foundations, this study posits the following hypotheses:

- **H5a:** The higher the Satisfaction, the higher the Intention to Relive.
- **H5b:** The higher the Satisfaction, the higher the Intention to Recommend.

The study's hypotheses are summarized in Figure 1.



Note. Arousal & Valence are perceived (self-reported) measures. Experienced (physiological) arousal was also measured.

Figure 1. Proposed Research Model

2.2 Method

2.2.1 Research Design

This study employed a within-subjects experimental design to examine the effects of haptic encoding methods on the QoE in a passive multimedia interaction (i.e. watching haptically enhanced movie clips). The primary experimental factor was the haptic encoding method, with two conditions: AI-encoded and human artist-encoded haptic feedback. The AI-encoded stimuli were generated using an advanced algorithm developed by D-BOX Technologies, designed to interpret and synchronize haptic feedback with the audiovisual content based on predefined parameters. The human artist-encoded stimuli, on the other hand, were crafted by a professional haptic artist who manually synchronized the haptic effects with the audiovisual content using a digital audio workstation (DAW). This artistic process involved high temporal precision to ensure that the haptic feedback was aligned perfectly with the visual and auditory elements of the clips. Both types of haptically enhanced stimuli were developed in-house by D-BOX Technologies and meticulously synchronized and delivered through the HFVK seat to optimize the immersive experience. The HFVK seat (D-BOX Technologies Inc. Longueuil, Canada) provides precise motion, vibrations and textures synchronized with the audiovisual content displayed on the TV.

The stimuli consisted of six movie clips, each ranging from 2 to 3 minutes in length. These clips were carefully selected from a variety of mainstream films, ensuring diverse movie genres to test moderation effects. The different genres included were Sci-Fi (Dune), Adventure (Guardians of the Galaxy), Action (John Wick), Animation (Moana), Romance (Love at First Sight), and Horror (Talk to Me).

Participants experienced all six clips, with three randomly assigned to the AI-encoded condition and three clips to the human artist-encoded condition. The assignment of haptic encoding methods to specific clips was randomized across participants to control potential order effects. A randomization of the conditions table (see Table C1 in Appendix C) was created beforehand using a Latin Square design as a counterbalancing strategy to counterbalance the presentation order of the clips and conditions, ensuring that each participant experienced a unique sequence. This setup guarantees that, although the study occurs in a laboratory setting, the experiment has a high ecological validity, providing a dependable measure of the impact that the haptic encoding method has on the viewers' QoE across various movie genres.

2.2.2 Participants

This study utilized a convenience sample of 29 participants (F = 10, M = 19), aged between 20 and 50 years old (M = 35.17, SD = 10.78). Participants were recruited through an online portal. The inclusion criteria for participants were aged between 20 and 50 years, regular consumers of content on streaming platforms, and fluent in English. Exclusion criteria were defined to exclude individuals with substantial prior experience with haptic cinema, such as enthusiasts or avid fans, to focus on assessing the reactions of participants with minimal or no prior exposure to this technology (see Table 2). Participants were asked about their familiarity with haptic cinema during the screening survey and were included or excluded accordingly (see Appendix D for details). Additionally, individuals who suffer from severe motion sickness were excluded to prevent any discomfort or adverse reactions during the experiment. Written informed consent was obtained from each participant prior to their involvement and all procedures were approved by the Ethics Review Council of HEC Montreal (Certificate No. 2024-5896) and adhered to the ethical principles outlined in the Declaration of Helsinki. Participants were compensated $30 CAD via Interac transfer upon completion of the study.

Table 2

Sample's Familiarity with Haptic Experiences

N	*Haptic Familiarity*	*%*
18	1	62.07
8	2	27.59
3	3	10.34

1, Don't know/have never tried a DBOX haptic seat.

2, Watches a movie in a DBOX haptic seat once a year or less.

3, Watches movies in a DBOX haptic seat about twice a year

2.2.3 Materials

The laboratory setup was carefully designed to replicate a comfortable, cinema-like environment while minimizing distractions. The experimental room was dark, with black curtains hung around the setup to isolate the participant from any potential visual distractions, ensuring their focus remained solely on the audiovisual content and the corresponding haptic stimuli. Participants were seated in a HFVK enhanced recliner seat (D-BOX Technologies Inc., Longueuil, Canada) positioned in front of a 70 × 120 cm high-definition Samsung TV, which displayed the AV stimuli. The audio was delivered in 5.1 surround sound through a Pioneer VSX-324 AV receiver and Pioneer S-11A-P speakers, fully immersing the participant in the experience (see Figure 2 & Figure 3).

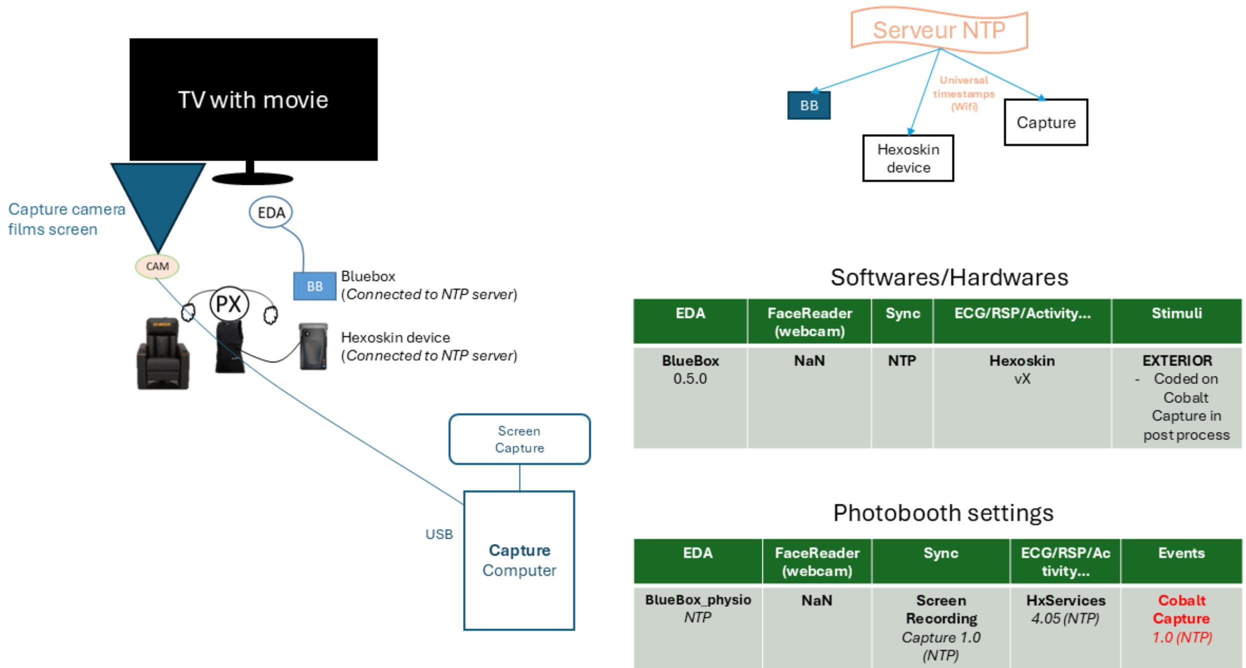


Figure 2. Synchronization Setup

Physiological data were collected using the Hexoskin Smart Garment (Carré Technologies Inc., Montreal, Canada), a biometric garment capable of continuously monitoring various physiological parameters such as heart rate, respiration, and activity levels throughout the experiment. Additionally, EDA was recorded using Cobalt EDA sensors (Cobalt System; Tech3Lab, Montreal, Canada), which were attached to the palm of the participant's non-dominant hand. These sensors provided real-time measurements of the participant's skin conductance, serving as an indicator of emotional arousal.

The moderator monitored the experiment from an adjacent observation room, equipped with a computer system that allowed for real-time observation and communication with the participant. This setup included software for controlling the start and stop of the AV stimuli, as well as tools for monitoring the physiological data being collected. Communication with the participant was conducted via a microphone and in-room speakers, allowing the moderator to provide instructions or assistance as needed. To ensure comprehensive data recording and synchronization with timestamps, a capture camera was used to video record the entire experiment. As shown in Figure 2, the Bluebox, Hexoskin, and Capture systems were all connected to the NTP Server, enabling synchronization of data with universal timestamps.

Figure 3. Experimental Setup

2.2.4 Experimental Procedure

The data collection procedure (see Figure 4) commenced when the participants were greeted at the entrance of the laboratory and guided to the experiment room. Upon entering the room, the purpose of the experiment was explained in detail to ensure that participants fully understood their involvement. Following this explanation, participants were asked to sign a consent form using an iPad, confirming their agreement to participate in the study.

Once the consent process was completed, participants were provided with instructions on how to wear the Hexoskin vest, a biometric garment designed to monitor physiological data throughout the experiment. They were then directed to a restroom to change into the vest. Upon returning to the experiment room, participants were seated in the HFVK chair developed by D-BOX Technologies. The research assistant then carefully attached Cobalt EDA sensors to the participant's non-dominant hand and verified the proper functioning of the Cobalt Bluebox, which was responsible for recording EDA. Once all equipment was properly set up and functioning, participants completed a pre-test questionnaire designed to gather control variables such as age, sex, gender, vision problems, and levels of alertness.

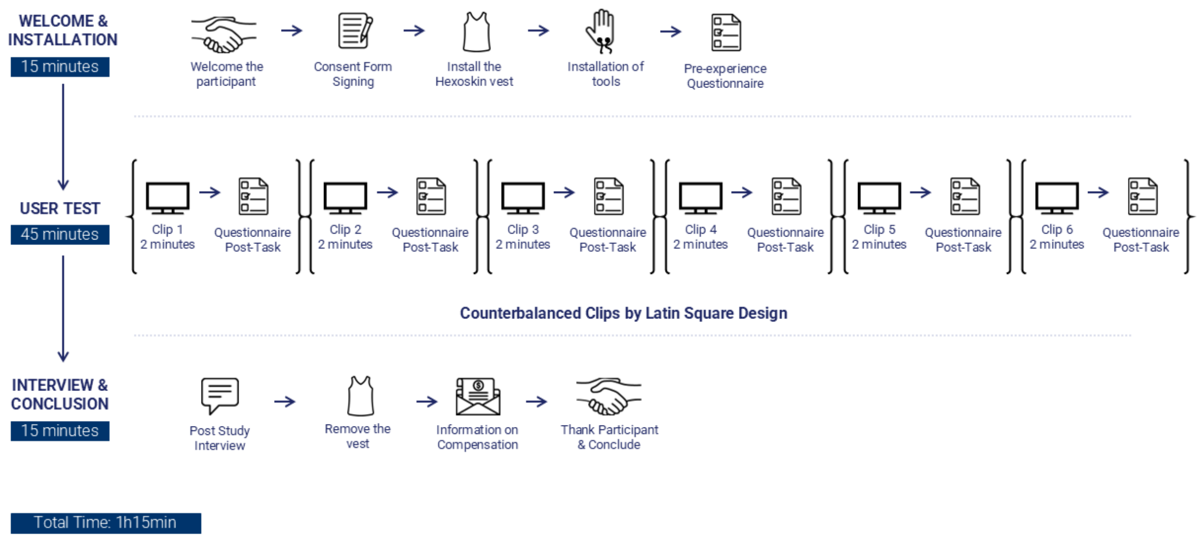


Figure 4. Data Collection Procedure

With the preliminary setup completed, participants were briefed further on the details of the study by the moderator (see Appendix D for details). This briefing ensured that participants were fully aware of the experiment ahead and the sequence in which they would occur.

The user test commenced with a baseline assessment, during which participants were instructed to focus on the center of the TV screen and breathe normally. The lights in the room were turned off to create a controlled environment, and the baseline assessment lasted for 60 seconds. This initial period was crucial for establishing a reference point for the participant's physiological state. Immediately following the baseline, participants were asked to complete a brief set of questions on a Qualtrics form accessed through the iPad. These questions helped ensure that participants were in a consistent state before viewing the movie clips.

Participants were then exposed to six different movie clips, each lasting between 2 to 3 minutes. These clips were encoded under two distinct conditions: Condition A (AI encoded) and Condition H (Human encoded). The presentation of these clips was counterbalanced (see Table C1 in Appendix C) to ensure that each participant viewed three clips haptically encoded by AI and three by a human artist, thus eliminating any potential order effects.

After viewing each clip, participants immediately completed a post-task questionnaire on the iPad. This questionnaire was designed to capture their immediate reactions to the clip. It included questions about whether they had seen the film from which the clip was taken, as well as measurements of perceived valence (affective slider), perceived arousal (affective slider), and three dimensions with adapted items of the cognitive absorption scale: focused immersion (FI), heightened enjoyment (HE), and temporal dissociation (TD). Participants also rated their overall satisfaction with the experience, their likelihood of reliving the haptic experience, and their willingness to recommend the experience to others. These measures provided a comprehensive understanding of the participant's experience with each clip.

Once all clips had been viewed and the corresponding questionnaires completed, the moderator re-entered the experiment room to conduct a post-study semi structured interview (see Appendix D). During this interview, participants were asked a series of open-ended questions to gather qualitative data about their overall impressions, preferences regarding the haptic effects, and general perceptions of the haptic experience. The interview was conducted face-to-face, with the moderator seated across from the participant. This interview provided valuable insights that complemented the quantitative data collected during the viewing sessions.

Following the interview, participants were directed to the restroom to remove the Hexoskin vest. Afterward, they returned to the experiment room, where they were thanked for their participation and filled out the compensation form of CA$30.

2.2.5 Measures

In this study, a combination of psychometric and physiological measures was used to collect data, ensuring a comprehensive evaluation of participants' experiences with haptic-enhanced audiovisual content. Data collection began with a pre-test questionnaire, which participants completed using a self-administered digital form on Qualtrics (Provo, UT, USA) via a provided iPad. This questionnaire was designed to gather demographic information and control variables such as watching habits, content preferences, frequency of streaming content usage, and familiarity with haptic cinema (see Appendix D). Additionally, to account for prior exposure to the movie clip, questions were asked post each movie clip such as, “Have you already seen the film from which the clip is taken?”

2.2.5.1 Cognitive Absorption

After viewing each movie clip, participants completed psychometric self-reports administered through Qualtrics. The scales employed in these questionnaires were adapted from validated measures to ensure both internal consistency and reliability. Cognitive Absorption (CA) was measured using dimensions such as Focused Immersion (FI), Heightened Enjoyment (HE) and Temporal Dissociation (TD), previously validated in the literature to capture the extent of user engagement with digital content (Agarwal & Karahanna, 2000). Each dimension comprised three to four items rated on a 7-point Likert scale (1 = Strongly Disagree to 7 = Strongly Agree). Example items include “time appeared to go by very quickly when I watched the movie clip” (Temporal Dissociation), “watching the movie clip provided me with a lot of enjoyment” (Heightened Enjoyment), and “while watching the movie clip, my attention did not get diverted very easily,” (Focused Immersion). Refer to Appendix D for the complete adapted scale.

2.2.5.2 Emotional State

Emotional state was assessed through both perceived and physiological measures to capture participants’ arousal and valence during the haptic-enhanced audiovisual experience. Perceived arousal and valence were evaluated after each movie clip through Qualtrics using the Affective Slider, a validated tool sensitive to immediate emotional responses (Betella & Verschure, 2016). Participants rated their arousal and valence on a scale from 0 (low) to 100 (high), providing self-reported data on the intensity and pleasantness of their emotional reactions to each clip.

Physiological arousal was measured through EDA and Heart Rate Variability (HRV), both reliable indicators of autonomic arousal. EDA, a measure of skin conductance regulated by the sympathetic nervous system, reflects eccrine sweat gland activity and is closely correlated with levels of arousal (Pauna et al., 2018; Riedl & Léger, 2016). EDA data were collected using Cobalt Bluebox sensors (Cobalt System; Tech3Lab, Montreal, Canada), attached to the palm of participants’ non-dominant hands, with data recorded continuously at a rate of 500Hz, offering high temporal resolution in capturing participants’ physiological arousal. (Ciuk et al., 2015). In addition, HRV was monitored using the Hexoskin Smart Garment (Carré Technologies Inc., Montreal, Canada), which recorded HRV at a high sampling rate, providing insight into participants’ physiological responses to emotionally engaging content. Changes in both HRV and heart rate are recognized for their sensitivity to emotional intensity, further enriching the data on participants' emotional arousal (Mohammadpoor Faskhodi et al., 2023).

2.2.5.3 Satisfaction & Intention to Relive and Recommend

Satisfaction and behavioral intentions, specifically the intention to relive and recommend the experience, were assessed to capture participants' overall QoE and potential future interactions with haptic-enhanced content. Satisfaction was measured using the Customer Satisfaction (CSAT) question, a single-item 7-point Likert scale (1 = Extremely Dissatisfied to 7 = Extremely Satisfied): "Are you satisfied with your overall experience while watching this movie clip?" (Farris et al., 2010).

Behavioral intentions were evaluated with two additional items: the intention to recommend and the intention to relive the experience. The recommendation intention was adapted from the Net Promoter Score (NPS) framework, asking, "Based on the last movie clip you saw, how likely is it that you would recommend this experience to a friend, a colleague or a member of your family?" Responses were recorded on a 7-point Likert scale (1 = Not Probable to 7 = Very Probable) (Reichheld, 2003). Intention to relive was also assessed with the question, "Based on the last clip you just saw, how likely is it that you'll decide to relive that haptic experience with this kind of film?". This item also used a 7-point Likert scale (1 = Not Probable to 7 = Very Probable). Together, these measures provided insight into participants' satisfaction and future behavioral intentions, which are key indicators of sustained engagement and perceived value in immersive media experiences.

2.2.6 Data Analysis

Data analyses were performed using SAS OnDemand for Academics (SAS Inst., U.S.A.) and SPSS Statistics (Version 29.0; IBM Corp., Armonk, NY).To examine the effects of the haptic encoding method (AI vs. Human artist) and movie genre on various QoE metrics, including cognitive absorption (CA, FI, HE, TD), perceived emotional responses (valence, arousal), and customer satisfaction (CSAT), a series of logistic regression models with random intercepts were conducted. The dependent variables were dichotomized using a median split due to their lack of normality and analyzed using logistic regression with a logit link function. Interaction effects between haptic encoding and film genre were also tested. For continuous physiological measures, such as phasic EDA and heart rate variability (HRV), linear mixed-effects models were employed using a normal distribution and identity link. These models included random intercepts to account for the repeated measures design and were used to assess the influence of the haptic encoding method on these physiological responses. Post-hoc comparisons were adjusted using Bonferroni corrections where applicable, and the threshold for statistical significance was set at $p \leq .05$.

2.3 Results

2.3.1 Descriptive Statistics

Participants' responses across haptic encoding methods highlighted distinct trends. Cognitive Absorption (CA) scores were similar between the AI-encoded (M = 5.49, SD = 1.22) and human-encoded conditions (M = 5.34, SD = 1.36), but arousal-related measures showed more variation. Perceived arousal was slightly higher in the human-encoded condition (M = 79.62, SD = 22.65) than in the AI-encoded condition (M = 76.20, SD = 22.56). Physiological arousal also showed marginally higher scores in the human-encoded condition (M = 0.15, SD = 0.38) compared to the AI-encoded condition (M = 0.13, SD = 0.48). See Table 3 for descriptive statistics by Haptic Encoding Method.

Table 3

Descriptive Statistics by Haptic Encoding Method

	Cognitive Absorption					***Perceived Valence***				
	M	SD	Min	Max	N	M	SD	Min	Max	N
A*	5.49	1.21	2	7	87	73.47	23.40	8	100	87
H*	5.34	1.35	1	7	87	70.25	27.78	0	100	87
	Perceived Arousal					***Phasic Arousal***				
	M	SD	Min	Max	N	M	SD	Min	Max	N
A*	76.20	22.56	6	100	87	0.13	0.48	0	4	85
H*	79.62	22.65	2	100	87	0.15	0.38	0	3	82
	SDNN HRV*					***Satisfaction CSAT***				
	M	SD	Min	Max	N	M	SD	Min	Max	N
A*	65.36	86.31	17	475	80	5.74	1.38	2	7	87
H*	72.22	91.44	16	426	80	5.52	1.64	1	7	87
	Intention to Relive					***Intention to Recommend***				
	M	SD	Min	Max	N	M	SD	Min	Max	N
A*	5.28	1.89	1	7	87	7.45	2.62	0	10	87
H*	5.09	2.12	1	7	87	7.32	2.95	0	10	87

A, AI; H, Human Artist; SDNN HRV, Standard Deviation of Normal-to-Normal Heart Rate Variability

Analysis by movie genre revealed notable patterns. CA was highest for action-heavy films like *Dune* (M = 5.69, SD = 1.18) and *John Wick* (M = 5.85, SD = 0.95), aligning with their dynamic content. Perceived arousal was elevated in *John Wick* (M = 83.79, SD = 16.27) and *Talk to Me* (M = 86.48, SD = 14.94), with *Talk to Me* also showing the highest physiological arousal (M = 0.25, SD = 0.33). For further details, refer to Table 4 for descriptive statistics by Movie Genre.

Table 4

Descriptive Statistics by Movie Genre

	Cognitive Absorption					*Perceived Valence*				
	M	SD	Min	Max	N	M	SD	Min	Max	N
Dune	5.69	1.18	2	7	29	75.97	23.21	21	100	29
GoG	5.34	1.38	1	7	29	73.79	26.12	0	100	29
JW	5.85	0.94	3	7	29	81.76	19.79	35	100	29
Moana	5.57	1.08	3	7	29	78.72	19.85	10	100	29
Love	4.42	1.49	2	7	29	61.83	26.42	13	100	29
Talk	5.61	1.11	3	7	29	59.10	30.30	0	100	29
	Perceived Arousal					*Phasic Arousal*				
	M	SD	Min	Max	N	M	SD	Min	Max	N
Dune	83.72	18.68	25	100	29	0.05	0.05	0	0	27
GoG	78.59	20.02	2	100	29	0.09	0.14	0	1	28
JW	83.79	16.27	48	100	29	0.20	0.60	0	3	28
Moana	79.59	19.21	17	100	29	0.09	0.15	0	1	29
Love	55.28	29.49	6	100	29	0.18	0.77	0	4	28
Talk	86.48	14.94	2	100	29	0.25	0.32	0	1	27
	SDNN HRV					*Satisfaction CSAT*				
	M	SD	Min	Max	N	M	SD	Min	Max	N
Dune	67.23	73.30	17	387	27	5.86	1.43	3	7	29
GoG	80.41	108.63	17	412	27	5.66	1.71	1	7	29
JW	72.09	90.08	16	382	26	6.21	1.04	3	7	29
Moana	56.01	63.28	17	341	26	5.97	0.90	4	7	29
Love	66.42	97.73	20	475	27	4.55	1.70	1	7	29
Talk	70.22	97.02	19	426	27	5.52	1.66	1	7	29
	Intention to Relive					*Intention to Recommend*				
	M	SD	Min	Max	N	M	SD	Min	Max	N
Dune	5.79	1.84	1	7	29	8.52	1.95	2	10	29
GoG	5.38	1.93	1	7	29	7.38	2.78	0	10	29
JW	5.76	1.61	1	7	29	8.17	2.36	0	10	29
Moana	5.45	1.63	1	7	29	7.72	2.25	0	10	29
Love	3.62	2.27	1	7	29	4.79	3.34	0	10	29
Talk	5.10	2.00	1	7	29	7.72	2.32	0	10	29

GoG, Guardians of the Galaxy; JW, John Wick; Love, Love at First Sight; Talk, Talk to Me.

2.3.2 *Hypothesis Testing*

The results of hypothesis testing are presented in Figure 5, Figure 6, and Table 5. Analyses began by evaluating Cognitive Absorption (CA) scores to determine if there were significant differences between AI- and human-encoded haptic feedback conditions and across movie genres. Due to the lack of normality in CA data, a logistic regression on median-split CA scores was conducted. The interaction between haptic encoding methods and movie genre was not significant, F (5, 134) = 1.11, $p = .35$. Similarly, the main effect of haptic encoding method on CA was also not significant, F (1, 144) = 0.03, $p = .87$, thus leading to a rejection of H1a and H2a.

For emotional state measures, the results revealed some nuanced findings. The interaction between the haptic encoding method and movie genre was not significant for perceived arousal, F (5, 134) = 0.37, $p = .86$, leading to a rejection of H2b. Additionally, the main effect of encoding method on perceived arousal was not statistically significant, F (1, 144) = 2.09, $p = .15$. However, for physiological arousal, the analysis showed a significant main effect of haptic encoding method, F (1, 129) = 6.28, $p = .013$, with higher phasic arousal observed in the human-encoded condition compared to AI. Consequently, H1b was partially supported through physiological arousal, though not by perceived arousal. Furthermore, neither the interaction between haptic encoding method and movie genre nor the main effect of haptic encoding on perceived valence reached significance, thus H1c and H2c were not supported.

As expected, significant main effects were found for CA, perceived arousal, and valence on perceived satisfaction, supporting H3 and H4b. However, interestingly, the main effect of physiological arousal on satisfaction was not statistically significant, F (1, 137) = 0.61, $p = .43$, providing partial support for H4a.

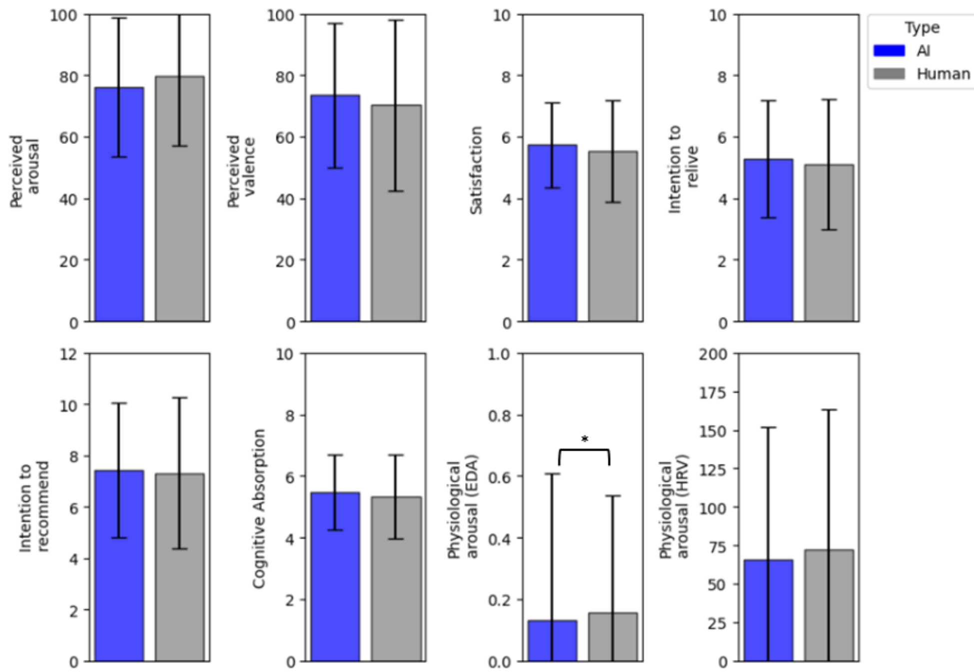
Table 5

Table of Hypothesis Testing for RQ1 and RQ2

H	From	Directionality	To	$F_{(df1, df2)} = F$	*p*	Status
H1a	HEM	H ↑	Cognitive Absorption	$F_{(1, 144)} = 0.03$	.87	Not Supported
H2a	HEM×MG	↕	Cognitive Absorption	$F_{(5, 134)} = 1.11$	.35	Not Supported
H1b	HEM	H ↑	Perceived Arousal	$F_{(1, 144)} = 2.09$	.15	Partially Supported
	HEM	H ↑	Physiological Arousal (EDA)	$F_{(1, 129)} = 6.28$	.013	
	HEM	H ↑	Physiological Arousal (SDNN HRV)	$F_{(1, 131)} = 1.52$	.22	
H2b	HEM×MG	↕	Perceived Arousal	$F_{(5, 134)} = 0.37$	.86	Not Supported
	HEM×MG	↕	Physiological Arousal	$F_{(5, 119)} = 1.49$	.19	Not Supported
H1c	HEM	H ↑	Perceived Valence	$F_{(1, 144)} = 0.09$	.75	Not Supported
H2c	HEM×MG	↕	Perceived Valence	$F_{(5, 134)} = 1.29$	.27	Not Supported
H3	CA	↑	Satisfaction	$F_{(1, 144)} = 40.88$	<.0001	Supported
H4a	PA	↑	Satisfaction	$F_{(1, 144)} = 29.77$	<.0001	Partially Supported
	Physio. Arousal	↑		$F_{(1,137)} = 0.61$	.43	
H4b	PV	↑	Satisfaction	$F_{(1, 144)} = 42.78$	<.0001	Supported
H5a	CSAT	↑	Intention to Relive	$F_{(1, 144)} = 37.81$	<.0001	Supported
H5b	CSAT	↑	Intention to Recommend	$F_{(1, 144)} = 31.44$	<.0001	Supported

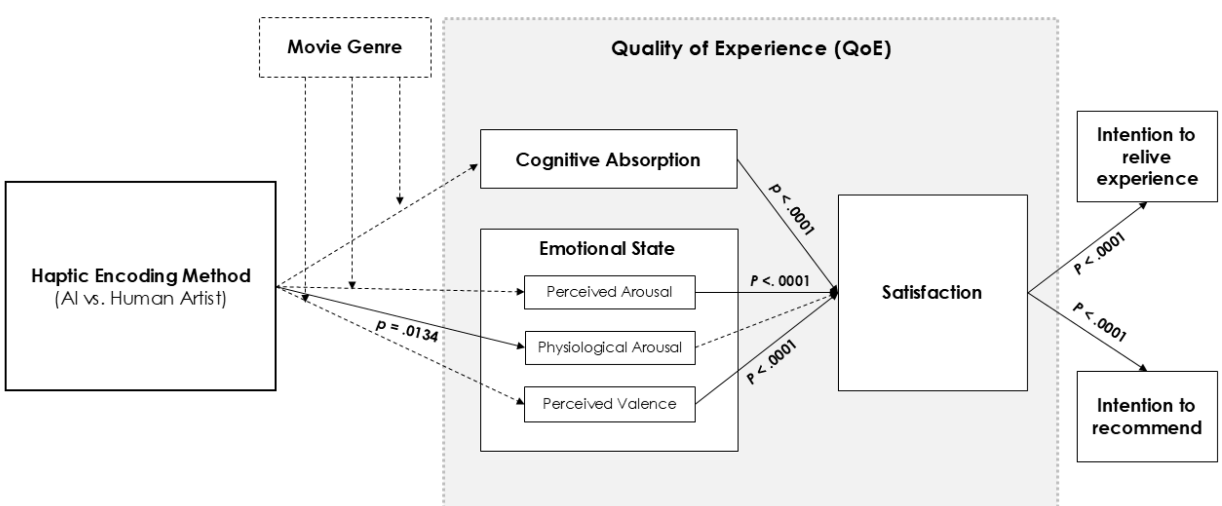
Directionality of hypothesis: ↑ Enhancing effect; ↕ Either direction.

HEM, Haptic Encoding Method; MG, Movie Genre; CA, Cognitive Absorption; PA, Perceived Arousal; PV, Perceived Valence; CSAT, Satisfaction; H, Human Artist.



Note. EDA: Electrodermal Activity, HRV: Heart Rate Variability

Figure 5. Summary of Results by Haptic Encoding Method



Note. Dotted lines indicate insignificant effects; solid lines indicate significant effects.

Figure 6. Validated Research Model

2.3.3 Post Hoc Results

Further exploratory analyses were conducted to examine the main effects of movie genre on Cognitive Absorption (CA) and emotional state measures, as well as the main effect of haptic encoding method on behavioral intentions to relive and recommend. Although the main effect of movie genre on CA was significant, F (5, 140) = 2.28, p = .049, suggesting that movie genre may influence cognitive absorption, this effect did not vary by haptic encoding method.

A significant main effect of movie genre on valence was found, F (5, 140) = 2.71, p = .022, indicating that valence varied across movie genres, independent of the encoding method. However, the main effect of haptic encoding method on intention to relive was not significant, F (1, 144) = 0.10, p = .748, nor was the main effect on intention to recommend, F (1, 144) = 0.03, p = .868. Detailed post hoc results are presented in Table 7.

Table 6

Post Hoc Results

No.	IV	DV	$F_{(df1, df2)} = F$	p	Status
1	MG	Cognitive Absorption	$F_{(5, 140)} = 2.28$	.049	Significant
2	MG	Perceived Arousal	$F_{(5, 140)} = 2.89$	.016	Significant
3	MG	Physiological Arousal (EDA)	$F_{(5, 125)} = 5.74$	<.0001	Significant
4	MG	Physiological Arousal (SDNN HRV)	$F_{(5, 127)} = 0.57$	.71	Non-Significant
5	MG	Perceived Valence	$F_{(5, 140)} = 2.71$	.022	Significant
6	HEM	Intention to Relive	$F_{(1, 144)} = 0.10$	.74	Non-Significant
7	HEM	Intention to Recommend	$F_{(1, 144)} = 0.03$	.86	Non-Significant

HEM, Haptic Encoding Method; MG, Movie Genre; SDNN HRV, Standard Deviation of Normal-to-Normal Heart Rate Variability

2.4 Discussion

This study investigated how AI-encoded haptic feedback compares to human-encoded haptics in shaping the QoE for viewers in a HFVK cinematic setting. Using both perceived and physiological measures, we assessed the impact of haptic encoding method on several QoE dimensions, using immersion as our theoretical basis. The results showed no significant differences in self-reported measures between AI and human-encoded haptics, particularly in CA, arousal, and valence. However, physiological responses revealed a nuanced effect: human-encoded haptics elicited significantly higher physiological arousal than AI-encoded haptics. Additionally, consistent with expectations, perceived CA, arousal, and valence significantly influenced satisfaction, which, in turn, mediated the intentions to relive and recommend the experience. These findings indicate that AI-encoded haptics is perceptually comparable to human-encoded haptics, yet they also highlight areas where AI may yet fall short of replicating the depth of human creativity. Therefore, this study offers a layered understanding of the potential and limitations of AI in haptic feedback design in terms of user experience.

2.4.1 Theoretical & Methodological Contributions

First, the lack of significant differences in perceived cognitive absorption, arousal, and valence between human and AI haptic encoding is contrary to previous research that often emphasizes the superiority of human artistry in generating richer and more immersive experiences (Koivisto & Grassini, 2023). On the other hand, the significant difference observed in physiological arousal measured by EDA between the human artist and AI encoding conditions highlights a distinction between perceived and physiological responses. We observed a significant effect of the haptic encoding method on physiological arousal such that the human artist encoding is associated with a higher level of physiological arousal than that of the AI. Subsequently we observed the conscious manifestation of the effects by the haptic encoding method on the emotional state via the user's perception. Both perceived arousal and valence, alongside CA, significantly influenced satisfaction. This finding leads to the rejection of hypotheses H1a and H1c, while partially supporting H1b, attributing the physiological arousal to the human-encoded method. Additionally, no moderating effect of movie genre on the impact of haptic encoding method on cognitive absorption, arousal, and valence was found, leading to the rejection of hypotheses H2a, H2b, and H2c.

Furthermore, CA, arousal, and valence were found to significantly affect satisfaction, which in turn substantially influenced behavioral intentions to relive and recommend the experience. This supports hypotheses H3, H4a, H4b, H5a, and H5b, confirming the substantial role of emotional and cognitive responses in shaping viewer satisfaction and subsequent behavioral intentions.

2.4.1.1 Perceptual vs. Physiological Emotional Response

The study's main findings align with several foundational theories of emotion, providing insights into the complex interplay between physiological arousal and perceived emotional experience. The James-Lange, Cannon-Bard, and Schachter-Singer theories each present distinct perspectives on this relationship (Cabanac, 2002; Cacioppo & Gardner, 1999; Gendron & Feldman Barrett, 2009). According to the James-Lang theory, emotions stem from physiological responses to stimuli, suggesting that bodily states, such as increased heart rate or tension, trigger the conscious experience of emotion (James, 1894; Lang, 1994; Lange et al., 1922). This theory finds some support in studies indicating that physiological feedback shapes emotional perception (Stanojlović et al., 2021). However, the theory has been critiqued for its simplicity, as it overlooks the role of cognitive interpretation in emotion formation (Cacioppo & Tassinary, 1990; Northoff, 2008; Scherer, 1993). By contrast, the Cannon-Bard theory posits that physiological and emotional responses occur simultaneously and independently; emotional experiences can, therefore, emerge without direct physiological changes (Cannon, 1927). Recent research supports this more complex interaction, showing that emotions often involve cognitive appraisal independent of physiological changes (Stanojlović et al., 2021). The Schachter-Singer theory, or two-factor theory of emotion, bridges these perspectives by proposing that physiological arousal occurs first, but emotion arises from cognitive appraisal of the arousal in a given context (Schachter & Singer, 1962).

In the context of this study, these theoretical frameworks provide insight into the observed relationship between physiological arousal, perceived arousal, and satisfaction. Specifically, the finding that human-encoded haptic feedback elicited higher levels of physiological arousal than AI-decoded feedback suggests an underlying bodily response that, according to the James-Lang and Schachter-Singer theories, may inform perceived arousal. However, the lack of significant differences in self-reported arousal between the haptic encoding methods may indicate that participants' cognitive appraisal may have downplayed or generalized these physiological differences, aligning with the Cannon-Bard theory's notion of independent emotional and physiological pathways. Additionally, the HFVK stimuli combined with audiovisual content created an immersive, multisensory experience, engaging various sensory channels simultaneously which may have reduced participants' ability to distinguish subtle encoding differences. This context of rapidly changing scenes and intense sensory input may have resulted in similar self-reported CA, arousal, and valence levels across the two encoding methods due to a generalized arousal response.

Moreover, the timing of data collection may have influenced these results. Participants completed psychometric assessments after each movie clip to capture immediate post-movie responses, meaning they could have retrospectively evaluated their experience, potentially leading to cognitive biases. As previous research suggests, post-evaluation measures introduce memory, recency and recall biases (Barrett, 2024; Marto & Gonçalves, 2022). Therefore, participants may have only remembered a general state of arousal from the overall multisensory experience. This delay may have smoothed over subtle physiological variations, supporting a holistic assessment that favored a subjective perception of enjoyment rather than distinct differences. This retrospective assessment aligns with the Schachter-Singer model, as it suggests that cognitive appraisal of general arousal rather than immediate physiological may have shaped participants' reported experience. Therefore, future studies could employ EEG measures of brain activity to counter these potential biases and get a better grasp of the user's real-time cognitive state and reactions (Alsuradi et al., 2020; Baumgartner et al., 2006; Lim et al., 2019).

Additional exploratory analysis was conducted to examine the main effect of the haptic encoding method (AI vs. Human) on the users' intentional behaviors, specifically their willingness to relive the experience and recommend it others. The post hoc analysis revealed no significant differences between the haptic encoding methods in these behavioral intentions. This result is logical and consistent with the broader findings of this study, which indicated no significant differences between AI and human haptic encoding on the perceived CA, arousal, valence and satisfaction – key constructs that typically drive these behavioral intentions. Although physiological arousal did differ significantly between the encoding methods, this distinction did not translate in the self-reported measures that directly shape intentions. Thus, the lack of perceived differences in these constructs further explain why the intentions to relive and recommend the experience, also self-reported measures, did not differ significantly across the haptic encoding methods. Consequently, these findings highlight the central role of perception in shaping user behaviors.

Taken together, these interpretations highlight that while physiological arousal significantly differed by encoding method, this variation did not significantly impact perceived satisfaction. Although unexpected, the lack of significant difference of the physiological arousal on satisfaction is logical in this case, as satisfaction was also a perceptual measure. Overall, this suggests a potential for future research to further explore this relationship of perceived and physiological emotions in comparing AI and humans by incorporating more objective physiological measures, such as EEG for cognitive absorption and facial electromyography for valence. These approaches could yield deeper insights into the complex interplay between physiological emotions, cognitive states, and satisfaction, refining our understanding of how AI and human-encoded haptics contribute to QoE in immersive environments.

2.4.1.2 Expertise vs. Familiarity

Another potential explanation could be that this study's participant recruitment requirement was aimed at only novice users of haptic cinema experiences. Therefore, given that 62% of participants had no prior experience with this experience, this lack of familiarity may have influenced the participants' ability to discern differences between the two haptic encoding methods. Research suggests that novice users often rely on peripheral cues when evaluating quality, which may have led them to perceive both encoding methods similarly without being able to detect nuanced differences (Halvey & Jose, 2012; Ooms et al., 2014). In contrast, experienced users may be better equipped to identify these subtle distinctions in the haptic feedback. This difference implies that novices may be less attuned to the subtleties of haptic feedback that experts would likely detect, potentially explaining the similar self-reported measures of QoE observed in this study.

To address this limitation, future research could employ a longitudinal study design as it would be valuable to investigate whether these physiological differences eventually translate into perceived differences over time. This could help examine how novice users' perceptions evolve with repeated exposure to haptic cinematic experiences (Das & Das, 2017). As novices gain familiarity with haptic cinema, they may begin to discern differences between AI and human-encoded haptic feedback. Future research could alternatively compare the two groups of participants with varying haptic expertise levels with the two haptic encoding methods to further provide valuable insights into how different target users' characteristics shape the QoE in immersive contexts, thereby informing the design of haptic technology for diverse user groups.

2.4.1.3 Role of Movie Genre

Although the movie genre was not found to be a significant moderator in the relationship between haptic encoding method and QoE, the study's exploratory analyses revealed genre-specific patterns that warrant further attention. Action-intensive films such as John Wick, Guardians of the Galaxy (GoG), and Dune were linked to heightened levels of CA, perceived arousal and overall satisfaction. These genres, marked by dynamic action sequences and intense audiovisual stimuli, are recognized in the literature for their ability to evoke strong emotional and physiological engagement(Carpio et al., 2023; V. T. Visch & Tan, 2009; Zwiky et al., 2024). Conversely, genres like *Love at First Sight* (romantic) and *Moana* (animation) elicited moderate responses, while horror films such as *Talk to Me* produced strong physiological arousal, likely due to the tension and fear intrinsic in this genre (Liu et al., 2020). This genre-specific variation highlights the intrinsic impact of content type on user engagement and in turn QoE (Rubin et al., 2022; Thompson et al., 2021)

The absence of significant interaction effects between the haptic encoding method and movie genre suggests that both AI and human-encoded haptics effectively support immersion across genres. However, the substantial main effects of genre emphasize that content type plays a pivotal role in shaping QoE, with action and thriller benefiting from the haptic feedback. This aligns with previous research highlighting the importance of genre in influencing viewer engagement (Cannavò et al., 2024; Rooney et al., 2012). Thus, while the haptic encoding method may not significantly alter QoE across genres, certain genres naturally enhance cognitive and emotional engagement, reinforcing the role of movie genre as a key driver in immersive media experiences.

This study set out to address two main research questions: the extent to which AI-generated haptic feedback can replicate human-encoded haptics in shaping viewers' QoE and how each method influences intentions to relive the experience and recommend it to others. Our findings indicate that AI-generated haptics closely matches human artistry in perceived QoE, yet human-encoded feedback elicited higher physiological arousal, pointing to a nuanced distinction. While AI has achieved impressive sophistication in user perception, these results suggest a residual physiological response favoring human-generated stimuli, indicating that AI is not yet a complete substitute for human creativity when the goal is to deliver the highest QoE.

Theoretically, this study advances the literature by addressing skepticism surrounding AI's ability to replicate the creative nuances and "human touch" associated with human-generated content in creative contexts. To our knowledge, this is the first study comparing AI-and human-encoded haptic feedback within the specific context of immersive cinematic experiences. The findings indicated no significant perceptual differences between the two methods suggesting that AI-generated haptic feedback can serve as a viable option under certain conditions.

Methodologically, this research emphasizes the value of integrating both perceived and physiological metrics to evaluate user experiences, as it reveals the divergence between self-reported data ana d underlying physiological responses. Our multidimensional approach adds to existing methodologies in HCI research, reinforcing the importance of examining user experience beyond surface-level perceptions. Our study also contributes to the evaluation of QoE in multimedia research. Finally, these results contribute to the ongoing discourse on AI's role in creative industries, positioning AI not as a replacement but as a complementary tool for human creativity.

2.4.2 Practical Implications

From a practical implications perspective, these findings could hold relevance for managers and professionals across industries that use haptic feedback, as it has the potential to enhance user engagement. Given that AI-encoded haptic feedback achieved similar perceived QoE as human encoding, AI presents a scalable and consistent option for content creation, especially when rapid production and resource management are key. However, the physiological differences noted suggest that human expertise may still be preferable in settings designed to evoke strong emotional responses.

For movie producers and managers in the cinematic industry, the findings on movie genres provide actionable insights. Action-intensive genres, such as *John Wick* and *Guardians of the Galaxy*, benefit significantly from haptic feedback, which amplifies cognitive absorption, arousal, and overall satisfaction. In contrast, romantic or animated films elicit moderate responses, while horror films evoke strong physiological arousal due to their inherent tension and suspense. These genre-specific patterns suggest that content type plays a pivotal role in shaping user engagement and QoE. Managers can leverage these insights to tailor haptic feedback strategies to match the emotional and sensory demands of specific genres, enhancing immersive experiences.

In gaming and VR, AI-generated haptics can streamline the production of tactile feedback across diverse scenarios, reducing costs and accelerating timelines. However, for emotionally charged applications, such as story-driven games or cinematic VR, incorporating human oversight to refine AI-generated effects ensures emotional engagement and user satisfaction. Similarly, in corporate training or educational simulations, AI can automate repetitive feedback tasks while human designers enhance critical scenarios requiring emotional nuance.

Adopting a hybrid approach is essential for maximizing the benefits of AI while maintaining high-quality standards (Z. Wu et al., 2021). AI can efficiently handle labor-intensive aspects of haptic feedback production, with human designers refining the output to align with specific emotional and contextual requirements. This collaboration ensures that haptic content achieves both scalability and depth, fostering innovation while meeting user expectations.

Ultimately, while AI offers transformative potential in automating haptic feedback production, it should complement, not replace, human creativity. By balancing AI efficiency with human ingenuity, industries can deliver impactful and engaging user experiences tailored to diverse applications, sustaining audience satisfaction and driving innovation.

2.4.3 Limitations

Finally, alongside the previously mentioned limitations, due to time constraints, the study's reliance on a convenience sample of 29 participants highlights opportunities for improvement. Future research could address this by incorporating a larger and more diverse sample to improve the generalizability of the findings.

2.5 Conclusion

This study aimed to examine the extent to which AI-generated haptic feedback can replicate the QoE provided by human-encoded haptics in a high-fidelity cinematic setting, motivated by the potential for AI to address labor-intensive demands in complex processes. The while AI-generated haptics performs comparably to human-crafted feedback in perceived QoE, human encoding still elicits higher physiological arousal, indicating subtle distinctions between the two methods. This does not imply that AI is inherently equivalent to human artistry; the physiological differences observed in this study highlight the complexities of replicating the subtle and emotional engagement that humans provide. Our findings only suggests that AI-generated content may be "close enough" to human-generated for new users, but not entirely similar. Therefore, this research provided insights into AI's role in creative fields, challenging traditional views of human-exclusive artistry and expanding the potential applications of AI in immersive media. Looking forward, advancements in AI-driven haptics and continued research on multidimensional user experiences promise to enhance both the accessibility and richness of future immersive experiences.

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Chapter 3
AI in Haptics: A Helping Hand, Lacking a Human Touch

Abstract

The role of haptic feedback in creating immersive experiences is gaining momentum across industries such as gaming, Virtual Reality (VR), and cinematic entertainment. Our recent study evaluated and compared AI- and human-generated haptic feedback based on the quality of experience (QoE) of users in haptic-enhanced cinematic experiences. Through an experimental laboratory study involving both perceptual and physiological measures, we found that while AI-generated haptics delivered a comparable QoE to human-generated feedback in terms of user perceptions, human-generated haptics elicited a stronger emotional reaction at a physiological level. This suggests that while AI can enhance scalability and efficiency in haptic feedback production, human expertise remains indispensable in certain contexts. Adopting a hybrid approach over using AI only is essential for contexts where emotional engagement and depth is required to enhance the experience.

3.1 Introduction

In today's digitally driven world, the sense of touch stands out as a profound yet often overlooked frontier. Why is touch so powerful? It connects us with our surroundings, evokes deep emotions, and shapes how we perceive the world [1]. This fundamental role of touch has fueled the rise of immersive technologies that replicate and amplify sensory experiences. As demand for seamless integration of digital and physical experiences grows – driven by innovations like the metaverse, VR, and other immersive experiences – companies are striving to blur the line between fiction and reality, crafting experiences that feel more authentic and engaging.

Among these technologies, haptic feedback stands out for its ability to simulate tactile sensations through vibrations, motion, and force. Industries such as gaming, VR and cinema are harnessing its potential to transform how audiences engage with content, making experiences more immersive and captivating by integrating the sense of touch [2]. For example, haptic-enhanced seats allow viewers to experience synchronized physical sensations that complement the on-screen visuals, pulling them deeper into the narrative. Imagine feeling the vibrations and movement of a car chase or the physical impact of an explosion feeling like you are physically in the movie while you're at the comfort of your home or theater [3–5].

However, creating these multisensory experiences is no small feat. Haptic feedback production is labor-intensive, requiring skilled designers to meticulously synchronize every tactile sensation with audiovisual cues [6]. For a single film, for example, this process can take hundreds of hours – posing a challenge to scalability in an era of growing demand for such content. In recent years, generative AI has become a major topic of discussion for its transformative potential to enhance efficiency and productivity by automating complex, routine tasks [7–9]. This raises the question: Could AI help automate the haptic feedback production process?

While the potential is promising, haptic feedback creation is a uniquely creative task. Designers must consider nuances such as the intensity and timing of tactile sensations to ensure they enhance, rather than disrupt, the user experience. Overly intense or poorly timed feedback can turn an immersive experience into an uncomfortable or overwhelming one. Therefore, can AI address the scalability challenge of haptic-enhanced content? More importantly, can AI truly replicate the quality of user experience delivered by skilled human designers? These questions formed the basis of our study, which sought to compare AI- and human-generated haptic feedback in delivering high-quality, immersive cinematic experiences.

3.2 Research Approach

To investigate and compare the impact of AI- and human-generated haptic feedback on user experience, we conducted a laboratory experimental study involving 29 participants (novice to haptic-enhanced cinema) seated in high-fidelity vibro-kinetic (HFVK) seats. Participants watched six short randomly ordered movie clips – three with AI generated haptic feedback and three with human generated haptic feedback. After each clip, they provided feedback on their experiences rating elements such as cognitive absorption, emotional engagement (arousal and valence), and overall satisfaction. They also indicated their intentions to relive and recommend the experience.

Additionally, we collected physiological data, including EDA and heart rate, to capture physiological emotional arousal. This combination of subjective and objective data provided a comprehensive view of how each method of haptic feedback influenced the audience's experience [10,11]. The findings were analyzed using regression analysis to uncover patterns and key insights.

3.3 What We Found

Our research revealed a compelling duality in how users perceive and experience AI- and human-generated haptics. On the surface, participants rated the two methods as comparable in terms of cognitive absorption, emotional engagement, and satisfaction. These perceptual metrics suggest that AI may deliver an experience that feels "good enough" to many users, matching human-generated in creating a satisfying immersive environment. However, a deeper examination into physiological responses painted told a different story. Human-generated haptics elicited significantly higher levels of arousal, signaling a stronger emotional reaction. This divergence between perceptual ratings and physiological data emphasizes a limitation of AI: while it can replicate the broad strokes of a human-designed experience, it struggles to capture the subtle emotional nuances inherent to human creativity. Additionally, this study targeted novice users in the context of haptic-enhanced cinema, which may have influenced the results. Expert users, for example, might be more adept at detecting differenced in the two methods [12,13]. Nonetheless, this study's findings suggest that AI-generated haptics may be suitable for novice users or for applications where emotional depth is less critical. Conversely, its limitations could become evident in contexts requiring intense emotional engagement or for expert users with heightened sensitivity to nuanced haptic feedback.

Despite these distinctions, participants' behavioral intentions –likelihood to relive or recommend the experience – remained consistent across both haptic encoding methods. This consistency is promising for companies, as it aligns with the perceptual data, where satisfaction and emotional engagement – key drivers of behavioral intentions – showed no significant variation between the two methods [14,15]. These findings suggest that AI may deliver a comparable perceptual QoE without compromising users' intentions to relive or recommend the experience.

3.4 Best Practices and Recommendations

In industries where scalability, cost-efficiency and consistency are critical – such as large-scale gaming projects or VR training modules – AI-generated haptics could offer a practical solution.

For example, managers in gaming can leverage AI to quickly and consistently create haptic feedback for a wide range of scenarios, reducing production timelines and costs. Similarly, in VR-based corporate training or educational simulations, AI can enable faster development of tactile feedback, ensuring scalability for broader deployment. However, managers should be cautious about over-reliance on AI in contexts demanding high emotional engagement, as these drive the user's intentions to reuse and recommend the experience. Contexts such as narrative-driven gaming, cinematic experiences, or therapeutic applications may benefit more from human-crafted haptic feedback as they can better capture the emotional nuances required to deeply engage users.

A hybrid approach presents the optimal strategy for AI use in haptic feedback production in certain contexts. AI can be employed to handle the labor-intensive aspects of haptic production. Human designers can then refine the AI-generated haptics, incorporating the depth and emotional resonance necessary in certain applications. Content creators in immersive cinema, for instance, can use AI for initial haptic feedback design while ensuring human oversight to align the tactile sensations with the emotional arc of the narrative. This synergy between AI and human input ensures that the final product meets high-quality standards without compromising user experience [7,16].

Furthermore, continuous evaluation and user feedback are essential for maintaining high quality of experiences when using AI. Managers should prioritize robust user testing to identify areas where AI-generated haptics may fall short and keep refining algorithms accordingly.

3.5 Conclusion

The broader implication of this research is clear: AI has the potential to democratize access to immersive technologies by reducing reliance on human labor and streamlining haptic feedback production. However, "good enough" is not always sufficient. Human expertise remains indispensable for crafting high-quality user experience, particularly in contexts requiring emotional depth and nuance. Therefore, AI should be embraces as a valuable complement to human creativity. By leveraging the strengths of AI and human ingenuity, industries can achieve a balance between efficiency and impactful user experiences, fostering innovation that meets audience expectations, sustains engagement, and ultimately enhances satisfaction.

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Chapter 4: Conclusion

This thesis investigated AI's application in creating immersive environments, aiming to provide creators, designers, and developers with a deeper understanding of AI's capabilities and limitations in tasks that traditionally require the nuanced emotional touch of humans. Specifically, the study assessed whether AI-generated haptic feedback can replicate the user's Quality of Experience (QoE) typically achieved through human-encoded haptic feedback within a high-fidelity cinematic context. By testing two conditions – AI-encoded and human-encoded haptic feedback – this research evaluated their effects on QoE through perceptual, psychological and physiological measures. The findings revealed that while AI-encoded haptic feedback achieved a similar perceived QoE to human-encoded haptic feedback, it lacked the physiological and emotional depth demonstrated by human-encoded haptics, as evidenced by significantly higher physiological arousal elicited by the human-encoded condition. This concluding chapter revisits the research questions and discusses the theoretical contributions and practical implications. Finally, it contextualized the significant results and formulated them into actionable insights for future applications.

4.1 Research Questions

The study in the second chapter aimed to evaluate and compare AI and human haptic encoding methods in immersive cinematic experiences by assessing viewers' Quality of Experience (QoE). The research addressed two key questions:

1. To what extent does the method of haptic feedback encoding (AI vs. human artists) of audiovisual content in a high-fidelity vibro-kinetic (HFVK) seat influence the QoE of viewers?
2. To what extent does the method of haptic feedback encoding (AI vs. human artist) of audiovisual content in a high-fidelity vibro-kinetic (HFVK) seat impact the viewers' intention to relive the experience and recommend to others?

The findings indicate that AI-encoded haptic feedback provides a QoE perceptually comparable to that of human-encoded feedback. However, there were notable differences in physiological arousal, as measured by electrodermal activity (EDA), with human-encoded feedback eliciting higher arousal levels. These results suggest that while both encoding methods deliver similar perceived QoE, AI may not engage users as deeply on an emotional and physiological level as human encoding does.

Moreover, despite these physiological differences, the intentions to relive and recommend the experience showed no significant difference between AI and human-encoded haptic feedback. This outcome suggests that the perceptual equivalence in QoE between the two methods positively influences behavioral intentions. Therefore, while AI haptic encoding is physiologically distinct from human encoding, it is not perceived differently by viewers in terms of QoE and subsequent behavioral intentions.

4.2 Theoretical Contributions

Overall, to our knowledge, this study pioneering in its comparison of AI and human-encoded haptic feedback within the specific context of immersive cinematic experiences. This thesis aimed to determine the extent to which AI-generated haptic feedback can replicate the QoE typically achieved through human-encoded haptic feedback in an immersive, high-fidelity cinematic environment, and examined the subsequent impact of QoE users' behavioral intentions to relive and recommend the experience.

Utilizing a comprehensive methodological approach that incorporated both psychometric assessments and physiological measures, this research provided us with a nuanced narrative. Our study's key findings revealed that AI-generated haptic feedback is comparable to human-encoded haptic feedback in terms of perceived QoE, with no significant differences observed in cognitive absorption, arousal, valence and satisfaction and its subsequent behavioral intentions. However, the divergence in physiological responses – specifically, the higher arousal elicited by human-encoded haptic feedback as measured by EDA – highlights a distinct gap in AI's ability. This could suggest that while AI may have the potential in replicating the perceptual aspect of QoE, it does not fully emulate the deeper, often subconscious emotional reactions facilitated by the human touch.

Therefore, this nuanced distinction between perceived and physiological adds complexity to this discourse, indicating that perceptual similarity does not equate to physiological equivalence, an important consideration in the field of immersive experience design. This further signifies the importance of integrating perceptual and physiological measures in research to gain a holistic understanding of user emotions and, in turn, experiences. This insight also adds to the literature of foundational emotion theories, such as those proposed by James-Lange and Schachter-Singer, which emphasize the interplay between physiological arousal and cognitive appraisal in shaping emotional experiences (James, 1894; Schachter & Singer, 1962). In this context, the heightened physiological arousal associated with human-encoded feedback may enhance the perceived intensity of the experience, even if it is not consciously recognized by users – a phenomenon that could explain the lack of significant differences in self-reported arousal between the two haptic encoding methods.

Furthermore, this research addresses and challenges the skepticism surrounding AI's capabilities in creative domains, providing a nuanced perspective on AI's potential and limitations. By demonstrating that AI can closely approximate human-encoded haptic feedback in terms of perceived QoE, the study challenges and adds a crucial perspective to the ongoing debate about the role of AI in creative industries. While prior literature posits that human artistry contributes to richer, more immersive experiences (Koivisto & Grassini, 2023), this research suggests that AI, when applied appropriately, may meet human performance, particularly in scenarios where the emotional depth required in experiences is within the capabilities of current AI technology.

Overall, these insights not only advance our theoretical understanding of AI's integration into creative processes but also enrich the broader QoE in multimedia and Human-Computer Interaction (HCI) research. Moreover, this study's dual examination of perceptual and physiological responses advances theoretical understanding of immersion and user experience, offering a more holistic framework for future studies that address AI-driven haptic design. This further highlights the significance of using a mixed-methods approach in user experience research as human emotions are complex and multi-layered (Bell et al., 2018; Ciuk et al., 2015; Hammond et al., 2023; Pauna et al., 2018). Hopefully this study lays a foundational framework for future inquiries into the synergetic potentials of humans and AI, propelling forward the discourse on how best to leverage technology to enhance human-centered experiences.

4.3 Practical Implications

From a practical perspective, the study's findings hold relevance for various industries seeking to incorporate AI into haptic feedback production. AI-generated haptics provide a viable solution in industries where scalability, cost-efficiency and consistency are paramount. For instance, managers in the gaming industry can utilize AI to quickly and consistently generate haptic feedback across diverse scenarios, thereby reducing production timelines and costs. Similarly, in VR-based corporate training or educational simulations, AI can expedite the development of tactile feedback, facilitating scalability for widespread application. However, managers should exercise caution in over-relying on AI in scenarios that demand high emotional engagement to enhance the user experience, as these elements are critical in influencing users' intentions to reuse and recommend the experience.

In addition, this research supports and adds to the hybrid approach method when choosing to integrate AI within business operations. A hybrid approach offers the most strategic use of AI in haptic feedback production. Specifically, AI can be employed to handle the more labor-intensive aspects of creating haptic feedback. Human designers can then refine this AI-generated output, adding the necessary depth and emotional resonance for specific applications. This collaboration between AI and human expertise ensures that the final product adheres to high-quality standards without compromising the user experience (Z. Wu et al., 2021).

The broader implications of this research are clear: AI holds the potential to streamline the haptic feedback production process by making it more efficient. Nonetheless, "good enough" AI often does not suffice. Human expertise remains indispensable in crafting high-quality user experiences, especially in contexts that require significant emotional depth and nuance. Therefore, AI should be viewed as a valuable complement to human creativity, not a replacement. Moreover, by leveraging the strengths of both AI and human ingenuity, industries can strike a balance between efficiency and impactful user experiences, fostering innovation that aligns with audience expectations, sustains engagement and enhances satisfaction.

4.4 Recommendations for Future Research

This study acts a stepping stone in understanding the nuances of AI and human-encoded haptic feedback in an immersive cinematic context. We further propose a few key recommendations for future research based on the limitations identified in this research.

Firstly, our study aimed to evaluate and compare the two haptic encoding methods with novices first. Notably, 62% of our participants were novices with no prior experience with haptic-enhanced cinematic experiences. Therefore, their ability to discern differences between the two haptic encoding methods may have been limited. Research suggests that novice users often rely on peripheral cues when evaluating quality, which may have led them to perceive both encoding methods, similarly, potentially overlooking nuanced differences (Halvey & Jose, 2012; Ooms et al., 2014). This could suggest that novices may have been less attuned to the subtleties of haptic feedback that experts would likely detect. As a result, this could further explain the similar self-reported measures of QoE observed in this study.

Therefore, future research could benefit from two options. First, a longitudinal study design could be valuable for investigating whether physiological differences eventually translate into perceived differences over time, as novice users gain familiarity with haptic cinema with repeated exposure (Das & Das, 2017). Additionally, future research could compare groups of participants with varying levels of haptic expertise to provide insights into how different user characteristics influence QoE in immersive contexts.

Furthermore, perceived measures were collected only after viewing each movie clip to capture immediate responses. This might have also affected our findings. Participants may have been assessing experiences retrospectively which could have introduced biases such as memory or recency effects, leading participants to recall an overall emotional state (Barrett, 2024; Marto & Gonçalves, 2022). To counter these potential biases and capture more immediate reactions, future studies should consider using real-time measurements tools like the electroencephalogram (EEG). Tools like the EEG can provide direct assessment of cognitive and emotional states during the haptic experience (Alsuradi et al., 2020; Baumgartner et al., 2006; Lim et al., 2019). Additionally, incorporating more direct measures of physiological responses, such as facial electromyography for assessing emotional valence, could deepen our understanding of how physiological and cognitive states interact to shape user experience.

Finally, due to time constraints, the sample size in this study was relatively small which may limit the generalizability of the findings. Future research could benefit from a larger and more diverse participant pool to enhance the robustness and applicability of the results across different demographics.

4.5 Closing Remarks

In conclusion, this thesis contributes to a growing body of knowledge on the role of AI in haptic media, suggesting that while AI demonstrates substantial promise as a scalable solution, human creativity may still offer irreplaceable value in delivering fully immersive, emotionally rich experiences. As AI continues to evolve, this research serves as a foundation for understanding how human and AI might complement each other in crafting the next generation of immersive content. The insights from this work are poised to inform future advancements in haptic technology, positioning AI not as a replacement but as an enhancer in the realm of user-centered design.

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Appendices

Appendix A: Ethics Approval

HEC MONTRÉAL

Comité d'éthique de la recherche

CERTIFICAT D'APPROBATION ÉTHIQUE

La présente atteste que le projet de recherche décrit ci-dessous a fait l'objet d'une évaluation en matière d'éthique de la recherche avec des êtres humains et qu'il satisfait aux exigences de notre politique en cette matière.

Projet # : 2024-5896

Titre du projet de recherche : Évaluation de l'haptique dans les expériences cinématographiques : Une étude comparative du feedback haptique codé par l'homme et l'IA avec les médias audiovisuels et la cohérence dans l'expérience finale

Chercheur principal : Pierre-Majorique Léger, Professeur titulaire, Technologies de l'information, HEC Montréal
Cochercheurs : Sylvain Sénécal; Constantinos K. Coursaris; Marc Fredette; Frédérique Bouvier; Luis Carlos Castiblanco; Juan Fernandez Shaw; David Brieugne; Xavier Côté; Salima Tazi; Shang Lin Chen; Élise Imbeault; Alexander John Karran; Jared Boasen; Maivel Hany Farhat Abdelnoor

Date d'approbation du projet : 04 avril 2024
Date d'entrée en vigueur du certificat : 04 avril 2024
Date d'échéance du certificat : 01 avril 2025

Maurice Lemelin
Président
CER de HEC Montréal

Signé le 2024-04-08 à 11:57

NAGANO Approbation du projet par le comité d'éthique suite à l'approbation conditionnelle
Comité d'éthique de la recherche - HEC Montréal 2 / 2

HEC MONTRÉAL

Comité d'éthique de la recherche

ATTESTATION D'APPROBATION ÉTHIQUE COMPLÉTÉE

La présente atteste que le projet de recherche décrit ci-dessous a fait l'objet des approbations en matière d'éthique de la recherche avec des êtres humains nécessaires selon les exigences de HEC Montréal.

La période de validité du certificat d'approbation éthique émis pour ce projet est maintenant terminée. Si vous devez reprendre contact avec les participants ou reprendre une collecte de données pour ce projet, la certification éthique doit être réactivée préalablement. Vous devez alors prendre contact avec le secrétariat du CER de HEC Montréal.

Nom de l'étudiant(e) : Maivel Hany Farhat Abdelnoor

Titre du projet supervisé/mémoire/thèse : Evaluating the Quality of Experience (QoE) in Cinematic Experiences: A Comparative Study of AI and Human-Encoded Haptic Feedback with Audiovisual Media

Titre du projet sur le certificat : Évaluation de l'haptique dans les expériences cinématographiques : Une étude comparative du feedback haptique codé par l'homme et l'IA avec les médias audiovisuels et la cohérence dans l'expérience finale

Projet # : 2024-5896

Chercheur principal / directeur de recherche : Pierre-Majorique Léger

Cochercheurs : Sylvain Sénécal; Constantinos K. Coursaris; Marc Fredette; Frédérique Bouvier; Luis Carlos Castiblanco; Juan Fernandez Shaw; David Brieugne; Xavier Côté; Salima Tazi; Shang Lin Chen; Élise Imbeault; Alexander John Karran; Jared Boasen; Maivel Hany Farhat Abdelnoor

Date d'approbation initiale du projet : 04 avril 2024

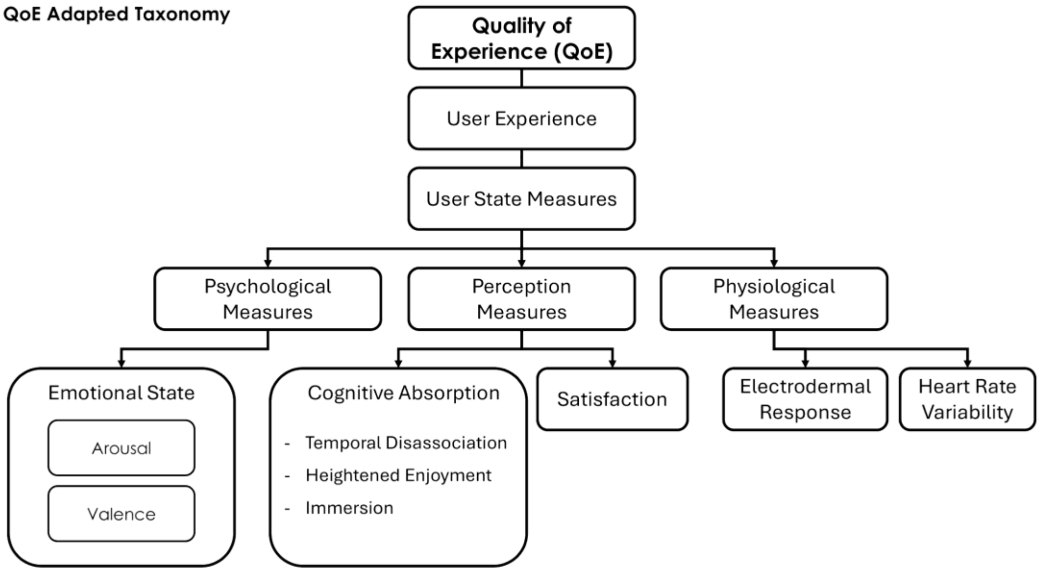
Date de fermeture de l'approbation éthique pour l'étudiant(e) : 04 décembre 2024

Maurice Lemelin
Président
CER de HEC Montréal

Signé le 2024-12-04 à 14:25

Appendix B: QoE Taxonomy

QoE Adapted Taxonomy



- A. Hamam et al.

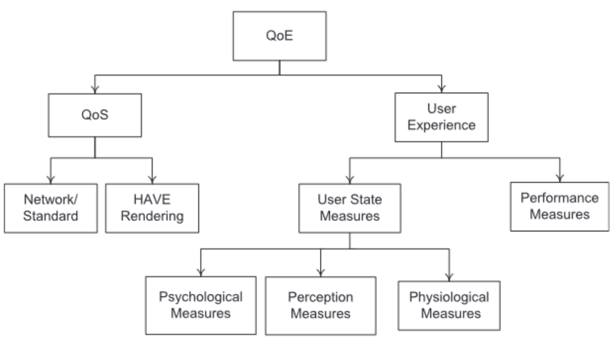


Fig. 1. Higher-level organization of QoE taxonomy.

A Quality of Experience Model for Haptic Virtual Environments • 28:9

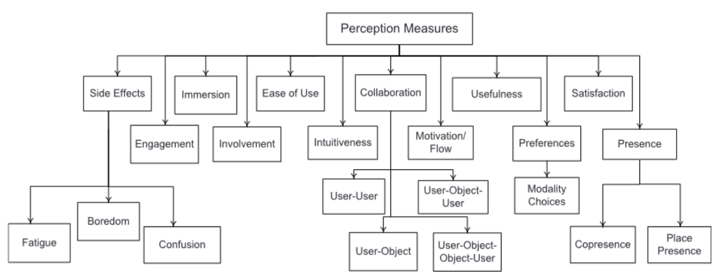


Fig. 3. Parameters of perception measures.

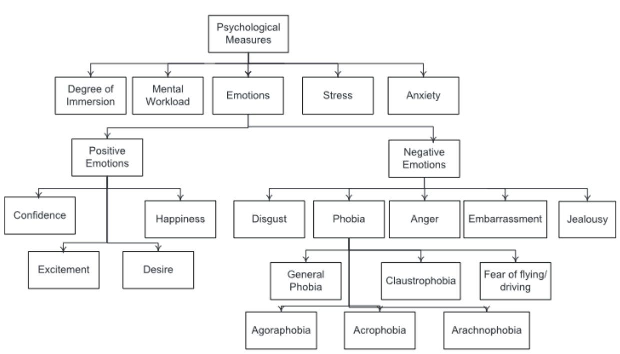


Fig. 4. Parameters of psychological measures.

- A. Hamam et al.

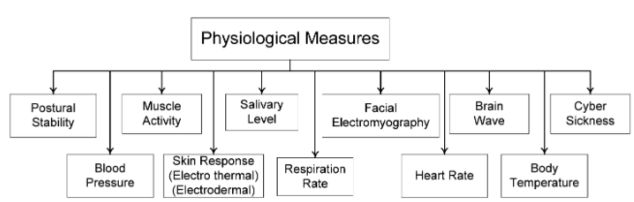


Fig. 5. Parameters of physiological measures.

Appendix C: Randomization of Conditions

Table C1

Randomization of Conditions Table

N	*Participant #*	*Film 1*	*Film 2*	*Film 3*	*Film 4*	*Film 5*	*Film 6*
1	P01	6A	2H	3H	4A	5A	1H
2	P02	6A	1A	5A	3H	4H	2H
3	P03	3H	4H	2A	6A	1A	5H
4	P04	2A	3A	4H	5H	6H	1A
5	P05	4A	5H	6H	1H	2A	3A
6	P06	5A	6H	1H	2H	3A	4A
7	P33	1H	2H	3H	4A	5A	6A
8	P08	3H	4H	5A	6A	1A	2H
9	P09	4H	5H	6A	1A	2A	3H
10	P10	6H	1A	2A	3A	5H	4H
11	P11	5H	6H	1H	2A	3A	4A
12	P12	2H	3A	4A	5A	6H	1H
13	P13	4A	6A	1H	2H	3H	5A
14	P14	6A	1A	2H	3H	4H	5A
15	P15	1A	2A	3H	4H	5H	6A
16	P16	3A	4H	5H	6H	1A	2A
17	P17	4A	5H	6H	1H	2A	3A
18	P32	2H	3A	4A	5AI	6H	1H
19	P19	4A	5A	6A	1H	2H	3H
20	P20	6A	2H	3H	4H	5A	1A
21	P34	3H	4H	5H	6A	1A	2A
22	P22	6H	1A	2A	3A	5H	4H
23	P38	5H	6H	1H	2A	3A	4A
24	P24	2H	3A	4A	5A	1H	6H
25	P35	1H	2H	3H	4A	5A	6A
26	P26	4H	5A	6A	1A	2H	3H
27	P27	5H	6A	1A	2A	3H	4H
28	P36	6H	1A	2A	3A	4H	5H
29	P37	3A	4A	5H	6H	1H	2A

A, AI; H, Human Artist;
Movie Codes: 1: Dune, 2: Guardians of the Galaxy, 3: John Wick, 4: Moana, 5: Love at First Sight, 6: Talk to Me

Appendix D: Qualtrics

Questionnaire Pre-Test

Welcome to Tech3Lab. Please answer the following questions to get to know us better.

1. How often do you watch FILMS on streaming platforms (Disney+, Netflix, Crave, HBO Max, Peacock, tou.tv, etc.)?
    - Each week
    - 1 to 3 times a month
    - 1 time each three-month approximately (must have been excluded)
    - 1 to 3 times a year (must have been excluded)
    - Never (must have been excluded)
2. Which streaming platform do you subscribe to? (*several answers possible*) **Mainly for partner*
    - Crave
    - Disney+
    - Netflix
    - HBO Max
    - Peacock
    - Other
3. What kind(s) of FILMS do you enjoy most in general? (*several answers possible*)
    - Horror (ex.: Saw)
    - Science-fiction (ex.: Dune)
    - Action (ex.: Aquaman and the lost kingdom)
    - Animation/Family (ex.: Wish)
    - Crime/Drame (ex.: Killers of the flower moon)
    - Musical (ex.: Bob Marley: one love)
    - Romance (ex.: Love at first sight)
    - History/Biographies (ex.: Oppenheimer)
    - Adventure (ex.: Indiana Jones and the dial of destiny)
    - Comedy (ex.: Barbie)
    - Anime (ex.: Demon slayer)
4. Who do you usually watch a FILM with at home?
    - Alone
    - As a couple
    - With friends
    - With kids
5. Do you have a home theater, i.e. a room dedicated exclusively to watching films? **Mainly for partner*
    - Yes
    - No
6. How familiar are you with DBOX haptic cinema seats?
    - I don't know or have never tried a DBOX haptic seat.
    - I watch a movie in a DBOX haptic seat once a year or less.

- I watch movies in a DBOX haptic seat about twice a year
- I watch movies in a DBOX haptic seat every three months approximately (must have been excluded)
- I watch each month movies in a DBOX haptic seat (must have been excluded)

Moderator Script Before Testing

"Hello, how are you?

My name is [MODERATOR'S NAME] and I work for the Tech3Lab at HEC Montréal. I will be your moderator during this experiment.

Today, you'll be watching six movie clips from a variety of genres, including science fiction, comedy, action, horror, and more. For these viewings, you'll be using a haptic chair. Before we start, the instructions for the study will be displayed on the tablet next to you, with each movie representing a different task. You'll need to fill out some questionnaires before the experiment begins, between tasks, and at the end.

Lastly, I'll return here to ask you a few questions. Before I leave, I want you to know that there are no right or wrong answers—only your opinions matter, so please feel free to answer the questions honestly and naturally.

If you have any questions before we begin a task, don't hesitate to ask.

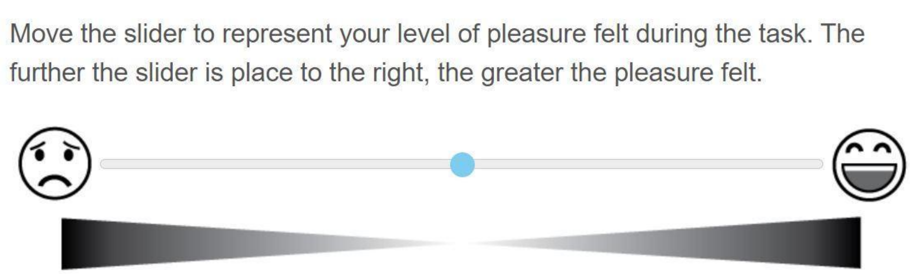
My colleague [Research Assistant] will take over on the microphone and guide you through the next steps."

Questionnaire post-task (after each clip watched)

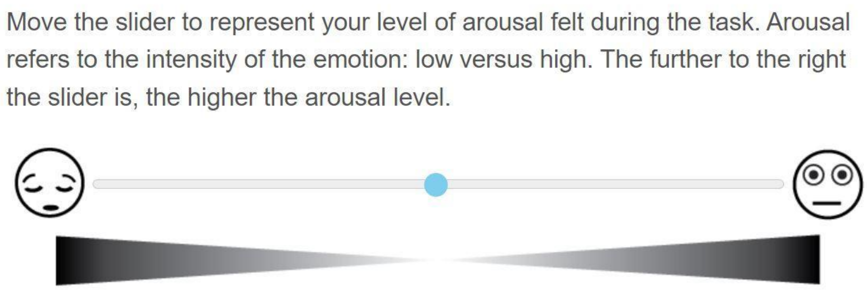
Please answer the following questions considering only the last movie clip you just saw.

Have you already seen the film from which the clip is taken? (yes / no)

1. Perceived Valence (affective slider)



2. Perceived Arousal (affective slider)



3. Focused Immersion (Cognitive absorption scale)
   Please rate your level of agreement with the following statements.
   - While watching the movie clip, I was able to block out most other distractions.
   - While watching the movie clip. I was absorbed in what I was doing.
   - While watching the movie clip. I was immersed in the task I was performing.
   - When watching the movie clip, I got distracted by other attentions very easily.
   - While watching the movie clip, my attention did not get diverted very easily.
4. Heightened Enjoyment (Cognitive absorption scale)
   Please rate your level of agreement with the following statements.
   - I had fun watching the movie clip.
   - Watching the movie clip provided me with a lot of enjoyment.
   - I enjoyed watching the movie clip.
   - Watching the movie clip bored me.
5. Temporal Dissociation (from Cognitive Absorption)
   Please rate your level of agreement with the following statements.
   - Time appeared to go by very quickly when I watched the movie clip.
   - Sometimes I lost track of time when I watched the movie clip.
   - Times flew when I watched the movie clip.
6. Are you satisfied with your overall experience while watching this movie clip? (*on a scale from 1-7, 1 being extremely dissatisfied and 7 being extremely satisfied*)
7. Based on the last clip you just saw, how likely is it that you'll decide to relive that haptic experience with this kind of film?
8. Based on the last movie clip you saw, how likely is it that you would recommend this experience to a friend, a colleague, or a member of your family? (*on a scale from 0-10*)

Questionnaire Post Last Task (after the last clip watched only: balance conditions 50/50)

1. To what extent do you agree or disagree with the following statements? Please consider only the last movie clip you just watched, and answer on a scale of 1 to 7, where 1 means Totally Disagree and 7 means Totally Agree.

   - Seat movements and vibrations correspond in real time to the action observed on screen (movements, camera movements, sounds, music, etc.). *(Persicion of the haptic feedback*)

- Seat movements and vibrations occur just when I was expecting them. *(Relevance of the haptic feedback*)
- Seat movements and vibrations seemed natural and in harmony with the context of the film. (*Relevance of the haptic feedback*)
- The intensity of the seat movements and vibrations accurately reproduces what I would normally feel in the context of this scene. (*Relevance of the haptic feedback*)

2. Move the slider to rate how you perceived the intensity of the seat movements and vibrations in the context of this specific movie clip.
    1. Slider : to the left - **Insufficient**, in the middle - **Adequate**, and to the right - **Excessive**.

Questionnaire Post-Test

1. There are two techniques for encoding appropriate and relevant movements and vibrations to enrich the viewing experience of a film. One technique involves a human artist, while the other uses artificial intelligence. Which technique do you think delivers a better result?
    - I think human encoding is better.
    - I think AI encoding is better.

1. For each movie clip you saw today, please indicate if you think the encoding was done ny a human artist or with AI.

(Screen capture for each clip: the participant ticks whether they think the clip has been encoded by a human or by AI).

Interview Guide

"Hi, I'd now like to discuss with you the experience you had while watching the movie clips with the haptic chair.

(Record with the iPad)

1. Can you briefly describe your overall experience with the haptic chair during the viewing of the movie clips?
2. Did you notice any variations in the quality of the haptic feedback, such as movements and vibrations, between different clips?
3. In your opinion, which clip was the most successful in terms of haptic feedback and why?
4. In your opinion, which clip was the least successful in terms of haptic feedback? Why?
5. Generally, after your experience today, would you be interested in watching movies in a haptic chair again? Why or why not?
6. Now, considering only the least successful clip, would your answer to the previous question be the same? (If not, why?)

7. When you were answering questions on the tablet, we asked you about the haptic encoding performed by humans and by artificial intelligence. Which did you consider to be better and why?
8. Are there any other aspects of the experience that we haven't covered that you would like to discuss?