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Negative emotions and gender shape learning gain within a multisensory immersive embodied mixed reality experience using MetaQuest3 to teach brain anatomy

Leila Ali [1,2], Lia Daniela Sasanelli[1], Maria Sarno[3], Clarissa Lella[1,4], Raffaele Di Fuccio[1]

[1] University of Pegaso; liadaniela.sasanelli@unipegaso.it; raffaele.difuccio@unipegaso.it
[2] University of Camerino, School of advanced studies; leila.ali@unicam.it
[3] University of Campania Luigi Vanvitelli; maria.sarno@unicampania.it
[4] Smarted SRL, Naples, Italy; clarissa.lella@unipegaso.it
* Correspondence: leila.ali@unicam.it

Abstract: Emotions can be embodied and externalized through physical gestures and have a role in associative learning. Emerging mixed reality (MR) solutions offer new embodiment states influencing emotions. This study aims through an-MR-brain-anatomy-game, to assess how virtual embodiment shapes emotional patterns and learning gain and how the emotion-learning dynamics (ELD) differ between men (M) and women (W). A brain anatomy lesson was designed using simulation and gamification combined to a 3D virtual brain model accessible with Meta Quest 3 through an embodied avatar. Experiments were performed with Doctoral and Masters' students from the universities of Pegaso and Frederico II in Naples from March 2025 till April 2025. Evaluation included a pre and posttest assessment and emotional report through the Geneva emotions Wheel. Statistical analysis was performed with Python 3.12.9 and significance threshold was set at $P < 0.05$. 17 students participated in the study with a predominance of W 70% and a mean age of 27,2. Emotions were affected by gender and education; with interest and love more common in W, and pride in doctoral neuroscience students $p < 0.05$. Emotional co-occurrence patterns in opposite valences in W were balanced and more positive, while for M they were more compartmentalized and negative. Emotions were principally positive after MR. Yet, learning gain was rather linked to negative emotions. ELD also differed by gender and followed opposite directions for some emotions. Emotions in MR learning have more tendency towards positive valences. Yet, this does not ensure the occurrence of a learning gain that can be influenced by education, and gender that shape the ELD.

Keywords: Embodiment, emotion-learning dynamics, gender, mixed reality, anatomy education

1. Introduction

Emotions do not only shape social behavior (Semin & Smith, 2008) but also help people interact and adapt to the environment through associative learning (Hasford et al., 2018). Often embodied, they can be internalized as thoughts or externalized through physical expressions (Semin & Smith, 2008). They have different valences, intensities and types. Emotions often co-occur and are rarely isolated: despite the different neural structures activated for various emotions, an overlap can be observed in certain brain regions for different emotions that can even have opposite valances (Ali et al., 2024). Emerging multisensory immersive MR approaches in anatomy education used embodiment to increase motivation and positive emotions through serious games to facilitate spatial learning (Aasekjær et al., 2023). Few studies have considered humans' diversity in terms of emotional patterns and how this affects their cognitive performance. The use of hands facilitates the 3D kinematic exploration of objects in the space and thus reduces the required workload of 3-dimensional spatial memory (Aivar et al., 2024). This revolutionary approach available in the Meta Quest 3 headsets allows people to experience a haptic embodiment in the virtual spaces and use bimanual virtual motor learning to explore autonomously virtual objects in MR environments. Within this perspective our study focused on how this innovative multisensory immersive MR experience can shape the emotion-learning dynamics of a brain anatomy lesson through the use of embodied virtual hands. And how demographics and prior exposure to VR can shape these dynamics.

2. Materials and Methods

Technological material and design of the educational game

The new Meta Quest 3 headset was used without the hand controllers for its virtual embodied manual features. The use of an embodied avatar allows the adaptation of real hand movements to the virtual hands and the motor bi-manual manipulation of virtual objects in space. The Thinglink application was used to create the learning experience and allow the manipulation of the 3D Virtual brain while accessing multimedia additional resources. The 3D virtual brain model was downloaded from a free available source of the University of Dundee, CAHID and BodyParts3D, The Database Center for Life Science. The design used a theory driven and evidence based serious game framework for healthcare education (Verschueren et al., 2019). The topic was about the neurofunctional anatomy of motor control. The lesson duration was 15 minutes with a linear storytelling format combining gamification features to each learning mechanic (Arnab et al., 2015). Instructions were used to guide learning and reduce indecision and distraction. The used technologies strengths and limitations were considered in the pedagogical design and trial tests helped identify and fix technical bugs.

Participants

The lesson was designed for health sciences students (medicine, neuroscience and psychology, rehabilitation) who need in their courses to learn about brain anatomy. Students participated voluntarily in the experiments and were principally recruited from doctoral and masters' programs of the Universities of Pegaso and Frederico II in Naples from March 2025 to April 2025. Invitations were communicated by email, and through posters shared in the halls of their home institutions. A quiet room was used to allow maximum immersive embodiment without external sensory distractions. Participants were trained in advance on how to use the virtual hands in the virtual space and technical assistance was available all along the intervention.

Assessment tools

Pre and post knowledge assessment tests were used to evaluate students' learning performance. The tests consisted of 8 multiple choice questions that were relevant to the content of the lesson and were targeted towards analyzing learning gain about brain regions spatial information and their principal functions.

Emotions were evaluated using the Geneva emotions wheel (Scherer, 2005) that consists of 20 felt emotions of different valences and intensities. Participants were asked to report their felt emotions at the end of the experiment and were asked to describe what they felt during the intervention.

Statistical analysis

Statistical analysis was performed using Python 3.12.9. Quantitative variables were analyzed through descriptive statistics. Normality tests were used to assess the distribution of age and knowledge tests scores. Comparative analysis relied on an independent t-test to analyze the role of gender and prior VR exposure on emotional patterns and a paired-sample t-test to compare pre and post-test with a significance threshold of $p < 0.05$. One-Way ANOVA was used to compare across multiple educational backgrounds with a statistical significance set at $p < 0.05$. Multivariate regression (MANOVA) was used to assess the impact of age on emotional patterns. Correlation analysis was performed to assess the relationships between demographics, emotions and learning gain: Pairwise Pearson correlation coefficients were calculated in the women and men group to study the emotional co-occurrence among participants with $|r| \geq 0.5$ indicating moderate to strong association. A scatter plot analysis with a regression line was performed to analyze how the intensity of the emotions reported by participants affect learning gain through the pre and post-test assessments.

3. Results

Demographics and educational background

17 students participated among whom 3 were doctoral neuroscience students, 1 was a medical student and 13 were psychology students. The mean age was 27.2 [min 23; max 31; STD 2.69]. 70% of the participants were women and only 5 were men. 53% have previously used VR and 47% did not.

Emotional patterns in an embodied MR experience to learn brain anatomy:

The principal reported emotions for each participant are summarized in the heatmap and radar chart showing a predominance of positive emotions with different degrees of intensity and a maximum average intensity reported for interest, amusement, and pleasure. And to a second degree, contentment, admiration, joy, pride and love (figure 1). Age did not influence the emotional patterns nor did prior exposure to VR. Gender seemed to affect the representation of some emotions, specifically interest p= 0,038 and love p= 0.01 that were more statistically significant in women than men. Pride was more statistically significant p= 0.017 in the group of neuroscience students with a mean of 3.7. The correlation analysis reveals distinct emotional co-occurrence patterns for men and women. While women had a balanced emotional co-occurrence distribution pattern between positive and negative emotions with moderate correlations between both domains, men displayed a more compartmentalized emotional experience with a higher clustering intensity of co-occurrence of negative emotions (figure 2). Women had strong emotions co-occurrence for positive emotions such as joy, admiration, and contentment as well as negative emotions such as anger, contempt, and regret. On the other hand, men had a stronger co-occurrence and intensity of negative emotions such as hate, fear, disappointment and guilt, and to a lesser degree of positive emotions such as amusement, pleasure and contentment (figure 2). A specific correlation feature was observed for compassion that despite being classified as a positive emotion was in both genders more associated with negative emotions (figure 2).

Figure 1. Emotions during the MR experience reported by all participants from the Geneva emotion wheel assessment: Average intensity (left), distribution by participant and by intensity (right)

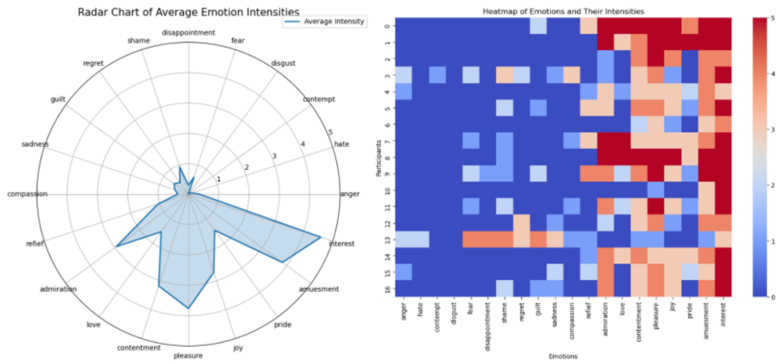
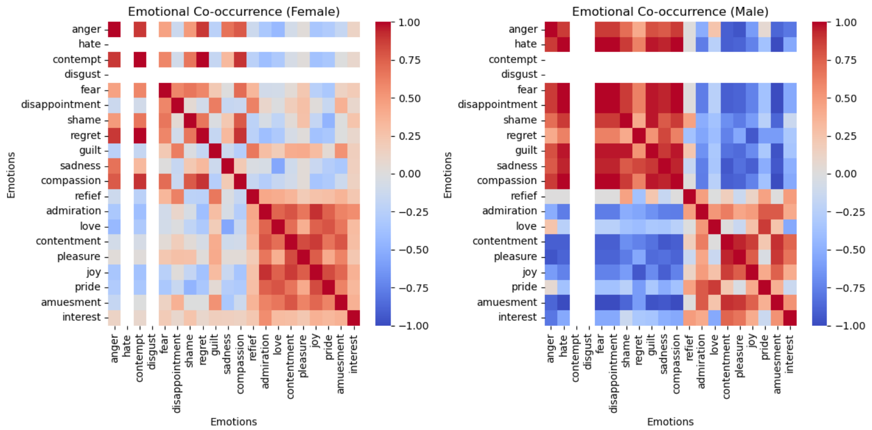


Figure 2. Correlation heatmaps for emotions co-occurrence for women (left) and men (right)



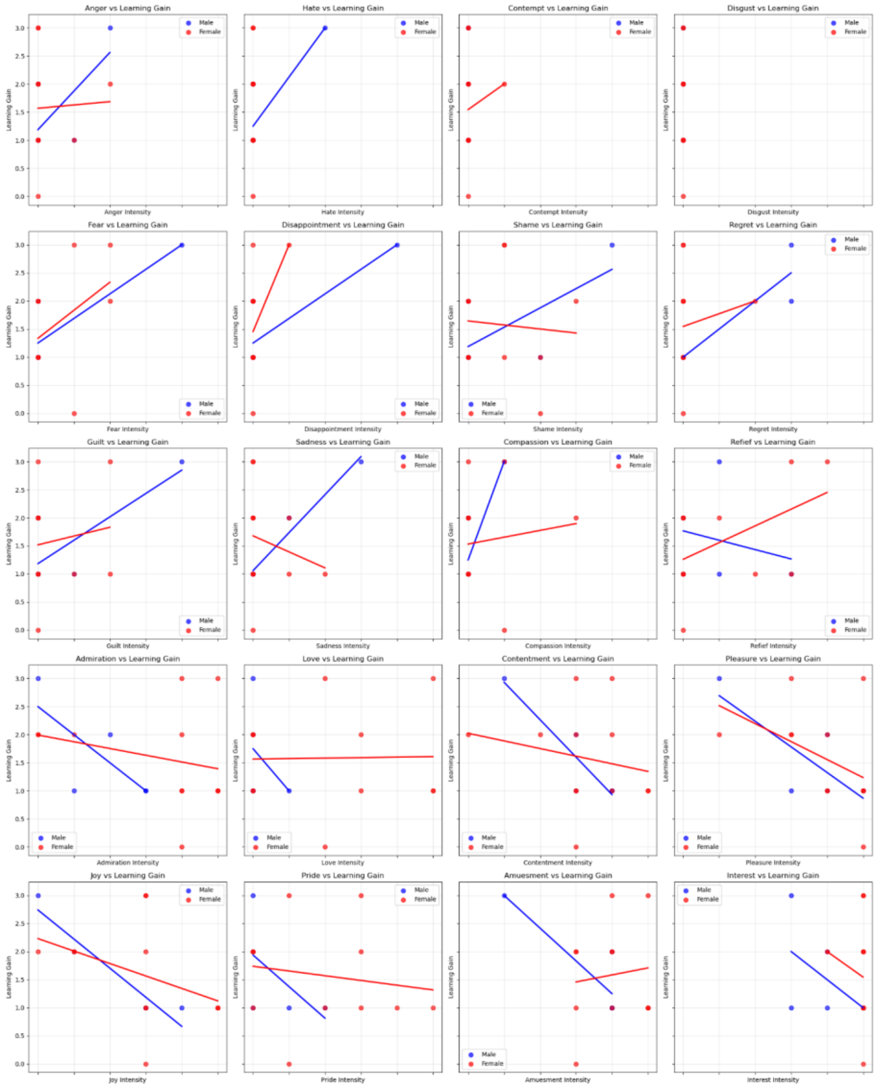
The role of demographics in learning gain and the emotional-learning dynamics

Learning gain was assessed through pre and post knowledge assessment tests. The mean value of pretest scores was 2.64 [min 0 max 5 std 1.58], for the post-test 4.23 [min 2 max 7 std 1.56]. The difference between the pre and post test scores was statistically significant P=0.000 indicating a general overall positive benefit of the learning experience.

- *How emotional patterns shape learning gain*

A scatter plot analysis with a regression line was performed to analyze how the intensity of the emotions reported by participants impact learning gain through the pre and post knowledge assessment tests. Figure 3 shows that learning gain was principally improved by negative emotions rather than positive emotions. Positive emotions also reduced learning gain (figure 3). The only positive emotions with positive learning gain were contentment, relief and compassion (figure3). Gender differences were observed in learning gain relationship with the intensity and nature of emotions that sometimes-had contradictory effects on learning: Positive emotions like amusement, relief and love reduced learning gain for men compared to women, while negative emotions like sadness and shame were associated to better learning gain for men compared to women (figure 3). The intensity of certain emotions seemed also to impact learning gain while anger, regret and guilt were associated with better learning gain for men, disappointment was associated with better learning gain for women (figure 3).

Figure 3. Gender differences in learning gain according to the experienced emotion



4. Discussion

MR technologies are different from virtual reality by their combination of virtual and real-life sensory stimuli (Ali et al., 2024). In MR environments, immersion differs from embodiment by the presence of at least one of three levels of virtual embodiment: virtual body part ownership, agency, and presence (Gall et al., 2021). While body ownership and presence can be perceived in static and kinematic states, agency is often kinematic (Crone & Kallen, 2024). Embodiment can increase the intensity of emotions both of positive and negative valences (Gall et al., 2021). The discussion in this study will focus on the role of demographics in shaping emotional responses in virtual embodied multisensory kinematic MR experiences, and the gender differences in emotion-learning dynamics.

Demographics and emotional patterns

This study did not show and impact of age on emotional patterns. Age differences were found in multisensory bodily experiences after using VR in young and middle-aged adults (Serino et al., 2018), and in emotional responses within immersive VR experiences that were more intense in older adults compared to younger adults in immersive compared to non-immersive experiences (Pavic et al., 2024). The absence of differences could be explained by the fact that only younger adults were included. Prior exposure to VR was reported to produce positive pleasant emotions and even improve task performance (Kourtesis et al., 2021). Such results were not identified in this study and this could be due to the low number of participants and the novelty factor in the new MR experience that required using bi-manual embodied virtual hands. That could generate technical difficulties of adjusting the virtual hand movements to the real hand and the limitations of the virtual hand performance in terms of timing, precision, and available virtual space. Neuroscience doctoral students had a statistically significant feeling of pride p= 0.017, compared to other students. The role of the embodied VR experience in stimulating this type of emotions could also be linked to the fact that pride is innate and embodied compared to other emotions (Tracy & Matsumoto, 2008). Weiner also reported that pride lies often within the self-directed emotions category of the intrapersonal theory that often shape the scientist's personality compared to anger and sympathy that are more directed towards interpersonal traits that can be observed in judges (Weiner, 2000).

- *Emotional patterns and gender differences*

An overall predominance of positive emotions was observed after the intervention. Similar results were reported in literature showing that MR experiences do not only stimulate positive emotions through haptics based multisensory immersion and gamification (Ali et al., 2024), but can also intensify both positive and negative emotions through embodiment (Gall et al., 2021). This learning intervention combined three levels of virtual embodiment: virtual body part ownership (hands), agency, and presence. Aske et al have shown that body ownership illusions and emotions influence each other with a predominant role of positive emotions is shaping virtual body ownership (Mottelson & Hornbæk, 2020). Fear, joy and empathy could also be stimulated through VR embodied experiences based on agency and presence features compared to passive immersive observations (Linares-Vargas & Cieza-Mostacero, 2024).

Gender seemed to affect the representation of some emotions, specifically interest p= 0,038 and love p= 0.01 that were more statistically significant in women. Zamir et al also reported gender differences in learning science with women's tendency to experience positive emotions more than men (Zamir et al., 2023). Correlation analysis revealed distinct emotional co-occurrence patterns for both genders in this study; while women, had a more cohesive emotional experience with stronger correlations among positive emotions joy, admiration, and contentment), as well as negative emotions (anger, contempt, and regret), men exhibited compartmentalized emotional co-occurrence patterns with stronger correlations with negative emotions (hate, fear, disappointment and guilt). Zamir et al have also reported gender differences in emotional dynamics in math learning with women being more prone to display positive emotions compared to men who have bigger tendencies to display negative deactivating emotions that may reduce learning motivation and engagement (Zamir et al., 2023). Gender differences in embodied emotions showed that both embodied positive and negative emotions like sadness and anxiety are linked to higher interoceptive sensitivity in women while externalized emotions such as anger are more common in men (Prentice et al., 2022). This could inform future tailored gender-based interventions or studies in emotional and psychological research.

Emotion-learning dynamics in embodied multisensory immersive MR

A statistically significant P=0.000 learning gain was found between the pre and posttest assessment, indicating a general overall benefit of the learning experience. In previous studies, using VR to teach anatomy improved learning gain through enhancing spatial conceptual knowledge, situated learning (Aasekjær et al., 2023), motivation, and entertainment (Aasekjær et al., 2023). Other positive activating emotions such as pride, hope and joy were also reported to stimulate science learning (Zamir et al., 2023). Despite the predominance of positive emotions after this MR experiment, the learning gain was improved principally by negative emotions such as anger, hate, contempt, fear, disappointment, regret and guilt. Only contentment, relief and compassion were associated to a learning gain in the positive valence emotions category. Zamir et al analysis of emotional valences and functions stated that also negative emotions like anxiety, anger and shame can stimulate learning science by stimulating resilience through repeated learning and motivation to avoid failure (Zamir et al., 2023). Klingenberg et al have found that VR embodiment despite increasing emotions intensity did not increase learning transfer (Klingenberg et al., 2024). Instructional design and content (Aasekjær et al., 2023), and other personal behavioral, cognitive, and emotional conditions could interfere with learning gain in VR (Dubovi, 2022). Striking gender differences with opposite emotion-learning dynamics were found in this study: positive emotions like amusement, relief and love reduced learning gain for men, while negative emotions like sadness and shame improved learning gain, and the opposite was observed for women. Shame presumably a negative emotion is reported as a learning activating emotion (Zamir et al., 2023). Intensity of certain emotions seemed also to impact learning gain differently in men and women; while anger, regret and guilt were associated with better learning gain for men, disappointment was associated with better learning gain for women. Different results have been observed in previous studies for anger having an activating learning function with no gender specificities (Van Doorn et al., 2014), and regret stimulating learning in engineering female students while reducing it in males (Johnson et al., 2021). Gendered emotional constructs can interfere with emotional patterns and their social representation: Ingleton showed how they interfere with women's learning behavior in academia who center pride and shame beliefs about themselves (Ingleton, 1995). On the other hand, men are culturally educated to suppress emotions of shame, disappointment and vulnerability, resulting in more emotional detachment, reducing struggle with competitiveness, and increasing aggressive emotions and behaviors (Ingleton, 1995).

5. Conclusions

Emotions in the virtual space can be embodied, intensified, externalized and even changed by the multisensory immersive experience. A predominance of positive emotions after the MR learning intervention did not ensure the occurrence of a learning gain. Learning gain seems to rely, not only, on pedagogical designs and technological facilities, but also on predisposition personal and socio-cultural factors that interfere with the emotion-learning dynamics. Some of these factors are the professional background, and gender. The role of a scientist seems to trigger internalized emotions, and gender influences emotional co-occurrence patterns driving sometimes emotion-learning dynamics in opposite directions for men and women.

6. Limitations and future perspectives

A limitation of this study is the small number, especially men. Another limitation could be the lack of emotional assessment information before and during the intervention that could have helped to clarify if the gender differences were linked to inner personality traits or if they were rather triggered and/or intensified by the virtual multisensory embodiment. Future studies should have a more holistic and dynamic approach in analyzing emotions: aside from their co-occurrence, intensity and valence and how the design and technologies can induce them, analyzing their impact on learning through embodiment, their learning activation/deactivation/neutral properties, gender-based and socio-cultural differences seems necessary.

Conflicts of Interest None

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