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From immersion to donation: neurophysiological evidences on AR/VR museum experiences in Italy and the United States

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Introduction

The COVID-19 pandemic has been a turning point for museums and cultural institutions. During this period, in-person visits were suspended, and digital access to cultural content consequently became more important (Radermecker, 2021; UNESCO, 2020). In this scenario, the cultural sector sought and found support through technology, using it to experiment with new formats to maintain its relationship with the public and identify more sustainable models (Agostino, 2024; Marras, 2021).

Subsequently, in the post-COVID period, the adoption of innovative technological tools has not ceased but has acted as a catalyst for the adoption of new means and modes of access. In this regard, the Museum Innovation Barometer 2021 highlighted how the pandemic fostered digital transformation in museums, including the introduction of immersive technologies such as augmented reality (AR) and virtual reality (VR). Currently, therefore, these solutions have proven to be relevant even beyond the emergency phase (Giannini & Bowen, 2022).

This change has given rise to the need to explore the gap between the potential of these technologies and their full integration into museum practices. Therefore, the need has recently emerged to investigate how technologies such as AR and VR can transform the visitor experience and its outcomes. In this new perspective, AR and VR are increasingly considered strategic levers for renewing the museum visit. Recent literature suggests that they can have a potentially transformative impact on the visitor experience, promoting immersion and enhancing engagement (Benghadbane et al., 2025).

In addition to the experiential dimension, however, there is an interesting aspect that has yet to be fully explored, namely how these technologies could generate significant economic benefits for the cultural sector. Some studies, for example, suggest that AR can increase perceived quality and willingness to pay (He et al., 2018) and create favorable conditions for financial support and donations (Joshi, 2018). Similarly, VR experiences have been shown to strengthen engagement and empathy, with possible positive effects on prosocial behaviors and donations in fundraising contexts (Kristofferson et al., 2022).

The scientific literature has therefore identified significant potential in the implementation of these new technologies. In many contexts, museums are encouraged to diversify their sources of income, including private support for culture, which is often limited or uneven (Bertacchini et al., 2011; Srakar & Čopič, 2012).

Despite growing interest in AR/VR, at least two major gaps emerge. First, it is worth noting that active engagement is central to economic sustainability, as it can lead to greater motivation to support the institution, for example through donations (Joshi, 2018). In this area, there are still relatively few studies, often with differing results, that can solidly demonstrate the ability of AR and VR to increase engagement in ways that translate into prosocial behavioral outcomes. Second, most research in the museum field has analyzed immersion and engagement mainly through self-report tools (such as interviews and post-visit questionnaires), which may be subject to memory bias and response distortions (Dufresne-Tassé et al., 2022; Jangra et al., 2025; Lee et al., 2019; Zak & Barraza, 2018). For this reason, the use of neuromarketing and consumer neuroscience tools, such as neurophysiological and autonomic measures, can offer a new and more comprehensive perspective, capable of capturing implicit processes and dynamics of the experience that are not always easily verbalized (Circi, 2023).

In light of these gaps in the scientific literature, this study investigates how the introduction of AR and VR in the museum context can produce differences in visitors' donation behavior at both the neurophysiological and behavioral levels. In particular, this is the first study in the museum field to use the neurophysiological tool of Immersion Neuroscience developed by Paul J. Zak. This approach conceptualizes immersion as the neural value of experience, resulting from two joint components (attention and emotion) measured through peripheral signals based on PPG and processed by computational algorithms (Merritt & Zak, 2024; Zak & Barraza, 2018). This tool is particularly important in this field because it overcomes the exclusive reliance on retrospective measures and self-reports, providing a theoretically grounded and continuous indicator of the experience. Furthermore, some studies show that the Immersion measure is able to estimate levels of engagement and predict the outcomes of subsequent behaviors (Lin et al., 2022; Zak & Barraza, 2018).

Finally, since cultural norms and models of economic support for museums can vary significantly between countries, this study explores whether a different culture can translate into different behavioral outcomes in terms of donations, despite a similar museum experience that implements AR and VR. Therefore, a final fundamental aspect investigated in this study is an innovative comparison between an Italian and an American sample using neurophysiological tools, questionnaires, and behavioral observations.

In summary, this study proposes new evidence on the phenomenon of the use of VR and AR in museums, through a cross-cultural lens and adopting both traditional and innovative tools from the field of neuromarketing. The final goal is to identify any effects on visitor donation behavior.

Chapter 1: Cultural economics: museums, donations and new technologies

Cultural economics is the field of study that applies economic thinking and tools to the arts and cultural institutions. It is not limited to financial aspects such as costs and subsidies, but uses an economic model of human behavior to understand the social dimensions of culture as well (Frey & Meier, 2006).

From this perspective, museums are not only places of symbolic value production but also organizations subject to institutional constraints and incentives (Frey & Meier, 2006). In this field, museum environments are analyzed through a lens that connects the behavior of individuals (visitors and non-visitors) and institutions (organizational forms, rules, traditions, and decision-making structures), adopting a model in which choices depend primarily on constraints (income, prices, time, institutions) rather than preferences that are difficult to measure separately (Frey & Meier, 2006). Museums have a particular cost structure. In fact, they have to bear very high fixed costs (building, collection, staff, insurance), while the cost of welcoming an additional visitor is almost zero. Furthermore, they often have to deal with expenses related to collections and museum spaces (Frey & Meier, 2006).

Museum economics distinguishes between private demand (visits influenced, among other things, by admission prices, opportunity costs of time, income, and alternative prices) and social demand, linked to non-use benefits, which justify the existence of forms of public and non-market support (Frey & Meier, 2006). In this context, the institutional configuration (public museum, private non-profit museum, or hybrid combinations) strongly influences management incentives: in public museums, for example, any surplus may reduce future transfers (a sort of 'implicit 100% tax'), while in private or more autonomous museums, there is growing pressure to generate revenue through ticket sales, ancillary services, and fundraising (Frey & Meier, 2006).

Donations in the field of cultural economics represent a form of financing closely linked to both the non-profit structure and inter-institutional competition for resources. In particular, donations are favored by the non-profit structure because donors prefer organizations where profit distribution is limited and therefore there is less risk of exploitation of the donor by managers (Frey & Meier, 2006).

On the one hand, museums must appear needy in order to attract contributions, and this can reduce the incentive to implement differentiated pricing strategies or to increase profits. The donors, however, can exercise forms of control over the institution, interfering in programming or imposing restrictions on donated collections, with direct effects on management (e.g., limiting or preventing the sale of donated works and thus imposing high opportunity costs) (Frey & Meier, 2006).

Importantly, donations are not neutral. A typical case concerns the sale of artworks. Donors tend to prevent the disposal of donated objects, which makes it more difficult for museums to manage their collections according to market logic, while also generating significant opportunity costs (Frey & Meier, 2006).

From a managerial perspective, the relationship between the museum and the donor therefore requires balance. On the one hand, philanthropists are essential resources for preserving and disseminating cultural heritage. On the other hand, the museum must maintain its independence and remain consistent with its scientific and social mission, building relationships based on trust and mutual respect (Babic, 2024).

Regarding monetary donations, recent literature emphasizes the importance of developing ethical and transparent fundraising practices. The reputation of the institution is crucial: a discredited museum is unlikely to be able to create partnerships and raise funds. Donors prefer to support museums that are reliable and perceived as consistent with clear values (Babic, 2024). In particular, transparency about expenses and fundraising goals increases trust and willingness to donate (Babic, 2024). Furthermore, the introduction of new technologies in museums is having a growing impact on donations (Babic, 2024).

Immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR) are becoming increasingly common tools in museums and are considered relevant for innovating the cultural experience. Recent literature highlights that VR and AR have a potentially transformative impact on the visitor experience, helping to make museums more dynamic and attractive, thanks in part to their growing use in internationally renowned institutions such as the British Museum, the Prado Museum, and the Vatican Museums (Benghadbane et al., 2025). The use of VR/AR can have a positive and statistically significant effect on aspects of the visit such as immersion (Benghadbane et al., 2025). AR and VR can also support the competitive capacity of museums, strengthening public engagement and promoting interest in visiting (Benghadbane et al., 2025).

Immersive technologies in museums can have positive economic effects on visitor behavior. In particular, AR can increase the perceived quality of the visit and lead to a greater willingness to pay more (He et al., 2018). Furthermore, AR can act as a tool to increase active user engagement, creating favorable conditions for financial support and donations (Joshi, 2018). Similarly, the implementation of VR experiences can strengthen engagement and empathy, helping to increase donations collected during fundraising campaigns (Kristofferson et al., 2022).

In this context, museum management is gradually moving towards greater diversification of business and sources of income, including donations. The introduction of immersive technologies such as AR and VR represents a strategic lever for innovating the cultural experience and increasing the attractiveness and competitiveness of museums (Benghadbane et al., 2025).

1.1 Donations in the cultural field

In the cultural sector, the share of private donations tends to be relatively limited compared to other non-profit areas. A review dedicated to donations for culture and heritage highlights how cultural organizations receive only a small proportion of total private investment, as donors tend to favor causes perceived as related to basic needs rather than cultural assets or

heritage (Bertacchini et al., 2011). Furthermore, a further explanation for this phenomenon is highlighted, namely that cultural institutions, having historically benefited from significant public support, may be perceived as the responsibility of the state rather than private donors (DCMS, 2005; Mermiri, 2011). In line with this interpretation, the international comparison proposed in the review reveals a significant structural difference: while in the United States public funding for cultural organizations is low and often politically controversial, in continental Europe culture is mainly funded by the state and private donations are much rarer (Srakar & Čopič, 2012). This framework makes the role of philanthropy in the European cultural sector particularly critical, not least because, as Bekkers (2022) points out, research on philanthropy in Europe suffers from a lack of comprehensive and reliable data, which limits the possibility of measuring its size and composition in a systematic and comparable way.

Further evidence reinforces this view, showing that private support for the cultural sector tends to be not only limited but also structurally vulnerable. First, donations in this area are often a second choice compared to other non-profit sectors. In fact, Bertacchini et al. (2011) observe that culture occupies a marginal position among donors' priorities and report estimates that only a small proportion of global private philanthropy is directed towards culture. These values are similarly low in contexts such as the United States and Italy, where sectors related to basic needs (e.g., health, religion, human services) are prioritized (Bertacchini et al., 2011).

The idea that increased private investment can compensate for public cuts appears problematic. For example, in the European context, Srakar and Čopič (2012) point out that during economic crises, reductions in public funds tend to be accompanied by a reduction in private resources as well, making diversification of sources less effective as a response to the contraction of state support.

Furthermore, UK data reported by Mermiri (2011) show that private investment in the cultural sector is also highly unevenly distributed. In fact, a significant proportion of organizations receive no income from private sources, and flows are concentrated in large institutions and specific geographical areas, such as London (Mermiri, 2011).

1.2 Donations in the cultural sector in Italy

The critical issue in the donation sector mentioned above is particularly evident in Italy, where donations tend to favor causes perceived as more urgent than artistic and cultural support. For example, in an article on donation trends in Italy, Atlantis Company (2022) highlights how the most supported causes are related to issues such as health emergencies, medical research, and social assistance in the fight against poverty, while culture ranks last. Even in the fourth annual report ‘Noi doniamo’ (We donate) published by the Istituto Italiano delle Donazioni (2023), the preservation of artistic heritage is one of the causes least cited by informal donors (6% in 2022), compared to other areas such as medical research (43%) and the fight against poverty (18%) (Italian Institute of Donations, 2023). In addition, cultural organizations are paying increasing attention to fundraising, partly due to the need to review their economic

sustainability models, given the critical events of recent years, particularly wars and health conditions (Istituto Italiano delle Donazioni, 2023).

In summary, private donations in the cultural sector remain limited and marginal because donors favor causes perceived as more urgent (health, poverty, assistance). In Europe, moreover, culture has historically been funded by the state. Therefore, it is seen less as the responsibility of private individuals. Private support is also fragile and uneven. In fact, it decreases during crises and is concentrated mainly in large institutions and in few areas. In Italy, too, culture is among the least supported causes, prompting cultural organizations to strengthen their fundraising efforts to ensure greater sustainability.

1.3 Donations in the cultural sector in United States

In the U.S. context, private donations are often regarded as virtuous within the culture of giving. The arts and culture sector, on the other hand, appears to be marked by a combination of cyclical vulnerability (in times of crisis) and structural fragility (due to a dependence on private donations that are distributed unevenly and concentrated in certain areas), with particularly critical consequences for small and medium-sized organizations (Katz & Reisman, 2020; Shekhtman & Barabási, 2023).

In the United States, the culture of giving is widespread. In fact, according to a survey conducted by the AP-NORC Center for Public Affairs Research (2025), 73% of the population made at least one monetary donation in the last year. However, this philanthropic propensity does not translate into equivalent support for all non-profit sectors. In particular, the arts and culture sector has received a reduced share of overall resources. According to the 2025annual Giving USA report, it is estimated that in 2024, out of $592.5 billion in total donations, only $25.13 billion will go to the arts, culture, and humanities sector, accounting for about 4% of the total. Furthermore, the growth of total donations is influenced by macroeconomic and financial factors, increasing the cyclical exposure of already fragile sectors, including cultural institutions (Giving USA, 2025).

Therefore, despite the United States being one of the countries with the strongest philanthropic tradition globally, the distribution of private donations is not uniform across different non-profit sectors. In particular, the arts and culture sector tends to occupy a marginal position compared to causes perceived as more urgent and related to basic well-being, such as health, poverty, and welfare (Katz & Reisman, 2020). This issue is crucial because, in the US system, public support for the arts is historically limited and politically controversial. This makes many cultural organizations heavily dependent on their own revenues (ticket sales, membership fees, events) and private contributions, within a decentralized, private, and local model. This differentiates the United States from many European countries where, as mentioned above, the cultural sector is more heavily supported by the state. This system also exposes American cultural institutions to structural fragility under economic and social shocks (Katz & Reisman, 2020).

This vulnerability emerges with particular intensity in times of crisis, when donation flows tend to be reallocated towards immediate needs. Katz and Reisman (2020) show how the COVID-

19 pandemic, together with other social issues in the US context, has led to a period of profound financial crisis in the arts and culture sector, highlighting the limitations of a system lacking strong central public support. In their study conducted in Philadelphia, the authors documented widespread vulnerability dynamics. In fact, many cultural organizations operated with minimal or no reserves and depended largely on revenue generated by the public (such as ticket sales) and private philanthropy (Katz & Reisman, 2020). During the emergency, the main local response funds initially prioritized organizations engaged in essential services, neglecting many cultural institutions. In addition, federal aid was highly competitive and financially limited. Against this backdrop, the sector experienced layoffs, closures, and increased job insecurity (Katz & Reisman, 2020).

Furthermore, in the United States, quantitative evidence indicates that donation dynamics in the arts sector are characterized by a high degree of concentration, a prevalence of local relationships, and significant stability in the relationships between donors and institutions. In particular, in one study, Shekhtman and Barabási (2023) analyzed the IRS e-file dataset, identifying over $36 billion in grants awarded by foundations to arts organizations between 2010 and 2019, showing that the distribution of donations was not uniform. Support was highly localized, with approximately 60% of grants and funds destined to be received in the same state as the donor. Therefore, philanthropy in the arts would seem to be predominantly anchored to the territorial dimension. The authors also highlighted that support tends to be persistent over time, with nearly 70% of donor-recipient relationships continuing into the following year, and that the allocation of resources is associated with institutional prestige, with the most prestigious institutions attracting higher levels of funding, although with some exceptions (Shekhtman & Barabási, 2023).

In summary, despite the widespread culture of philanthropy in the United States, the arts and culture sector receives a small and uneven share of total donations, making it structurally marginal compared to other causes. This dependence on private philanthropy, which is geographically concentrated and sensitive to macroeconomic fluctuations, increases the vulnerability of cultural organizations, especially small and medium-sized ones.

1.4 Characteristics of donors in the arts and cultural sector

In the cultural sector, behaviours related to giving appear to be quantitatively limited and characterised by specific donor profiles. In Europe, Ateca-Amestoy and Gorostiaga (2022) used data from Special Eurobarometer 466 (2017 a, b) on 28 EU countries, noting that only a small proportion of the population reported supporting organizations active in the field of cultural heritage through monetary donations (6.2%) or volunteering (7.7%), with significant variability between countries.

Furthermore, the authors showed that the likelihood of donating time or money was associated with indicators of greater cultural access and participation (such as living in a historic environment or regularly visiting heritage sites or events), and that education was one of the most relevant correlates of the propensity to donate (Ateca-Amestoy and Gorostiaga, 2022).

In the United States, according to a review conducted by Gow (2024), most donors in this sector tend to be male, white, with an average age of around 45, and with higher income and education than donors in other non-profit sectors. In addition, donors belonging to racial minorities tend to direct their donations more frequently towards causes perceived as more directly related to supporting their community (e.g., local networks, religious causes, education, and civil rights) than towards traditional cultural institutions (Gow, 2024).

These results are consistent with more general evidence on inequalities in cultural participation and the existence of a social gradient in artistic engagement, in which education and socioeconomic status emerge as particularly strong predictors. For example, Bone et al. (2021), analyzing data from the General Social Survey (1993–2016), showed that higher levels of education (and parental education) are systematically associated with increased arts engagement, confirming the centrality of cultural capital in determining the likelihood of contact with artistic institutions. Since cultural donation practices are often triggered or reinforced by direct experiences of cultural participation (membership, participation in events, subscriptions), the presence of barriers to access and participation therefore tends to indirectly amplify inequalities in the potential donor base (Bone et al., 2021).

Furthermore, the literature on donations highlights how giving is strongly linked to socioeconomic indicators. Awan and Hameed (2014) confirmed that factors such as income, education, perceived economic security, and trust in the organization are important determinants of the amount donated, whereas variables such as gender and age show less stable results in terms of statistical significance, depending on the context analyzed. In the direct comparison between donors and non-donors proposed by the authors, donors are more frequently male (57.7% versus 52.3%), concentrated in midlife (60% between 36 and 50 years old), and have much higher levels of income (e.g., 13.3% over 200,001 versus 3.3% among non-donors) and education (60.3% with a Master's degree compared to 39.7% among non-donors; Awan and Hameed, 2014).

Another specific feature of the arts and culture sector concerns the nature of the donor, who is often also a consumer of the institution. In this regard, Heger et al. (2021) have shown that, for cultural institutions, consumer spending (e.g., tickets, memberships, merchandise) and donations can compete with each other. Specifically, increased spending on access or cultural services may reduce the propensity to make additional donations. This implies that pricing policies and fundraising strategies should be designed in an integrated manner (Heger et al., 2021).

Therefore, giving in the cultural sphere is a minority practice that is socially stratified, strongly linked to participation and socioeconomic capital, with significant implications for equitable access and the sustainability of fundraising for arts institutions.

1.5 The impact of COVID-19 on the arts and cultural sector

The COVID-19 pandemic has caused an unprecedented crisis for the arts and culture sector, as the suspension of social activities and the closure of cultural institutions have interrupted in

person cultural participation, while increasing the centrality of digital access to cultural content (Radermecker, 2021; UNESCO, 2020). In this context, cultural operators have attempted to maintain a minimum level of activity through digital technologies, the effect of a veritable inventiveness shock (Négrier & Teillet, 2020), while consumers have shown a growing demand for content that can be enjoyed from home. However, the rapid expansion of digital alternatives (e.g., virtual exhibitions, online sessions with curators and artists, streaming music festivals, 3D concerts, and free access to video archives) has highlighted three main challenges: the delay or inability of some cultural actors to effectively enter the digital age, the immediate need to migrate to an exclusively online format, and the possibility of reaching new audiences (Radermecker, 2021). This 'digital race' has revealed stark disparities across institutions, with the museum sector less prepared than industries where innovation and digitization are central strategies, prompting traditional institutions to increase their online visibility, create new content, and digitize collections (Agostino, 2024). Despite the benefits of more interactive virtual cultural participation and information environments capable of stimulating the public, limitations remain in terms of economic resources, staff training, and the possible increase in inequalities between local and leading institutions. Furthermore, this has brought the issue of monetization and consumer willingness to pay for digital content to the forefront, in a process that could accelerate with advances in artificial intelligence (Radermecker, 2021).

Therefore, the pandemic has prompted many museums to accelerate the digitization of communication and expand online access to content as a strategy for resilience during this exceptional period. The increase in online offerings has highlighted the need to critically evaluate the quality of digital services and products, as well as issues of inequality in access to technology (the digital divide) and the accessibility of content for audiences with different needs (Marras, 2021).

During the period of social distancing, digital media served as a relational and cultural bridge, allowing people to stay connected and access diverse cultural experiences even remotely. This is precisely why it is essential to understand the often gradual and not immediately visible effects that digital transformation is having on museums and cultural institutions. This is because these changes will determine the design of new forms of relationship with users, including potential visitors, as well as existing audiences. Furthermore, it seems that young people and teenagers tend to prefer forms of participation based on immersive digital tools (Giordani, 2021).

In 2021, despite a reduction in the overall number of initiatives, the digital component persisted. During and after the COVID-19 pandemic, Italian museums accelerated the adoption of digital technologies to continue interacting with the public and experimenting with new forms of economic sustainability (Agostino, 2024). At the institutional level, during the first lockdown, Italy saw an immediate shift towards online access, including by the relevant ministry. In fact, the Ministero per i Beni e le Attività Culturali e per il Turismo (MiBACT), now the Ministero della Cultura (MiC), promoted access to digital initiatives to allow for continued contact with art. In particular, the page 'La cultura non si ferma' (Culture does not stop) was created on the institutional website, designed to collect and make virtual initiatives easier to find, organizing them into thematic sections (museums, books, cinema, music, education, and

theater) and including proposals from cultural venues and the entertainment, music, and audiovisual sectors (MiBACT, 2022).

At the same time, numerous museums have strengthened or more actively communicated their presence on Google Arts & Culture, leveraging its visibility to keep collections and content accessible during the closure period. Other institutions, by contrast, have focused their digital offerings on their own official channels. For example, the Uffizi Gallery has promoted virtual tours available directly on its website. In general, the most widespread strategy has been to maintain connections with the public through social networks, websites, and third-party platforms, offering digital content and, where possible, structured virtual visit experiences (Artribune, 2020).

In terms of revenue, most digital experiences were offered free of charge (78%), although some museums began to explore alternative monetization models, including some based on donations (Agostino, 2024). In this case, access to digital content is provided through a voluntary contribution by the user, who takes on the role of donor. However, this approach is still marginal in the Italian context, as it is adopted by only 2% of the museums surveyed (Agostino, 2024).

While recognizing that the dimension of the place remains central to the visitor experience, this period has reinforced the idea that it is useful to complement traditional in-person access with unconventional ways of accessing heritage, especially when physical access is limited or problematic (e.g., for those who are far away, for places that are temporarily closed to visitors, or for contexts where excessive tourism creates pressure). From this perspective, digital solutions can become a complementary resource for keeping the memory and knowledge of cultural heritage alive, across time and space (Marras, 2021). In particular, technologies such as AR and VR can support a richer experience. These technologies can not only broaden the understanding of a place or cultural object, but can also function as effective communication tools to represent transformations that have taken place over time (modifications, restorations, reconstructions) and to make complex processes more understandable to the public (Mandarano, 2019). An example of large-scale digital infrastructure is the Google Arts & Culture ecosystem in collaboration with CyArk and the Open Heritage project, which enables virtual explorations and digital reconstructions of cultural sites that are at risk or no longer accessible. The approach is based on the creation of archives and digital models that are useful both for educational purposes and as an information backup, supporting scholars and researchers and serving as a reference base for future interventions (Mandarano, 2019).

This strand includes examples of applications in which digital documentation has been used to create three-dimensional models and monitoring tools, as well as VR experiences for the public. In the case of Wat Phra Si San Phet (Ayutthaya, Thailand), a 3D model was used to check the stability of the structures and also as the basis for an educational VR experience. Similarly, digital documentation can be considered a resource that can support knowledge, conservation, and communication of heritage (Mandarano, 2019).

From this perspective, digitization is not only an emergency response but also an opportunity to rethink modes of access and cultural participation. In addition to their conservation dimension, 3D reconstructions and VR allow audiences who are far away or unable to travel to access and learn about cultural heritage, while also contributing to raising awareness of the importance of these places and their transmission over time (Teba, 2020).

During the COVID-19 pandemic, museums in the United States also accelerated a digital transformation that was already underway, driven by the closure of physical spaces and the need to maintain their relationship with the public through online and hybrid experiences. The Museum Innovation Barometer 2021 identified COVID-19 as a key period for digital transformation in museums and the introduction of new immersive technologies, including AR and VR, emphasizing how these technologies were introduced to endure and further develop, despite critical issues related to sustainability and economic feasibility (Giannini and Bowen, 2022).

Despite increasing digitization, a gap still exists between the potential of these technologies and their full integration into museum practice (Giannini and Bowen, 2022). In the United States, some significant examples of the application of these new technologies can be found in the immersive experiences developed during the pandemic. For example, the Van Gogh exhibition *The Immersive Experience* in New York City and other locations in the United States, where works such as *Starry Night* were recreated through digital art and the AR and VR experience was used to produce an immersive engagement integrated into a physical environment.

Overall, VR and AR can be seen as central tools in the reconfiguration of various post-COVID museums and exhibitions towards an integrative model between physical and digital reality, oriented towards new forms of cultural participation and interaction (Giannini & Bowen, 2022).

Therefore, in both Europe and the United States, the pandemic served as a catalyst, accelerating digital innovation processes already underway, making them more widespread and accessible. This has led to the need to thoroughly analyze the impact of these changes on museum practices and modes of cultural participation, redefining the very role of the museum in its relationship with the public.

Chapter 2: virtual and augmented reality in museums

2.1 Virtual reality in the arts and cultural context

VR is now considered an important tool for museums and archaeological sites because it broadens the visitor experience, offering the public the opportunity to immerse themselves in reconstructions of historical environments and contexts. This allows visitors to overcome the limitations of an experience based exclusively on the physical dimensions of the place. In this way, VR not only enhances visitor engagement, but also reconstructs aspects of heritage that have been altered or are incomplete compared to their original form (Errichiello, 2018).

Although it has been around since the 1990s, VR is a technology that is heavily dependent on hardware developments, which has influenced its use in different sectors. After initial applications in the military and experimental fields, VR has gradually been adopted in the cultural and museum sector (Simonetta, 2012).

The use of VR in museums has made a tangible impact, particularly in terms of transforming the visitor experience, making it more engaging, exploratory, and interactive. In 2016, for example, the Franklin Institute in Philadelphia introduced immersive experiences in which visitors can explore normally inaccessible environments, highlighting VR's ability to offer highly immersive simulations (Richardson, 2023). Similarly, in 2017, the New Museum in New York experimented with an exhibition entirely focused on VR (First Look: Artists' VR), which could also be accessed via low-cost devices such as Google Cardboard. This showed how technological accessibility can support the wider dissemination of such experiences, reducing economic and participation barriers (Calveri, 2023).

Significant examples are also emerging in Italy, where VR is used to enhance cultural storytelling and emotional engagement. The Teatro alla Scala Museum, for example, has complemented traditional visits with a VR tour, symbolically guided by artistic figures from the theater tradition, with the aim of accompanying visitors through the history and contents of the museum (Armelli, 2017). At the same time, the Museum of Science and Technology in Milan has experimented with immersive experiences related to space missions (such as Apollo 11 and the exploration of Mars), revealing how VR can also amplify the educational and outreach dimension through the simulation of an event (Mussi, 2018).

In Europe, the introduction of VR has highlighted further impacts on the way visitors read and interpret works of art. For example, Mona Lisa: Beyond the Glass, launched by the Louvre in 2019, has made it possible to view the painting up close and in detail through sounds, animations, and interactive design, emphasizing how VR can support a more detailed understanding of artistic processes and the work’s material changes over time (Richardson, 2024; Pistola et al., 2021). A similar approach can be found in the case of the Victoria and Albert Museum with the Curious Alice experience, where VR is integrated as a playful and immersive extension of the exhibition, transforming the visit into a narrative and multisensory experience (Richardson, 2024).

VR then uniquely offers an immersive experience that allows the audience to participate directly in historical, artistic, and cultural scenarios (Carrozzino & Bergamasco, 2010). This ability to create three-dimensional environments and realistic simulations increases attention, engagement, and the intention to visit, proving particularly effective in virtual experiences that stimulate emotional and cognitive dimensions, reinforcing the perception of immersion (Xin, 2022; Othman, 2024). In this case, immersion is a core mechanism of engagement. The user, feeling present in the virtual scene, develops curiosity, a desire for exploration, and an emotional connection with cultural heritage, to the point of perceiving themselves as an integral part of the museum narrative (Bailenson, 2018; Chang et al., 2018). In this context, VR is able to change the relationship between visitors and content. It does not simply convey information, but shapes the spatial and temporal perception of the experience and makes the audience an actor involved in the process of creating cultural meaning (Pantile et al., 2016).

Therefore, VR can significantly enhance the quality of the museum experience by increasing the perception of presence within a simulated cultural space (Christopoulos et al., 2024). In this context, it is useful to distinguish between mobile VR solutions, which are generally semi-immersive and characterized by a more limited level of interaction, and wearable VR solutions, which support more advanced modes of engagement thanks to sensory feedback and multimodal interactions, generating higher levels of immersion (Sylaiou et al., 2010; Rafeiro et al., 2024). Immersion, therefore, is not simply a visual effect, but represents a central variable for perceived realism, the significance of the experience, and engagement in heritage contexts, where the reconstruction of places and cultural heritage requires a credible perception of digital space (Jangra et al., 2025). The greater immersive effectiveness of wearable headsets depends in particular on 6DoF support (Subramanian et al., 2020), higher-performance displays and higher refresh rates, as well as the integration of controllers and haptic feedback systems, elements that also contribute to reducing the onset of motion sickness compared to mobile VR configurations (Bekele et al., 2019; Somrak et al., 2021). A significant example of this technology in action is the development of a virtual tour for the Le Corbusier Museum in Chandigarh (India), where the adoption of a wearable framework has allowed visitors to explore more freely and access richer informational content (Rodríguez-Lora et al., 2021; Sendai et al., 2017).

From a broader perspective, numerous international museums have experimented with VR implementations (British Museum, Metropolitan Museum of Art, Louvre, Acropolis Museum, Smithsonian National Museum, Vatican Museums, and Rijksmuseum), confirming that VR can be seen as a technology capable of making the museum experience more intense, interactive, and customizable, increasing learning, engagement, and immersion (Jangra et al., 2025; Hazarika & Rahmati, 2023; Vlahovic et al., 2022).

2.2 Augmented reality in the arts and cultural context

AR is a technology capable of transforming the perception of space on which artistic experience is based, because it can expand the visitor's three-dimensional experience and reformulate the real environment through superimposed digital content. Furthermore, AR

seems to be increasingly accessible thanks to the spread of devices such as smartphones and tablets (Simonetta, 2012). What makes AR particularly relevant is its ability to hybridize the real and the digital without replacing the physical context. Through this technology, the narrative experience is integrated with non-real elements and can transform a museum exhibition into a digital story (Chipa, 2012). A concrete example is the installation *Be Careful, Fragile* (Madrid, 2006), which shows how AR can engage the senses with the presence of a non-existent object. The digital vase prompts the user to touch it. In the AR content, the vase then breaks after being touched, creating an experiential dynamic that arises from the visitor's action (Ludovico, 2012). AR is also used as a tool to convey messages and narratives (Xu, 2025). AR is a particularly effective tool for museum storytelling, as it allows digital narratives to be integrated directly into the physical space of the visit, making historical and cultural content more accessible and engaging. In this sense, AR facilitates a situated and interactive narrative experience, capable of enhancing both learning and the visitor's emotional engagement. Xu's (2025) study, conducted at the Chinatown Storytelling Center, highlighted how a marker-based AR prototype produced high and statistically significant levels in experiential dimensions such as engagement. These results suggest that AR storytelling can help transform the museum experience into a more immersive, meaningful, and culturally memorable one (Xu, 2025).

In museums, there are other examples that highlight the effect of AR on visitor engagement. In Italy, at the Museo Novecento in Milan, an AR app dedicated to *Il Quarto Stato* allows visitors to immerse themselves in the work, interact with additional content, and even see the characters come out of the image, creating experiential storytelling (Tanni, 2018). With the widespread adoption of smartphones, AR has become more widespread and practicable at scale. The National Gallery in London has experimented with AR experiences across urban space via QR codes that can be activated with smartphones, extending the collection beyond the physical boundaries of the museum (Dao, 2023). Another example is ARtours (Stedelijk Museum, Amsterdam), which explores the use of ‘relocatable’ works in urban spaces via smartphones, also to compensate for constraints of space and exhibition resources (Chipa, 2012). Finally, Voyager X-Drive reconstructs the Imperial Forums in AR during the visit, adapting the display to the visitor's movement and perspective and integrating a multilingual audio guide (Chipa, 2012). In the heritage field, AR supports storytelling, especially when it reconstructs what is missing on site. For example, LIFEPLUS in Pompeii combines more accurate reconstructions with interactive videos depicting scenes of everyday life (Papagiannakis et al., 2025).

Therefore, AR can support museum storytelling because it integrates digital content directly into the physical context of the visit, transforming the room or site into an augmented space, where a progressive narrative is constructed as the visitor explores and interacts with the environment (Benghadbane et al., 2025). Engagement comes not only from the addition of information, but also from the possibility of experiencing a sequence of narrative events and context-based interactions, which make the experience more personal and memorable (Benghadbane et al., 2025). The relationship between storytelling, immersion, and engagement is also consistent with the idea that AR requires spatial storytelling. The story must be rooted in the real environment so that the user perceives continuity between what they see in person and what is digitally superimposed, increasing the sense of presence and

participation (Dao, 2023). In terms of outcomes, empirical evidence shows that the use of AR/VR in museums can increase immersion and flow, which in turn have a positive impact on engagement and the quality of the visitor experience (Benghadbane et al., 2025).

2.3 VR and AR as immersive tools

The integration of immersive technologies such as AR and VR is becoming increasingly important in museums as it allows the visitor experience to be rethought in a more interactive, participatory, and meaning-making way. In particular, AR is described as a technology capable of increasing engagement through the overlay of digital and informational content onto real space (Asogwa, 2024). At the same time, VR allows for a greater level of immersion by creating digital environments in which visitors experience a strong sense of presence and emotional involvement. In museums, this enhanced experience is associated with greater participation, attention, and interactivity compared to more traditional media (Sun & Othman, 2025). Furthermore, as already mentioned, the literature highlights that the difference between semi-immersive (mobile VR) and fully immersive (wearable VR) experiences has concrete consequences for the outcomes of the experience, as the latter significantly improve the perceived quality of the virtual tour and visitor satisfaction (Jangra et al., 2025). In this context, AR and VR are also interpreted as strategic tools capable of modernizing museum practices and supporting sustainability and economic diversification objectives, helping to make visits more dynamic and satisfying, with possible positive effects on economic performance and the relationship with the public (Besana et al., 2024). From this perspective, the relationship between immersion and behavioral effects can extend beyond the visit itself. Some neurocognitive studies on storytelling show that immersion in a story can activate physiological processes associated with prosocial responses. In particular, experimental research indicates that emotionally engaging narratives increase oxytocin and strengthen empathy. These processes can then translate into subsequent supportive actions, such as a willingness to donate, highlighting a link between narrative intensity and donation behavior (Zak, 2015). Therefore, the use of AR and VR in museums, by increasing engagement and immersion and enhancing the narrative dimension, could help create the psychological and emotional conditions that, according to the neuroscientific literature on storytelling, are associated with a greater propensity to financially support causes and institutions through donation (Zak, 2015).

Chapter 3: The contribution of behavioral economics and neuroscience theories to explaining donations

3.1 Behavioral economics and neuroscience: exploring donations in the museum context

Behavioral economics theories offer relevant tools for interpreting donations as decisions that are not entirely rational, but influenced by subjective reference points, emotions, and cognitive biases. A fundamental starting point is Prospect Theory, according to which individuals evaluate outcomes not in absolute terms but as deviations from a reference point, perceiving gains and losses asymmetrically (Kahneman & Tversky, 2013; Bonini et al., 2008). The theory distinguishes between a framing stage (in which the reference point is defined) and an evaluation stage, in which an S-shaped value function is applied (Figure 1): concave for gains, convex for losses, and steeper in the domain of losses, describing the phenomenon of loss aversion (Kahneman & Tversky, 2013).

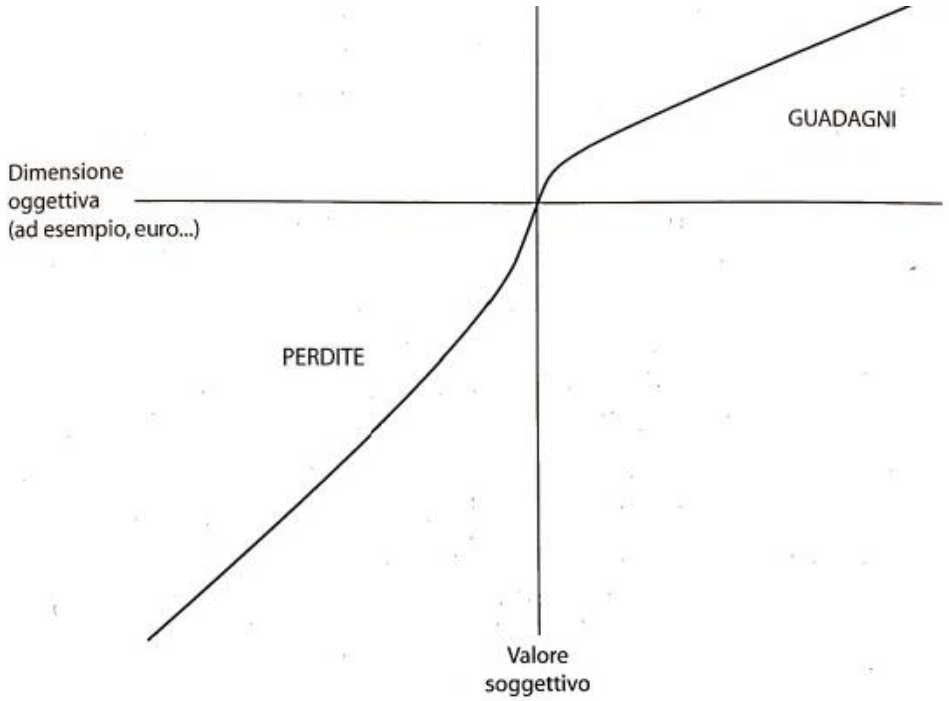

Figure 1 Value Function

An important implication is the framing effect, whereby equivalent choices can lead to different decisions depending on how they are presented (Tversky & Kahneman, 1985). This perspective has been extended to donation behavior, hypothesizing that donating is not simply a loss of resources, but also a source of subjective value linked to psychological well-being and social recognition (Strahilevitz, 2011; Andreoni, 1990; Dunn et al., 2008). In this vein, the donation curve (Figure 2) proposed by Strahilevitz (2011) suggests that the act of donating generates a subjective benefit, but that this benefit increases at a decreasing rate as the amount donated rises. For example, the perceived difference between donating €0 and €5 is

much greater than that between donating €25 and €30. Furthermore, the propensity to donate also depends on the psychological value attributed to money, which can count for more than its actual purchasing power (Witkowski, 2021).

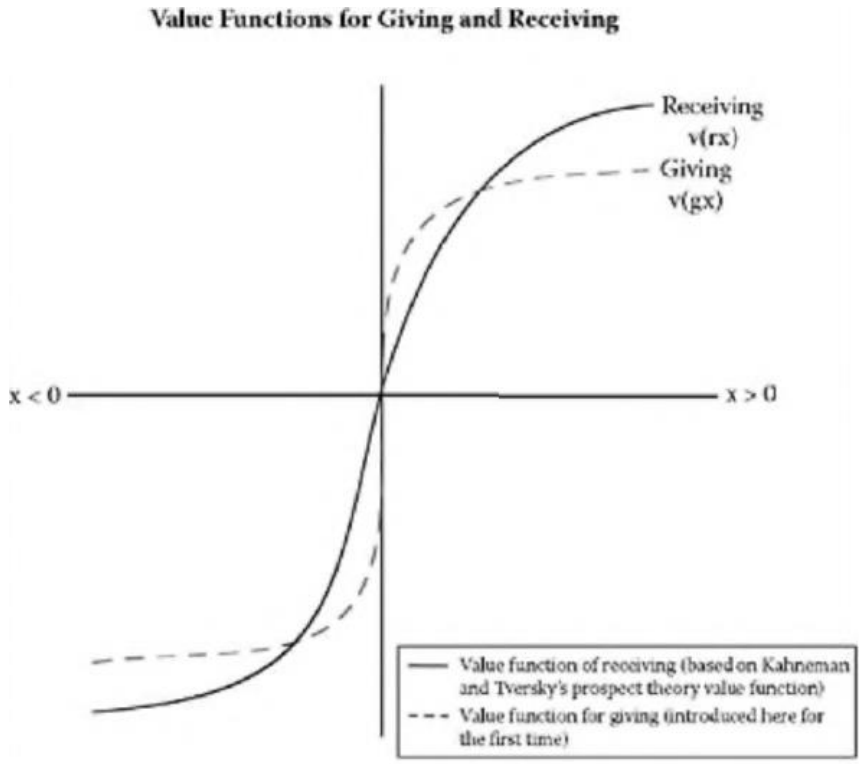

Figure 2. The Donation Function

Alongside cognitive models, numerous studies highlight the emotional component as a key determinant. Donating can be encouraged by a positive mood; in fact, when people feel good, they are more likely to help others. At the same time, donating can make those who do so feel better, creating a virtuous circle between emotional well-being and prosocial behavior (Anik et al., 2009). Experimental evidence suggests that events that boost mood (such as good news or a sports victory) can temporarily increase the willingness to donate (Sautua, 2022; Minnich, 2022), just as creative activities and acts of kindness received can encourage prosocial behavior (Xu et al., 2022; Shiraki & Igarashi, 2018). Finally, with regard to framing applied to charitable communication, the literature presents mixed results. While negative messages may have a greater cognitive and emotional impact (Rozin & Royzman, 2001; Taylor, 1991), they may also generate reactance or anxiety, reducing the willingness to donate (Cho & Sands, 2011; H. Lee & Cameron, 2017; Sharma, 2021), while cumulative analyses show no stable differences between positive and negative frames in terms of persuasiveness (J. Xu & Huang, 2020). Overall, these data suggest that donation can be explained as a choice influenced by the interaction between subjective value assessments, decision biases, and emotional dynamics that underpin prosocial motivation (Kahneman & Tversky, 2013; Strahilevitz, 2011).

Among the behavioral theories that attempt to explain donation behavior, there are also studies drawing on the Theory of Planned Behavior (TPB). TPB interprets donation as a planned behavior, in which action depends primarily on intention. This, in turn, is determined by attitudes toward donation, subjective norms (perceived social pressure/expectations), and perceived behavioral control (how capable one feels of donating in a simple and feasible way) (Ajzen, 1991).

A recent meta-analysis on donations confirms that this model is particularly effective in predicting the intention to donate and, to a lesser extent, actual donation. In particular, both the perception of how feasible and controllable donating is and the sense of moral duty are very important. Nevertheless, the factor most directly linked to final behavior remains intention itself (White et al., 2023).
However, many studies show that there is often a gap between what people intend to do and what they actually do. Even individuals who intend to donate may ultimately fail to do so. Practical strategies can be useful in reducing this gap, such as establishing a small plan in advance, such as 'if X happens, then I will donate Y', or making the donation an immediate and simple action that requires little decision-making effort (White et al., 2023; Sheeran, 2016; Sheeran & Orbell, 2000).

In the museum setting, AR/VR experiences designed to increase engagement and immersion can act on multiple components of the TPB. For example, they can reinforce positive attitudes (a more meaningful/satisfying experience), support the perception of self-efficacy and ease of action when donation is integrated into the visitor experience, and activate social norms through contextual cues (e.g., when visitors see that other visitors have donated), with evidence that descriptive norms can increase the likelihood of donating compared to standard altruistic messages (Agerström et al., 2016). Furthermore, as already mentioned, neuroeconomic research on storytelling shows that emotionally engaging narratives can increase empathy and prosocial behavior (Zak, 2015). Similarly, experimental studies on neurophysiological immersion also indicate that a more immersive experience increases viewing time and the likelihood that the content will influence subsequent behavior, including prosocial behaviors such as donating (Lin et al., 2022).

Overall, these contributions show that donation cannot be interpreted as fully rational behavior, but rather as a decision influenced by cognitive biases, emotional processes, and socio-normative factors, in line with what is emphasized by both behavioral economics (Kahneman & Tversky, 2013) and the TPB (Ajzen, 1991). Nevertheless, donation remains a complex phenomenon, as the final choice depends not only on attitude and intention, but also on contextual and situational elements that can strengthen or weaken the translation of intention into actual behavior (White et al., 2023; Sheeran, 2016). Precisely because of this complexity, numerous neuroscientific studies have emerged in recent years to complement the behavioral economics approach, helping to better clarify the underlying mechanisms (e.g., emotional involvement, empathy, and immersion) through more direct measures of the cognitive and affective processes related to prosocial behaviors and donation.

3.2 Neurophysiological tools and measures

In recent years, consumer neuroscience and neuromarketing have shown how neurophysiological tools, including electroencephalography (EEG), skin conductance, and heart rate, can be used to better capture the emotional and cognitive processes that drive decisions, even in areas related to prosocial behaviors such as donation (Kenning & Plassmann, 2008; Circi, 2023). Compared to questionnaires alone, these tools allow for continuous and implicit measurement of audience engagement, capturing reactions that are often not immediately conscious or easily verbalized, and thus providing useful indicators for evaluating the quality of the experience (Circi, 2023). In the museum context, this approach becomes particularly relevant because the adoption of immersive experiences based on AR and VR aims precisely to enhance the visitor experience through greater engagement and immersion, dimensions that the literature associates with a better experience and a more meaningful relationship between the cultural institution and the visitor (Sun & Othman, 2025; Christopoulos et al., 2024; Ifeanyi, 2024). From this perspective, neuroscience tools can help to empirically verify whether AR/VR constitute a measurable positive experiential factor and, indirectly, whether this improvement can encourage forms of financial support, such as a willingness to support the museum through donations (Zak, 2015; Circi, 2023).

Donating, in fact, does not only imply an economic loss, but can also produce psychological and motivational benefits (as described in warm-glow theory), due to the perception of having contributed to the well-being of others (Andreoni, 1990; Dunn et al., 2008). Neuroscience has also shown that donating activates reward circuits in a similar way to receiving a monetary reward, supporting the idea that donation has an intrinsically rewarding component (Moll et al., 2006; Harbaugh et al., 2007). At the same time, the literature on prosocial communication and charity advertising highlights that emotional involvement is often built through a narrative sequence capable of activating empathy and attention, accompanying the viewer from an initial problematic phase to a solution frame in which donating is presented as a concrete and meaningful action (Merchant et al., 2010; Pracejus & Olsen, 2004). In this vein, experimental studies also show that positive emotional states or those consistent with an organization's goals can increase the propensity to donate (Goenka & Van Osselaer, 2019; Zemack-Rugar & Klucarova-Travani, 2018). From a neurobiological perspective, further evidence supporting the link between emotional experience and prosocial behavior comes from studies on hormones. For example, intranasally administered oxytocin has been associated with an increase in donations, regardless of economic resources (Barraza et al., 2011). Furthermore, more recent findings indicate that neurochemical changes (oxytocin and ACTH) in response to an emotionally charged narrative stimulus may be associated with observable increases in donations (Zak et al., 2022). This framework is particularly consistent with the new technologies that are increasingly being adopted in museum contexts. AR and VR experiences aim to enhance the presence, engagement, and significance of the visit, often through storytelling. Precisely because donations in the cultural sphere are highly sensitive to the quality of the experience and the connection with the institution, neurophysiological measures can be useful in verifying whether the adoption of AR/VR represents a potential antecedent of willingness to financially support the museum (Circi, 2023; Tusche et al., 2016).

Recent evidence in the museum sector shows that the integrated use of EEG and autonomic measurements can objectively describe the quality of the cultural experience, going beyond what visitors report retrospectively, for example through self-report questionnaires. In a neurophysiological study focusing on the *Sarcophagus of the Spouses*, EEG, together with skin conductance (SC) and heart rate (PPG), were used to explore visitor responses during VR viewing compared to in-person viewing (Giorgi et al., 2023). These tools proved useful in capturing the emotional and cognitive components of the experience (Giorgi et al., 2023). To capture the implicit affective dimension, the combination of SC and PPG is often used as a basis for obtaining an Emotional Index (EI), showing how these measures can detect differences in responses during the visit (Giorgi et al., 2023).
Overall, this type of approach supports the idea that neurophysiological analysis allows for a multidimensional assessment of what happens during exposure to a stimulus. Neurophysiological indices can provide clues as to how engaging and cognitively and emotionally activating a stimulus is. These factors may be central as potential antecedents of prosocial and financial support behaviors, such as donation.

In this regard, one of the indicators that can be obtained through EEG signals is the so-called Frontal Theta Asymmetry (FTA). FTA is defined as prefrontal asymmetry in the theta band (difference between right and left prefrontal theta). This index has been proposed as a measure capable of providing information on the degree of orientation towards a stimulus and on interest/pleasure or disinterest/displeasure towards the object under examination (Cavanagh & Frank, 2014).
In particular, the theoretical rationale derives from the role of frontal theta oscillations in cognitive control, evaluation, and motivational orientation processes. In this case, theta waves are interpreted as a neurophysiological component linked to active cortical functioning and the implementation of high-level cognitive operations (including novelty detection, memory encoding/retrieval, and the need for top-down control), especially in frontal and medial frontal areas (Cavanagh & Frank, 2014). In terms of application, FTA is particularly useful in a museum because it allows researchers to observe whether certain moments of the visit (e.g., encountering interactive and narrative VR or AR experiences) produce a measurable change in motivational response and attentional orientation. This point is crucial because the intention to donate in the cultural sphere depends not only on overall satisfaction but also on feeling involved and activated by what has been experienced (Ajzen, 1991; Bone et al., 2021).

Another relevant measure is the Memorization Index (MI), calculated as theta power in the left frontal area and interpreted as mental activation associated with working memory processes (Summerfield & Mangels, 2005). From a conceptual point of view, this index is particularly well suited to the evaluation of AR/VR experiences. Many experiences that adopt these technologies in museums aim not only to entertain, but also to promote learning and retention (Mandarano, 2019). Consequently, being able to measure how much the experience activates working memory processes is important both for evaluating the quality introduced by the digital intervention and for interpreting possible indirect effects on prosocial variables. In particular, this indicator can be important if it reveals, for example, that content delivered via AR and VR technologies is easier to remember and therefore activates fewer processes related to working memory effort. Furthermore, a visitor who has better internalized the

content may develop a stronger connection with the museum and its conservation and enhancement objectives (Bone et al., 2021).

In terms of attention and engagement, another useful measure is the Beta/Alpha Theta Ratio (BATR), i.e., the ratio between beta power and the sum of alpha and theta, averaged across multiple areas. This index was originally proposed as a measure of cognitive engagement (Pope et al., 1995). The beta band is typically associated with states of cognitive activation and alertness, while alpha and theta may reflect reduced alertness/relaxation and control/monitoring processes, respectively, so that the ratio between these components provides a summary index of the level of mental involvement (Pope et al., 1995). Estimating BATR in a museum context would therefore allow researchers to understand whether VR and AR are actually capable of increasing engagement (in a neurophysiological sense, not just a declared one), i.e., whether they really capture the visitor's attention. Engagement is one of the most robust preconditions for interpreting a possible transition from experience to prosocial decision-making (Frey & Meier, 2006). Therefore, if there is no engagement, it is much more difficult to activate a sense of meaning or connection with the museum institution (Bone et al., 2021).

Finally, another useful EEG index is the Workload Index (WL), defined as the ratio between frontal theta and parietal alpha, and interpreted as a measure of mental workload (Aricò et al., 2018). The combination of these two signals is informative for understanding how cognitively demanding a task or interaction is (Marucci et al., 2021). Aricò et al. (2018) demonstrated the effectiveness of the index in discriminating between human–machine interaction conditions and its sensitivity to the cognitive demands imposed by the environment. Therefore, this index is useful for analyzing interaction with AR/VR experiences in museums. An immersive experience can increase interest and enjoyment, but it can also generate overload (e.g., due to interface complexity or the number of stimuli) or, conversely, simplify content delivery. Consequently, WL allows researchers to verify whether the technology enhances the experience without negatively affecting mental workload. This point is also decisive for the decision to donate. If the experience is tiring, confusing, or frustrating, it can reduce overall satisfaction and therefore decrease the willingness to financially support the museum (Preko et al., 2020).

Overall, the combined usage of these EEG indicators would allow for an empirically grounded analysis of the effects of AR/VR on the museum visit experience. In particular, to summarize what has been said: FTA could provide information on motivational orientation and interest; MI would allow to assess working memory activation; BATR would capture cognitive-attentional engagement; WL would measure the mental load of the interaction; and, finally, the use of SC and PPG would allow to get an assessment of emotional state through the Emotional Index (EI) (Pope et al., 1995; Aricò et al., 2018; Cavanagh & Frank, 2014; Summerfield & Mangels, 2005; Werkle-Bergner et al., 2006; Giorgi et al., 2023). No study to date has reported the use of all these neurophysiological indices in the same investigation to fully understand the effects of VR and AR within a museum.

3.3 Immersion as a behavioral predictor

In the literature on immersive media and interactive experiences, the constructs of immersion, absorption, and flow often overlap and are sometimes used interchangeably, although they describe partially distinct processes (Nilsson et al., 2016). First, immersion is commonly defined as a subjective state of deep involvement, associated with intense attention, reduced awareness of the external environment, and temporal distortion, and is conceptualized as the feeling of being inside the content (Jennett et al., 2008). This construct has been conceptualized in several forms. The literature emphasizes that immersion may depend on the degree of sensory envelopment, but also on the narrative component or the presence of challenges and tasks that capture attention (Nilsson et al., 2016). By contrast, the concept of absorption represents a psychological dimension focused primarily on prolonged concentration and attentional experience, in which the individual minimizes the processing of external stimuli. In this sense, absorption is a cross-cutting component of the immersive experience, but it can also occur in conditions that are not necessarily immersive (Nilsson et al., 2016). Finally, flow describes an optimal state of performance and engagement that typically emerges when the activity being performed requires active participation, the presence of goals and feedback, and, above all, a balance between perceived skills and level of challenge. This construct is characterized by intense focused attention, loss of self-awareness, altered perception of time, and a feeling of control over the action being performed (Nilsson et al., 2016). From this perspective, flow and immersion share experiential elements, but differ in that flow more clearly implies a component of agency and interaction, while immersion can also occur in predominantly passive experiences (Zak & Barraza, 2018). Consistently, some authors emphasize that immersion and engagement should not be understood as opposites. In interactive experiences, for example, moments of immersion can alternate with moments of decision-making and cognitive engagement, and their integration can facilitate states close to flow (Douglas & Hargadon, 2000). Overall, conceptually distinguishing between immersion, absorption, and flow is fundamental in museum and VR/AR studies. Narrative VR or AR can, for example, increase immersion perceptual and narrative sense (being transported), while flow requires that the experience include appropriate interaction and challenge mechanics. Absorption, on the other hand, is an attentional element that may explain why some experiences are particularly memorable even in the absence of active performance (Jennett et al., 2008; Nilsson et al., 2016).

Therefore, returning to the definition, immersion is traditionally understood as a subjective state of deep involvement in an experience, characterized by attentional absorption, reduced awareness of the external context, and, often, an altered perception of time (Jennett et al., 2008). In this context, the construct of immersion is historically close to concepts such as narrative transport and flow, which describe, respectively, mentally entering a story and being totally focused on an activity (Zak & Barraza, 2018).

However, Zak points out that the state of the art in applied immersion measurement has long been based on data derived from retrospective self-reports, which have significant limitations. Such limitations include bias, social desirability, and the inability to accurately report implicit emotional reactions (Zak & Barraza, 2018). In contrast to this approach, Paul J. Zak proposes a neurobiological definition of Immersion as the neural value of experience, built around two

necessary and conjunct components: attention and emotional resonance. In his most recent work, Immersion is described as a neurophysiological indicator that measures the value that the brain derives from social and emotional experiences through a two-factor structure: the first factor is attention to what is being experienced, associated with dopaminergic mechanisms (dopamine activity in the prefrontal cortex), and the second is emotional resonance, associated with the release of oxytocin from the brainstem (Merritt & Zak, 2024). This model is consistent with previous experimental evidence, according to which effective and interesting narratives produce sustained attention and empathic engagement, two neurophysiological signatures capable of predicting subsequent prosocial behavior and economic choices (e.g., donations) (Zak, 2015). The main difference from the classical definition is therefore epistemological and methodological. While traditional immersion is described primarily as a subjective (psychological) experience, Zak's Immersion is conceptualized as a predictive neurophysiological construct, designed to be continuously measurable (1 Hz) using sensors (PPG) and algorithms applied to peripheral nervous system signals, resulting in a single indicator (Immersion) capable of anticipating choices and behaviors (Lin et al., 2022; Merritt & Zak, 2024; Rancati et al., 2025). In summary, the common element between the two perspectives is the idea of an experience characterized by strong attentional and emotional involvement. What changes radically, however, is that Zak treats Immersion not as a measure of 'how immersed I feel', but as the neural value generated by the experience, transforming Immersion from a phenomenological construct into a neuroeconomic and computational metric useful for predicting behavior (Zak & Barraza, 2018).

In museum contexts, assessing the effectiveness of immersive technologies such as VR and AR requires tools capable of capturing not only the informational dimension or reported enjoyment of the experience, but above all the deeper experiential value that these technologies can generate compared to a traditional visit. The museum literature highlights that VR and AR can increase engagement, presence, and involvement, making the visit more dynamic and potentially more meaningful than a standard visit (Lee et al., 2019). However, most studies in the museum field have measured immersion through self-report measures, defining it mainly as a subjective state of involvement and attentional absorption with reduced awareness of the external context and an altered perception of time (Jangra et al., 2025; Jin et al., 2024; Ariya et al., 2025). As mentioned above, this approach has limitations in that self-assessments can be influenced by various biases (Zak & Barraza, 2018).

Therefore, in the present study, the use of tools such as Zak's neurophysiological Immersion measure may represent a particularly relevant theoretical and methodological advancement (Zak & Barraza, 2018). Measuring neurophysiological Immersion can be particularly useful for the cultural sector because it allows researchers to determine whether a VR/AR visit actually generates experiences with added value and potentially greater memorability than a traditional visit. Furthermore, the validity of this indicator is supported by evidence showing that neurophysiological Immersion predicts concrete post-experience outcomes, such as enjoyment, recall, and subsequent actions, with a high degree of accuracy (Zak & Barraza, 2018). In particular, experimental studies show that higher levels of Immersion predict the likelihood that content will influence behavior, including prosocial support (Lin et al., 2022). In

the museum sector, private financial support is a strategic resource for the sustainability of cultural institutions, and the decision to donate is often influenced by emotional involvement and the perceived quality of the experience (Frey & Meier, 2006). Consequently, the present study aims to fill a gap in the literature by introducing, for the first time in the museum context, the neurophysiological measurement of Immersion, with the aim of investigating whether the implementation of AR and VR experiences can effectively increase measurable experiential value and, through it, support prosocial behaviors such as donating to museums (Zak, 2015; Zak & Barraza, 2018; Lin et al., 2022).

Chapter 4: the experiment in Italy

4.1 Introduction and hypotheses

To analyze the effects of implementing AR and VR experiences in museums, certain neurophysiological indices were taken into consideration. These indices have also been used in previous studies to measure the effects of these new technologies, including in the arts and culture sector.
For example, based on the literature on electroencephalography in relation to cognitive engagement, it is hypothesized that EEG-based engagement measures could show higher values for the experimental group. In this regard, the BATR index has been widely used in neuroscientific literature as a measure of cognitive engagement, as it is often associated with the allocation of attentional resources and the processing of stimuli, especially visual ones (Freeman et al., 1999; Cherubino et al., 2019). Higher BATR values are associated with tasks that require perceptual integration and cognitive involvement.

Recent studies in consumer neuroscience show that digital, immersive, and interactive environments have BATR index values that can increase during the platform experience (Fici et al., 2024). Further supporting this, Accardi et al. (2025) used EEG measurements to show that immersive AR elicits higher BATR levels than static AR, suggesting that interactivity and narrative components promote greater allocation of attentional resources and deeper cognitive processing (Accardi et al., 2025).

Furthermore, in the museum context, Castiblanco Jimenez et al. (2023) demonstrated that interaction with cultural content in VR environments is associated with an increase in EEG engagement indices, suggesting that the characteristics of these technologies can enhance the cognitive processing of the experience compared to traditional modes of cultural participation. In light of this evidence, it is hypothesized that the experimental group, exposed to an immersive AR/VR visit, will show higher BATR values than the control group, indicating a higher level of cognitive engagement during the museum experience.

H1: The BATR index, interpreted as a measure of cognitive engagement, is expected to be higher in the experimental group in rooms featuring AR/VR content.

Furthermore, it is expected that an exhibition featuring VR and AR will be more engaging and will more strongly orient visitors toward stimuli of interest. Thanks to their ability to introduce elements of novelty, surprise, and perceptual reorientation, these new technologies could make certain museum content more salient and relevant than in a traditional visit. Studies based on virtual environments show that the appearance of unexpected or particularly relevant stimuli induces rapid attentional allocation and increased theta activity in frontal regions (Lin et al., 2008).
Among the indices of theta activity that can be obtained through the EEG signal, FTA is commonly associated with processes of orientation towards salient stimuli, where there is often a discrepancy between expectations and outcomes, and which may constitute a neurocognitive prerequisite for the emergence of states of interest and engagement (Cavanagh & Frank, 2014).

Furthermore, the literature on VR experiences highlights how engagement through VR can modulate prefrontal activity, making theta oscillations particularly sensitive to the experiential relevance of the scenario (Gerber et al., 2025).

H2: The FTA index, interpreted as an indicator of orientation toward salient and interest-relevant stimuli, is expected to be higher in the experimental group in rooms featuring AR/VR content.

A structured experience with a narrative guide can also play a crucial role in managing cognitive resources. The WL index is defined as the amount of mental resources needed to process information, make decisions, and complete a task. Excessive levels of WL are often associated with increased mental fatigue, reduced efficiency, and a lower quality of experience (Wickens, 2017; Longo, 2018).
Digital storytelling in VR, when it has a clear narrative structure, can support user attention and experience without increasing WL. In this regard, Skola et al. (2024) analyzed a VR storytelling experience applied to cultural heritage, highlighting moderate levels of WL and a strong relationship between presence, immersion, and perceived performance. These results suggest that a well-designed narrative guide can allow for functional, non-excessive levels of WL, even in highly immersive contexts. De Paolis et al. (2023) also show that AR applications designed as narrative guides for cultural heritage promote content comprehension, concentration, and immersion, while keeping the perceived mental load at manageable levels. The authors highlight how a clear and coherent narrative structure helps to reduce attention dispersion and the load associated with the autonomous integration of heterogeneous information, preventing forms of cognitive overload (De Paolis et al., 2023). Therefore, a structured narrative delivered through AR/VR during a museum visit should provide support to facilitate content processing, plausibly reducing WL levels. Conversely, without the support of AR/VR storytelling, visitors may incur greater effort to orient themselves, understand, and integrate information, leading to higher WL values. Therefore, it is hypothesized that cognitive load will be higher in the control group than in the experimental group.

H3: WL, interpreted as cognitive load, is expected to be higher in the control group in rooms featuring AR/VR content for the experimental group.

It is also hypothesized that introducing AR and VR into museum galleries may reduce the effort required by working memory processes during the processing of the visit experience. The power in the theta band in the left frontal region has been interpreted as an indicator of top-down control processes involved in memory retrieval. It is also associated with memory load and working memory (Jensen & Tesche, 2002; Hsieh & Ranganath, 2014). It is hypothesized that a traditional museum experience requires visitors to select what to observe, orient themselves in the environment, integrate visual and textual stimuli, and construct coherent meaning from often fragmentary information. In contrast, technologies such as AR and VR could reduce the load on these processes by providing a clearer experiential structure supported by environmental and narrative cues.
For example, a study on the application of AR in museums indicates that such technologies increase motivation and learning effectiveness by making content more accessible, relevant,

and clear to visitors, and by promoting greater acceptance and engagement in the visiting experience (Chen & Lai, 2021).

Kisker et al. (2021) also show that the recall of experiences in VR is associated with a reduction in frontal theta oscillations compared to content presented on screen. The authors interpret this result as an indication of more direct retrieval that is less demanding in terms of top-down control, suggesting that the increases in theta observed in less immersive contexts mainly reflect episode reconstruction processes (Kisker et al., 2021).
A further recent study by Srdanović et al. (2025) is consistent with these findings. According to the authors, structured narration in AR/VR contexts can provide cognitive support by organizing the experience and reducing extraneous cognitive load, facilitating stimulus integration and supporting relevant processing. In line with this, their review of the neurocognitive bases of learning in immersive cultural contexts highlights how AR/VR systems can promote more effective encoding through spatial, multisensory, and narrative cues (Srdanović et al., 2025).
Therefore, the control group is expected to show greater use of working memory, as evidenced by higher MI values.

H4: MI, interpreted as an indicator of working memory engagement, is expected to be higher in the control group in rooms featuring AR/VR content for the experimental group.

Furthermore, AR and VR could influence the affective component through two complementary mechanisms: emotionally engaging narratives, which promote empathy and prolonged attention (Zak, 2015), and richer, multimodal sensory stimulation (Uvnäs-Moberg et al., 2015). In the literature, EI has been proposed as a neurophysiological index of emotional response, derived from the integration of peripheral autonomic signals such as heart rate and skin conductance, and has been used to assess the intensity of emotional activation during aesthetic and cultural experiences (Babiloni et al., 2016).

In particular, in museum contexts, the literature shows that virtual reality can evoke emotional responses that are largely comparable to those experienced in real environments.
In this regard, Marin-Morales et al. (2019) compared the free exploration of a real museum and its immersive virtual counterpart, highlighting how VR environments can activate consistent psychophysiological patterns along the dimensions of valence and arousal. These results support the use of VR as a valid tool for eliciting emotionally relevant experiences.
The study by Sun and Othman (2025) also shows that VR experiences can have a positive and significant effect on visitors' emotional resonance. The study also highlights that more immersive and interactive VR environments promote greater emotional connection with cultural content. Although based on self-report measures, the results support the use of VR as a tool capable of enhancing emotional responses in museum contexts (Sun and Othman, 2025).

In the case of AR, neuroscientific evidence also indicates that these experiences can elicit greater emotional involvement than more static solutions. Accardi et al. (2025) show that

immersive AR applications lead to higher levels of physiological EI than static AR content. These results suggest that higher levels of immersion and interactivity in the AR experience are associated with increased emotional activation during interaction. Therefore, in the present study, it is hypothesized that the experimental group, exposed to an immersive AR/VR museum visit, will show higher EI values than the control group, reflecting greater positive emotional involvement.

H5: EI, interpreted as an emotional index, is expected to be higher in the experimental group in rooms featuring AR/VR content.

As for the neurophysiological Immersion index, the experimental group is expected to show higher values, thanks to the introduction of VR and AR technologies. In particular, as mentioned above, the Immersion Neuroscience platform conceptualizes Immersion as a composite index that integrates components related to attention (associated with dopaminergic mechanisms) and emotional resonance (associated with oxytocinergic mechanisms), derived from peripheral signals processed using proprietary algorithms (Merritt & Zak, 2024). This index is particularly suitable for capturing the neurophysiological value generated by intense experiential events, such as those typical of immersive experiences (Merritt & Zak, 2024; Rancati et al., 2025).

From an experiential point of view, the literature on cultural contexts highlights that extended reality technologies tend to enhance immersion, the sense of presence, and agency, making the experience more engaging on both a cognitive and emotional level (Innocente et al., 2023). Additionally, AR is described as a technology intrinsically oriented towards creating immersive experiences. For example, Chen et al. (2024) describe AR as a system capable of providing experiences that promote greater integration between virtual content and the real environment, with positive effects on the visitor's sense of presence and engagement. Other studies conducted in museums show that VR experiences promote a transition to immersive states (escapism and aesthetics), increasing the degree of psychological engagement among visitors (Lee et al., 2019). Lee et al. (2019) also reiterate that immersion is a key construct of the VR-mediated museum experience, as it mediates the relationship between initial cognitive absorption and overall evaluation of the experience. The high sensory quality, the possibility of entering the virtual environment, and the feeling of experiencing it firsthand contribute to strengthening the sense of presence and escapism, making the experience feel more intense, memorable, and engaging. Furthermore, VR and AR technologies can increase the multisensory engagement of the experience. Neurophysiological studies indicate that non-harmful, multimodal sensory stimulation can be associated with the release of oxytocin, which often occurs in relation to processes of well-being, emotional connection, and stress reduction (Uvnäs-Moberg et al., 2015). Oxytocinergic mechanisms are, as already mentioned, among those on which the Immersion index used in this study is based (Merritt & Zak, 2024).

This mechanism is consistent with evidence that greater neurophysiological involvement (Immersion) can predict subsequent behaviors, suggesting greater experiential value (Lin et al., 2022; Rancati et al., 2025). Consequently, compared to the traditional visit, the AR/VR-

mediated experience should generate peak engagement moments more frequently and more intensely, leading to higher Immersion values in the experimental group.

H6: The experimental group is expected to show higher overall Immersion peak levels than the control group, especially in rooms featuring AR/VR content.

AR and VR experiences can also influence prosocial and decision-making behaviors. For example, AR experiences can foster deep emotional engagement and stimulate personal reflection on complex and sensitive issues, such as donation. Pitsillides et al. (2022) show, through an artistic AR installation, that this type of experience can increase dialogue, awareness, and reflection on the value of donation, helping to build trust and openness to prosocial behavior.
According to Kristofferson et al. (2022), exposure to VR content, compared to two-dimensional or less immersive formats, can lead to higher monetary donations. Through three experimental studies with actual donations, the authors found that participants exposed to VR content donate more than those who view the same content in 2D or non-immersive 360° formats (Kristofferson et al., 2022).

Furthermore, it is assumed that the experimental group has higher levels of Immersion, which, according to the literature, can predict donation behavior (Zak & Barraza, 2018; Lin et al., 2022). In particular, so-called Immersion peaks, which represent moments of maximum engagement relative to the individual baseline, are strongly associated with the likelihood of performing a prosocial action immediately after the experience (Lin et al., 2022). Considering these results in the museum context, the introduction of an AR- and VR-mediated visit should increase perceived experiential value, overall enjoyment of the visit, and emotional engagement with the museum. Therefore, the experimental group, exposed to a visit capable of producing higher Immersion peak levels, is expected to show a greater propensity to donate than the control group, which experiences a traditional visit.

H7: The experimental group is expected to make more donations to the museum than the control group.

H8: It is hypothesized that higher levels of Immersion predict a greater likelihood of donating to the museum, and that Immersion mediates the effect of the experimental condition on donation behavior.

In addition to immediate effects on donation behavior, the literature suggests that immersive experiences may also influence future intention to donate. According to the TPB, behavioral intention is the main antecedent of future actions and is influenced by attitudes, moral norms, and emotional involvement (Ajzen, 1991; White et al., 2023). Therefore, experiences capable of generating a high level of Immersion and meaning could produce effects that go beyond the experiential moment.
VR experiences in prosocial contexts can increase empathy, a sense of responsibility, and intention to donate, even when there is no immediate donation effect (Kandaurova & Lee, 2018). At the same time, neuroscientific literature highlights that immersive and narrative experiences promote deep emotional processing, associated with greater memorization of the experience and a more lasting predisposition to cooperative and prosocial behaviors (Zak,

2015; Zak, 2022).
In the cultural sphere, the use of these technologies can also stimulate processes of reflection and value attribution regarding heritage, strengthening the emotional bond between visitors and cultural institutions. As already mentioned, qualitative studies on the use of AR indicate that immersive experiences can promote awareness, engagement, and openness to support and donation practices (Pitsillides et al., 2022). Therefore, it is hypothesized that participants exposed to an immersive AR/VR visit will develop a greater future intention to donate than those who experience a traditional visit.

H9: The experimental group is expected to report a higher future intention to donate than the control group.
H10: Higher levels of Immersion are expected to predict a higher future donation intention and to mediate the effect of the experimental condition on that intention.

4.2 Method

4.2.1 Participants

In line with previous studies that used the Immersion Neuroscience platform, a sample size of approximately 50 participants was adopted. This sample size (N = 50) is consistent with previous literature, in which Immersion measures have yielded significant results with comparable samples (Lin et al., 2022). Furthermore, the use of similar sample sizes is common in studies that consider neurophysiological data, such as EEG, skin conductance, and cardiovascular signals (Garczarek-Bąk et al., 2021; Fici et al., 2024).

Furthermore, a sensitivity analysis was conducted using GPower (Faul et al., 2009; $\alpha = .05$; $1-\beta = .80$; two-tailed test; $n_1 = n_2 = 25$). This analysis indicated Cohen's d = 0.81, corresponding to a medium-to-large effect for the comparison between the experimental group and the control group (Cohen, 2013). An additional sensitivity analysis was also conducted using GPower (F-test; $\alpha = .05$; $1-\beta = .80$) to evaluate a linear regression model with two predictors (group and Immersion). The analysis yielded a moderate effect size ($f^2 = 0.164$; Cohen, 2013). Therefore, the proposed sample size would appear to provide sufficient power to detect a unique effect of the mediator Immersion on the donation outcome, controlling for group.

The study was approved by the IULM University Ethics Committee and was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013) and the General Data Protection Regulation (GDPR). Before taking part in the experiment, participants signed an informed consent form to participate in the study.

4.2.2 Materials

The museum selected for the experiment was chosen based on its representativeness of the national context and its functional feasibility in relation to the experimental objective. In the Italian context, the Museum of Art and Science (MAS) was chosen because it is consistent with the most common museum types in the country. According to Istat data, the most represented categories in the Italian museum sector are ethnography/anthropology (12.8%), archaeology (12.7%), and ancient art (12.3%) (Istat, 2019).

MAS has a mixed collection, which includes works and artifacts related to these fields, such as objects of material culture, extra-European artifacts, historical finds, and works of ancient art, alongside a scientific approach to the analysis of materials and authenticity. This composition makes MAS a representative case study of the Italian museum context.
For the augmented reality experiences, participants in the experimental group used a Lenovo Tab M10 tablet, through which they accessed AR content via the ARLOOPA application (ARLOOPA, Inc.). The application allows users to view augmented reality content by scanning physical markers placed inside the museum rooms (Figure 3)

Figure 3. Marker used with the ARLOOPA app to access AR content

The virtual reality experiences were delivered via a Meta Quest 3 headset. The first VR experience, set in a Thai Buddhist temple, was created using Blockade Labs' Skybox AI platform. The content was approved in advance by the museum director, as it was deemed consistent with a traditional Thai Buddhist temple in terms of visual and symbolic characteristics. The second VR experience, located in the second African art room (Room 7), offered a symbolic journey to the afterlife inspired by traditional African rituals. This experience was created by an engineer commissioned by the museum director.

4.2.3 Experimental conditions

The study adopted a between-subjects experimental design, with two conditions: the experimental group and the control group. The sample consisted of 50 participants, assigned to the two groups in a balanced manner (24 in the experimental group and 26 in the control group). Group assignment was conducted using stratified (sex- and age-balanced) randomization, in order to ensure a comparable distribution of sociodemographic characteristics between the two conditions.

The inclusion criteria were: age 18 or older, no history of neurological, psychiatric, or neurodevelopmental disorders, and daily use of a smartphone or tablet. In addition, given the need to use an eye-tracking device during the visit and its incompatibility with eyeglasses, participants were required to have no uncorrected visual impairments and to wear contact

lenses rather than eyeglasses, if needed, at the time of the experiment. Participants who did not meet one or more of these criteria were excluded from the study.

Participants assigned to the experimental group visited the museum with additional AR and VR content. Specifically, AR content was present in four galleries of the museum (rooms 1, 2, 3, and 4). This video content was designed as introductory narratives aimed at presenting the theme of each room, after which visitors were free to explore the spaces independently. The narratives were consistent with the specific theme of each exhibition section, and their content was supervised by the museum director (Figure 4).

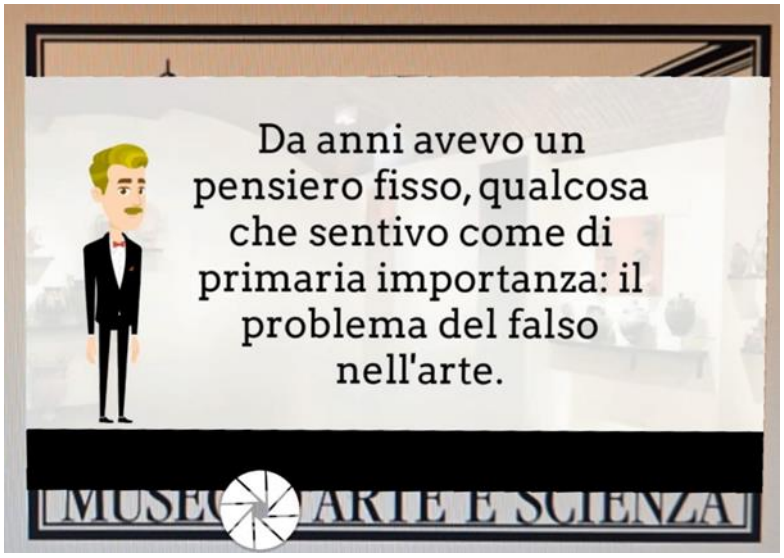

Figure 4. Example of AR storytelling content presented via ARLOOPA

In addition, two museum rooms offered VR experiences. The first (in the fifth room) consisted of a VR experience set in a Thai Buddhist temple. The second, in the final room (no. 7) dedicated to African art, offered a symbolic journey to the afterlife inspired by rituals and representations from African cultural traditions.
Participants assigned to the control group completed a traditional museum visit, following the same room sequence as the experimental group but without AR/VR content.

4.2.4 Instruments

Since participants needed to move freely during the museum visit, portable neurophysiological recording devices were used. EEG data were collected using X.on (Brain Products GmbH, Gilching, Germany). This device has seven semi-dry Ag/AgCl electrodes, which, once applied, require a 0.09% NaCl water solution. They must be positioned on the scalp according to the standard 10-10 system (F3, F4, C3, Cz, C4, P3, P4). The montage was monopolar, with reference and ground positioned on the left earlobe (A1). The sampling frequency was 500 Hz and the vertical resolution was 24 bits. The EEG data was transmitted wirelessly (BLE5 connectivity) to a recording PC running the Lab Streaming Layer (LSL) connector and recorded using LSL's LabRecorder app.

Data relating to skin conductance (SC) and photoplethysmography (PPG) were collected using a Shimmer GSR+ device (Shimmer Sensing Ltd., Dublin, Ireland). The sampling frequency was 128 Hz and the vertical resolution was 16 bits. Two Ag/AgCl electrodes were placed on the index and middle finger phalanges to acquire SC data. The PPG signal was recorded using a reflective optical sensor clipped to the right ear (A2). The SC and PPG data were written and saved on an SD card integrated into the Shimmer device.

Neurological responses related to immersion were obtained using a platform called Immersion Neuroscience (Henderson, NV). Participants were asked to wear a Scosche Rhythm+ device (Scosche Industries, Oxnard, CA), which also included PPG sensors. This device made it possible to detect volumetric changes in blood in the peripheral circulation using a light-emitting diode (LED) and software that identifies the cardiac cycle (Nitzan and Ovadia-Blechman, 2022). The sensor was placed on the non-dominant forearm (Rancati et al., 2025). The cardiac data was sent to a cloud server, where the Immersion Neuroscience platform uses algorithms to derive neural responses from the cranial nerves (Zak, 2022; Barraza and Zak, 2009). The platform provides an output file containing clean, signal-processed data. This tool is particularly suitable for field studies such as the following, as the device is minimally invasive and the data are motion-corrected (Zak, 2022).

Eye tracker (ET) data were collected using Tobii Glasses 3 (Tobii AB, Stockholm, Sweden). The sampling frequency was 50 Hz and the angular accuracy was 0.6°. The data were recorded on an SD card. The ET was used to synchronize neurophysiological data and extract time intervals related to the seven museum rooms and the two baselines. These consisted, for participants, of first staring at a white dot on a black background for 60 seconds with their eyes open and then closing their eyes for 120 seconds.

The event markers, necessary for analyzing EEG data during tasks, were positioned according to the following criteria. The start of the experience in a room occurred when the subject entered a room in the museum and had at least 3/4 visibility of it. The end of the experience in the same room occurred when the researcher gave the indication to proceed to the next room or when the participant left the room and its visibility was less than 3/4.

The EEG, SC/PPG, ET, and Immersion recordings were launched from the same PC, ensuring a common initial timestamp for all devices. The Shimmer's SC and HR biological signals were recorded using Consensys V1.6.0. The analysis of SC and HR values allowed the Emotional Index (EI) to be calculated (Vecchiato et al., 2014). The neurophysiological data relating to EEG, SC, and PPG were processed in Matlab following a standardized pipeline (Laureanti et al., 2021; Russo et al., 2023).

4.2.5 Neurophysiological indexes used: brief definition and recap

The Emotional Index (EI) is a composite indicator that integrates two autonomic physiological signals: skin conductance, indicative of emotional arousal (Dawson et al., 2007), and heart rate, associated with affective valence processes (Nardelli et al., 2015). The combination of these signals allows the individual's overall emotional response during the experience to be synthesized into a single continuous measure.

The EI is structured on a bipolar scale, where positive values indicate a predominantly positive emotional response, while negative values reflect a negative emotional response. This index has proven to be a reliable and effective measure of implicit emotional involvement in experiential contexts, making it particularly suitable for studying human–environment interactions and consumer-related experiences (Vecchiato et al., 2014).

In the context of the present study, the use of the Emotional Index allows researchers to capture variations in physiological affective response throughout the museum tour and to objectively compare the emotional impact of different modes of experience, including immersive AR/VR applications. In line with previous literature, the EI is an appropriate tool for investigating how specific technological formats influence implicit emotional processing during cultural and museum experiences, overcoming the limitations of self-report measures alone (Modica et al., 2018; Fici et al., 2024; Babiloni et al., 2023).

Frontal Theta Asymmetry (FTA) is calculated as the difference between right and left prefrontal theta activity, has been proposed to provide information on the degree of interest/pleasure versus disinterest/displeasure, in line with models of motivation and implicit emotional processing (Cavanagh & Frank, 2014). This approach is based on evidence that frontal theta activity is associated with cognitive control and emotional evaluation processes, reflecting motivational engagement and interest toward environmental stimuli (Cavanagh & Frank, 2014).

The Workload Index (WL), also known as the cognitive load index, was calculated as the ratio between theta-band power and alpha-band power, computed over frontal and parietal electrodes. This index reflects the level of cognitive resources required during information processing and task execution, and is sensitive to changes in the cognitive demand imposed by the stimulus or environment. The literature has shown that an increase in frontal theta activity, associated with a reduction in parietal alpha activity, is indicative of an increase in mental load. In particular, Aricò et al. (2018) demonstrated the effectiveness of the index in discriminating between different conditions of human–machine interaction and its inverse relationship with behavioral performance. WL has been successfully used to assess the cognitive impact of different consumption/engagement experiences, including digital environments and interactions with multimedia stimuli (Modica et al., 2018; Ismail & Karwowski, 2020).

Memorization Index (MI) was computed by calculating the average theta-band power across prefrontal electrodes. This index has been proposed as a measure of the activation of mnemonic processes involved in encoding and maintaining information related to a specific stimulus. It has been shown that frontal theta activity is closely associated with memory encoding and consolidation mechanisms, with higher values indicating greater involvement of memory-related processes (Klimesch, 1996). In particular, increases in theta power during stimulus exposure have been associated with a higher probability of subsequent recall, suggesting a key role for this oscillation in the formation of the mnemonic trace (Sederberg et al., 2003; Summerfield & Mangels, 2006). In applied contexts, MI has been used to evaluate the communicative effectiveness of audiovisual and commercial content, demonstrating a significant relationship between mnemonic activation and stimulus impact (Kong et al., 2013).

It has also been used to analyze memorization processes in metaverse-based virtual environments (Fici et al., 2024).

Immersion is able to capture the combination of sustained attention and emotional resonance, which is associated with a reduction in awareness of the external context and can promote a sense of absorption in the activity or narrative being experienced (Zak & Barraza, 2018). At the neurophysiological level, there is concurrent activation of systems associated with attention and emotional processing, including mechanisms related to dopamine and oxytocin. Immersion can therefore be described as a reliable indicator of the subjective value attributed to social and emotional experiences (Zak, 2015; Merritt & Zak, 2024).

4.2.6 Self-report measures

Before and after the museum visit, participants were asked to complete a set of questionnaires. The questions were essential for characterizing participants regarding art and donation-related variables. They also made it possible to detect any post-visit changes. The scales were translated into Italian using the back-translation procedure (Brislin, 1970) to ensure linguistic and conceptual equivalence. For each scale, a 6-point Likert scale was used (6 = strongly agree; 1 = strongly disagree) to avoid neutral responses (Kankaraš et al., 2024).

Arts Engagement

Engagement in the arts was measured using the Arts Engagement Scale developed by Kemp (2015), which conceptualizes artistic engagement as a multidimensional construct composed of five dimensions: affective, cognitive, behavioral, social, and connection.
The subscales were translated into Italian and administered both before and after the museum visit in order to assess any changes in arts engagement.

Affective: This subscale measures the emotional and affective responses elicited by engagement in the arts.

- *Essere coinvolto nelle arti mi fa sentire bene*;
- *Le arti sono stimolanti emotivamente per me*;
- *Le arti sono soddisfacenti emotivamente per me*.

Cognitive: This dimension captures the intellectual and cognitive stimulation associated with artistic experiences.

- *Le arti mi incoraggiano a valutare le cose in modo diverso*;
- *Le arti mi ispirano intellettualmente*;
- *Le arti suscitano la mia curiosità*;
- *Le arti aprono la mia mente a nuove possibilità*.

Behavioral: This subscale assesses active and behavioral engagement in the arts.

- *Partecipo a spettacoli artistici ogni volta che posso*;
- *Sostengo le arti attraverso il volontariato*;
- *Sostengo le arti donando denaro*;
- *Sono un frequentatore abituale di eventi artistici*.

Social: This subscale measures the social value of artistic experiences.

- *Ricevo soddisfazione sociale dalle arti*;
- *Essere coinvolto nelle arti è importante per me per motivi sociali*;
- *Le arti sono un'uscita sociale per me*;
- *Essere coinvolto nelle arti mi permette di interagire con gli altri*.

Connection: This subscale captures the identity-related and relational bond with the arts.

- *Ho un legame speciale con le arti*;
- *Una parte di me è definita dalle mie esperienze artistiche preferite*;
- *Sento che le arti fanno parte della mia identità*.

Intention to donate (ID)

The intention to donate in support of cultural heritage was measured using two items adapted from the literature on the TPB, originally used to assess the intention to donate blood (Faqah et al., 2015). The items were reformulated to reflect the cultural context of the present study:

- *Donerò a sostegno del patrimonio culturale nei prossimi sei mesi*;
- *Voglio donare a sostegno del patrimonio culturale nei prossimi sei mesi*.

Attitude toward donations (ATD)

To measure attitude toward donations (ATD), a subscale adapted from that developed by Chen et al. (2022) was used, originally employed in the context of donations via crowdfunding platforms for serious illnesses.

In the present study, the items were semantically modified to adapt them to the context of donations to interactive and innovative museums, while maintaining the conceptual structure of the scale unchanged. In particular, the reference to “critical illness crowdfunding platforms” was replaced with the context of museums and cultural heritage protection. The final items used are as follows:

- *Donare ai musei interattivi e innovativi è qualcosa che può contribuire a risolvere i problemi legati ai beni culturali*;
- *Vale la pena fare donazioni ai musei interattivi e innovativi per sostenere i beni culturali*;
- *Donare ai musei interattivi e innovativi è qualcosa che mi piacerebbe fare per supportare i beni culturali*.

Charitable attitude toward cultural organizations (ACO)

Charitable attitude toward cultural organizations was measured using an adapted subscale of the Attitude toward Charitable Organizations (ACO) scale developed by Webb, Green, and Brashear (2000). The original ACO scale was designed to assess individuals' attitudes toward charitable organizations, including dimensions related to perceived efficiency, image, social utility, and appropriate use of economic resources.

In the present study, the scale was semantically adapted to refer to cultural and museum institutions, while maintaining the original conceptual structure and number of items. In particular, the generic reference to charitable organizations was replaced with cultural institutions, consistent with the research context. The items used are as follows:

- *Il denaro donato agli enti culturali è destinato a buone cause*;
- *Gran parte del denaro donato agli enti culturali viene sprecato* (reverse);
- *L'immagine che ho degli enti culturali è positiva*;
- *Gli enti culturali hanno avuto successo nel sostenere il patrimonio culturale*;
- *Gli enti culturali svolgono una funzione utile per la società*.

4.2.7 Procedure

Participants were recruited mainly through flyers and word of mouth. Participants were healthy volunteers with no history of neurological, psychiatric, or neurodevelopmental disorders. In addition, during recruitment, all participants reported daily smartphone or tablet use and being able to use these devices independently.

Participants attended the MAS museum in Milan. Experimental sessions were scheduled by assigning each participant a specific time slot, during which the visit was conducted individually.

Participants were welcomed to the museum by laboratory staff and provided written informed consent. They were then asked to complete the pre-visit questionnaires, which also included demographic items (gender, age, number of children, education level, occupation, income).

Once these were completed, EEG, HR, and SC sensors, as well as the wearable device connected to Immersion Neuroscience, were applied to the participant, who was also asked to wear the eye-tracker. Before the experimental tasks, participants underwent a 60-second eyes-closed baseline (EYC) to record resting-state activity. A second baseline (BSL) was then recorded, during which participants were asked to keep their eyes open and fixate on a white dot on a black background for 120 seconds. These baseline recordings were used for data processing.

Thereafter, participants in the control group could enter the first room. By contrast, participants in the experimental group completed a short training session on how to use the tablet with the ARLOOPA augmented reality application before starting the visit. They were informed that tablets and physical markers were available in the rooms and that scanning the markers would activate additional storytelling content. Once this phase was complete and participants had become familiar with AR use, those in the experimental group could also begin the visit.

Both participants in the experimental group and those in the control group visited all seven rooms of the museum. For each room, a maximum time limit was set in advance, with a margin of a few minutes. The time limits were determined in the seven days prior to the start of the experiment based on the time normally spent in each room by visitors. Participants were instructed to move on to the next room once the maximum time limit had been reached. Similarly, in previous experimental studies on museum experiences, visitors were assigned a maximum exploration time (Krukar & Conroy Dalton, 2020; Giorgi et al., 2023). To encourage participants to move on once the maximum time was reached, and given that the X.on, Shimmer, and Immersion Neuroscience devices require a Bluetooth connection with a maximum range of approximately 5 meters to function, participants were accompanied by the experimenter, who followed them through the rooms with a laptop.

The first room was dedicated to the theme of authenticity and the recognition of artificial signs as opposed to real signs of the passage of time, particularly on wooden artifacts (Figure 5). For example, there were several materials concerning real and fake woodworm marks on antique furniture. The room contained both authentic and forged artifacts, with the aim of introducing visitors to the concept of authenticity and forgery in art. In this room, participants in the experimental group could access augmented reality content in which the museum's founder appeared and provided information on how to recognize authentic objects from forged ones in the room. The control group, by contrast, explored the room in a traditional way, without augmented reality content. The maximum time allowed was nine minutes.

Figure 5. Some of the elements in the museum's first gallery

The second room was dedicated to excavated ceramics (Figure 6). In this room, too, participants in the experimental group could find an AR marker to scan with the tablet to activate a video. In the video, which could be activated at a small interactive station (test station; figure 7), the museum's founder explained how a magnifying glass was sufficient to distinguish authentic encrustations and lichens from those created by forgers. He also urged participants to perform an olfactory test to smell the thousand-year-old ceramics and to touch the edges of a broken vase to understand when the crack was intentionally created. Participants in the control group also had access to this multisensory area of the room, but not to the AR video that provided guidance for this experience. The room contained authentic collections of ceramics from the Mediterranean area and a rare collection of Ban Chiang ceramics from Thailand. The maximum time allowed for visiting the room was approximately nine minutes.

Figure 6. The second room of the museum

Figure 7. The test station

The third room was divided into three areas, as it was very large and organized into different thematic sections (Figure 8). For this reason, three AR stations were set up for the experimental group, each providing video content aligned with the area in question. In particular, the first section addressed copies, forgeries, and authentic paintings, as well as the characteristics of an authentic book or print.

Moving on, the second section compared authentic amber, dating back millions of years, with copal and other plastics used to imitate it. In addition, this area highlighted how materials such as ivory can be replicated using a variety of substances, both natural and synthetic. The third section focused on the use of UV lights and microscopes to distinguish forged artifacts from authentic ones. This area featured objects made of stone, glass, porcelain, bronze, and silver, compared with various types of imitations. It is worth noting that this

environment was highly interactive, as all participants had access to microscopes and UV lights. The maximum time allowed in this room was approximately 12 minutes.

Figure 8. The third room of the museum

The fourth room featured various tapestries hanging on the walls (Figure 9). This room also included a short AR video that could be activated by participants in the experimental group using a marker. The AR video explained that forged tapestries are unlikely to exist, given the amount of time required to produce them. The maximum time allowed in the room was approximately five minutes.

Figure 9. The fourth room of the museum

The fifth room was dedicated to Buddhist art, with objects from Thailand and Burma (Figure 10). This room contained numerous statuettes depicting the different postures and mudrās of the Buddha (e.g., Dhyāna Asana/Mudrā, Bhūmisparśa Mudrā, Abhaya Mudrā, Parinirvāṇa Asana; Figure 11). There was also the façade of a wooden Buddhist temple. The room featured different shades of gold, which created an immersive atmosphere and conveyed a strong sense of sacredness. In this room, the experimental group experienced an immersive 360-degree VR Buddhist temple via a Meta Quest 3 headset. The VR content was created using Blockade Labs, and the experience duration was set at one minute. The maximum time allowed in the room was approximately six minutes.

Figure 10. The fifth room of the museum

Figure 11. Statuettes depicting the different postures and mudrās of the Buddha

The sixth room was dedicated to African art and was the only one that was identical for both groups. This room did not feature any VR or AR content. It included a lot of objects of historical and artistic value from various ethnic groups in sub-Saharan Africa. In particular, there were many African ritual masks (Figure 12) and many wooden statues related to the theme of

motherhood and pregnancy (Figure 13). The maximum time allowed in the room was approximately eight minutes.

Figure 12. African ritual masks

Figure 13. Wooden statues related to the theme of motherhood and pregnancy

The last room contained several traditional African art statuettes linked to ritual and religious contexts, often symbolically associated with themes of death, transition, and the afterlife (Figure 14). In the room, a replica African mask was available to participants in the experimental group (Figure 15). Inside it, a virtual reality headset was installed. By shaking the mask, participants could activate a VR experience in which they embarked on a journey on the shell of a turtle toward the afterlife. During the experience, participants could watch the landscape change and observe it in 360°. The journey took place in a forest and ended in an open area where animals were roaming free. The colors were bright, and natural ambient sounds could be heard. This experience lasted just over a minute and was developed by an engineer commissioned by the museum director. The maximum time allowed in the room was approximately four minutes.

Figure 14. Traditional African art statuettes linked to ritual and religious contexts

Figure 15. The replica of an African mask with a VR headset inside

At the end of the visit, the sensors were removed from the participant, who was then asked to complete a post-visit questionnaire consisting of the Arts Engagement Scale and the ID subscale.
At the end of the experiment, the participant received a museum pen and a free ticket to revisit the museum (worth €10) as compensation.

Near the exit door, a donation box for the museum was visible. Direct donation behavior was recorded by observing whether participants made a donation, in both groups.

4.2.8 Data processing

The EEG, SC, and PPG data were processed using MATLAB (The MathWorks, Inc., Natick, MA, USA). These were synchronized with each other using individual timestamps. Specifically, for each ET recording, markers corresponding to the entrance and exit of each museum room were inserted, as well as the two initial baselines. These markers were then exported and added to the data. The Immersion data were synchronized using Python code in the Spyder

console (Spyder Project Contributors, version 6.0.6, 2025), which produced a timestamp that matched the time indicated in the Immersion data Excel sheet with the time of the markers in the ET file.

The EEG data were processed using the EEGLab toolbox (Delorme & Makeig, 2004). Slow voltage drifts and high-frequency noise were attenuated using a band-pass filter (0.1–40 Hz, zero-phased IV order Butterworth filter).

Power line interference was filtered using the CleanLine method (Bokil et al., 2010) based on multi-taper regression (50 and 100 Hz). Non-stationary artifacts were corrected using the Artefact Subspace Reconstruction method (Chang et al., 2018) with standard cut-off values (k = 10).

Stereotypical artifacts were corrected using Independent Component Analysis (FastICA algorithm; Hyvärinen & Oja, 2000). Independent components (ICs) with a not-brain probability P > 0.9 were identified and automatically removed using ICLabel (Pion-Tonachini et al., 2019). Non-artifactual IC were then back-projected to the original sensor space.

Using the REST algorithm (Dong et al., 2017), which has also performed well under conditions of limited electrode density (Hu et al., 2018), the EEG signal after the cleaning phases was re-referenced to a potential reference equivalent to an ideal zero.

For each subject, the Individual Alpha Frequency (IAF) was estimated as the center of gravity (Klimesch, 1997) of the Power Spectral Densities (PSDs), averaged across channels P3 and P4. The PSDs were calculated using Welch's method, with 1-second Hamming windows with 50% overlap (Bilucaglia et al., 2019), considering the baseline with eyes closed.

The IAFs calculated in this way were necessary to define the various EEG bands for each participant: theta = [IAF−6, IAF−2], alpha = [IAF−2, IAF+2], and beta = [IAF+2, IAF+26] (Borghini et al., 2019). The BATR index was calculated as the ratio between the instantaneous beta powers and the sum of alpha and theta, averaged across all channels; MI was calculated as the theta power averaged across the left frontal electrodes; WL was calculated as the ratio between the power of the theta band of the electrodes in the frontal area and the power of the alpha band of the electrodes in the parietal area; Finally, FTA was calculated as the difference in theta band power between the prefrontal areas, by subtracting the left theta signal from the right. The temporal resolution of the signal was 0.5 seconds. During the analysis, EEG data from 7 subjects were lost due to interference and repeated disconnections of the X.On Bluetooth signal. Therefore, these indices were calculated on a total of 43 subjects for each of the 7 rooms.

The SC signal was resampled to 32 Hz, and high-frequency noise components were attenuated using a zero-phase IV-order low-pass Butterworth filter with a double threshold method ((0.05–60 µS, ±10 µS/s). Finally, these were removed and linearly interpolated from neighbor data (2s-long centered window - Kleckner et al., 2017). The tonic SC level (SCL) was finally obtained using the cvxEDA algorithm (Greco et al., 2015).

PPG peaks, corresponding to maximal blood perfusion, were detected using the AMPD algorithm (Scholkmann et al., 2012). HR was then estimated by applying a 2 s moving-average smoothing filter to the inverse of the inter-peak (peak-to-peak) time intervals.

The EI index was obtained by applying the two-argument arctangent function to the SLC and HR signals, yielding a time-resolved series with a temporal resolution of 1/32 s.

In order to obtain a summary measure associated with the stimulus, the EEG and EI signals were divided into epochs defined according to the experimental tasks, then averaged over time and standardized using z-score normalization with reference to the mean and standard deviation calculated within the baseline epoch (Russo et al., 2022).

4.2.9 Computation of immersion peaks

Immersion was analyzed by calculating Immersion peaks rather than average values calculated over the entire duration of the experience. This methodological choice is consistent with existing literature, which indicates that the dynamics of neurophysiological Immersion show a marked tendency toward mean reversion. Accordingly, averages calculated over extended time windows are poorly informative and weakly predictive of behavioral and psychological outcomes (Merritt & Zak, 2022; Zak et al., 2022).

On the contrary, Immersion peaks capture moments of maximum emotional and attentional engagement, which represent the most neurophysiologically relevant portions of the experience. Numerous studies have shown that these metrics have greater predictive power than average values. In particular, metrics based on the cumulative amount of Immersion associated with above-threshold values, rather than average values, accurately predict daily mood (Merritt & Zak, 2022) and propensity for prosocial behavior (Zak et al., 2022). Similarly, in real commercial contexts, the use of metrics based on Immersion peaks has explained a significant portion of the variability in dwell time and purchasing behavior (Rancati et al., 2025). Taken together, these findings indicate that peaks are highly informative indicators of engagement, methodologically more appropriate than raw averages for describing experiential dynamics and predicting observed behaviors.
As already mentioned, from a neurophysiological point of view, Immersion is an intrinsically temporal construct and reflects the convolution of two distinct but interdependent components, namely attention and emotional resonance, which is closely associated with oxytocinergic activity (Zak, 2020, 2022). Signals regulated by neuromodulators, such as oxytocin, are characterized by pulsed and transient release in response to emotionally salient stimuli, followed by a rapid decay to baseline levels (Zak et al., 2009; Sporns & Kosslyn, 2018). Consistently, Immersion also shows rapid oscillations and distinct peaks, with a progressive loss of predictive power when analyzed over prolonged time intervals, as evidenced in some studies (Merritt & Zak, 2022). For example, in Immersion analyses applied to video narratives, the focus is on well-defined and shorter time windows (Zak & Barraza, 2009; Lin et al., 2022). In the present study, the average duration of the experience was around 41.40 minutes of museum visitation, and for some participants it exceeded 50 minutes. Given the oscillatory

nature of oxytocin and the length and variability of visitation time for each participant, it was decided to find a common time threshold for calculating Immersion peaks.

Based on participants' museum visit, the maximum average time spent per room was 479 seconds (approximately 8 minutes). Therefore, the time window used exclusively to estimate the threshold for calculating peaks was set at 479 seconds from the start of each session. This methodological choice made it possible to control for interindividual variability in exposure duration, reduce habituation effects, and maintain comparability between participants in the experimental conditions. Over this 479-second window, the average Immersion signal plus 0.5 standard deviation was used to calculate the threshold. This approach reduces the effect of non-specific fluctuations over time and allows for a more reliable comparison of Immersion patterns, given the dynamic nature of oxytocin release, which varies according to emotionally salient stimuli (Barraza & Zak, 2009; Zak et al., 2022).

4.2.10 Method used to calculate Immersion peaks

In this study, neurophysiological Immersion was analyzed using a discrete time series sampled at 1 Hz, obtained using the Immersion Neuroscience platform. The Immersion value of participant $i$at discrete time $t$during event e(i.e., a room) is denoted by $x_{i,e,t}$. For each participant–event pair, a discrete time sequence of the Immersion signal is therefore available. Let $S_{i,e}$be the set of all time samples related to the entire event e.

In order to identify the moments of maximum neurophysiological engagement, an adaptive threshold was adopted, estimated individually for each participant and for each event. As described above, the threshold was calculated using an initial time window of fixed duration of 479 seconds from the start of the event. The set of time samples included in this initial window is denoted by $S_{i,e}^{(479)} \subseteq S_{i,e}$.

Within the window $S_{i,e}^{(479)}$, the sample mean and sample standard deviation of the Immersion signal were calculated:

$$\mu_{i,e}^{(479)} = \frac{1}{\mid S_{i,e}^{(479)} \mid} \sum_{t \in S_{i,e}^{(479)}} x_{i,e,t}$$

$$\sigma_{i,e}^{(479)} = \sqrt{\frac{1}{\mid S_{i,e}^{(479)} \mid -1} \sum_{t \in S_{i,e}^{(479)}} \left(x_{i,e,t} - \mu_{i,e}^{(479)} \right)^2}$$

Where the standard deviation is estimated using the denominator $\mid S_{i,e}^{(479)} \mid -1$, to obtain an unbiased estimate of sample variability.
The adaptive Peak Immersion threshold for participant i and event e is therefore defined as:

$$\theta_{i,e} = \mu_{i,e}^{(479)} + 0.5\,\sigma_{i,e}^{(479)}$$

This threshold identifies Immersion values that significantly exceed the average level of the individual signal, capturing fluctuations with high information content compared to baseline activity (Zak, 2020, 2022).

Once the threshold $\theta_{i,e}$was estimated over the initial window, it was applied to all time samples of the event. Absolute Peak Immersion was defined as the sum of Immersion values exceeding the threshold throughout the entire duration of the event:

$$P_{i,e} = \sum_{t \in S_{i,e}} x_{i,e,t}\ \mathbf{1} \cdot \left(x_{i,e,t} > \theta_{i,e} \right)$$

where $\mathbf{1}(\cdot)$is the indicator function, which takes the value 1 if the condition is satisfied and 0 otherwise.

The total Immersion of the event was defined as:

$$I_{i,e} = \sum_{t \in S_{i,e}} x_{i,e,t}$$

To account for interindividual differences in overall signal intensity and the duration of the experience, the final Peak Immersion was calculated as a normalized measure, defined as the proportion of total Immersion attributable to above-threshold values:

$$\text{PeakImmersion}_{i,e} = \frac{P_{i,e}}{I_{i,e}} = \frac{\sum_{t \in S_{i,e}} x_{i,e,t}\ \mathbf{1}(x_{i,e,t} > \theta_{i,e})}{\sum_{t \in S_{i,e}} x_{i,e,t}}$$

In the event that $I_{i,e} = 0$, the Peak Immersion value was set to 0 to avoid division by zero.

This index expresses the proportion of overall neurophysiological activity attributable to moments of maximum engagement. This normalization allows for reliable comparisons between participants across events of different durations and is consistent with the theoretical model of Immersion, according to which signal peaks, rather than average values, represent the most informative moments in terms of the coupling between attention and emotional resonance (Zak, 2020, 2022; Rancati et al., 2025). Similar approaches are widely used in the analysis of physiological time series to identify salient events relative to the baseline level of the signal (Bravi et al., 2011).

4.3 Results

4.3.1 Reliability of self-report measures

Regarding the pre-visit administration of the Arts Engagement Scale, the Affective subscale showed good internal consistency (α = 0.946), as did the Cognitive (α = 0.948), Behavioral (α =

0.856), Social (α = 0.892), and Connection (α = 0.945) subscales. In the post-visit phase, the Arts Engagement Scale subscales were administered again using a six-point Likert scale. Reliability analyses showed good to excellent levels of internal consistency for all dimensions of arts engagement.
In particular, the Affective subscale showed high reliability (α = 0.918), as did the Cognitive subscale (α = 0.955). The Behavioral (α = 0.871), Social (α = 0.921), and Connection (α = 0.956) subscales also showed good internal reliability post-visit.

The good reliability of all subscales, both in the pre- and post-visit phases, confirms the psychometric validity of the Italian translation used for the Arts Engagement Scale (Taber, 2018). Repeated administration was necessary to accurately capture the impact of the visit experience on participants' artistic engagement, in line with the multidimensional conceptualization of engagement proposed by Kemp (2015).

The ID items were also administered both before and after the museum experience. In line with the reference paper (Faqah et al., 2015), intention was treated as a composite variable, calculated as the average of the two items. Since the construct consists of only two items, its reliability was calculated using the Spearman–Brown reliability coefficient, as recommended in the literature (Eisinga et al., 2013). In the pre-visit phase, the inter-item correlation was very high ($r = 0.878$, $p < .001$), corresponding to a Spearman–Brown reliability of 0.935. Similarly, in the post-visit phase, the inter-item correlation ($r = 0.875$, $p < .001$) produced a Spearman–Brown reliability of 0.933, indicating an excellent level of reliability for the donation intention measure. Overall, the results support the use of the translated items as a reliable measure of donation intention (Eisinga et al., 2013).

The ATD subscale demonstrated good internal consistency (Taber, 2018), with a Cronbach's reliability coefficient of α = 0.887. The ACO scale, consisting of five items, also showed good internal consistency (Taber, 2018), with a Cronbach's reliability coefficient of α = 0.723. The adaptation is therefore acceptable and consistent with the theoretical framework of Webb et al. (2000), according to which attitude toward organizations represents an assessment of the role of the entity as an intermediary between the donor and the final beneficiary. In the context of this study, cultural entities take on a similar role, acting as mediators in the protection and enhancement of cultural heritage.

4.3.2 The Italian sample

The Italian sample consisted of 50 participants, of whom 26 were male (52.0%) and 24 were female (48.0%). The mean age of the sample was 32.80 years (SD = 13.49). Most participants were single (n = 36; 72.0%), while 14 participants (28.0%) were married or cohabiting. In terms of educational level, 22 participants (44.0%) had a high school diploma, 19 (38.0%) had a bachelor's degree, and 9 (18.0%) had a postgraduate degree.

In terms of employment status, 18 participants (36.0%) were students, 7 (14.0%) were employed, and 10 (20.0%) were self-employed; 2 participants (4.0%) were unemployed, 1

(2.0%) was retired, and 12 (24.0%) fell into the category of other occupations. In terms of monthly income, half of the sample (n = 25; 50.0%) reported an income of less than €1,000, 18 participants (36.0%) reported an income between €1,000 and €1,500, 8 (16.0%) between €2,000 and €3,000, while 5 participants (10.0%) reported an income of €3,000 or more per month.

The demographic characteristics of the participants did not differ significantly between the experimental group and the control group. In particular, the mean age did not differ between the groups, $t(48) = 0.17$, $p = .869$, and the gender distribution was comparable between the experimental conditions, $\chi^2(1, N = 50) = 0.32$, $p = .571$.

Furthermore, no significant differences emerged between the experimental group and the control group in relation to marital status ($t(48) = 1.26$, $p = .216$), the number of children ($t(48) = 1.55$, $p = .128$), educational level ($t(48) = 1.73$, $p = .090$), occupation ($t(48) = 1.00$, $p = .323$), and monthly income ($t(48) = 0.88$, $p = .381$).

In the pre-visit questionnaires, the two groups did not show statistically significant differences in any of the subscales considered. In particular, the Arts Engagement Scale did not reveal any differences between the groups for Affective ($t(48) = -0.43$, $p = .666$), Cognitive ($t(48) = 0.06$, $p = .954$), Behavioral ($t(48) = 0.82$, $p = .417$), Social ($t(48) = 0.25$, $p = .807$), and Connection ($t(48) = -1.08$, $p = .287$).

Similarly, no significant differences were found for ATD ($t(48) = -0.86$, $p = .394$), ID – intention to donate in the next 6 months ($t(48) = 0.39$, $p = .701$), and ACO ($t(48) = -1.01$, $p = .318$).

Overall, the results suggest that the two groups started from substantially comparable levels.

4.3.3 Neurophysiological results: EEG neurometrics

For each neurophysiological index, a Linear Mixed Model (LMM) was estimated using the restricted maximum likelihood (REML) method. The index value was the dependent variable, while Group (experimental vs. control), Entry (i.e., entry into each museum room), and their interaction were included as fixed effects. Interindividual variability was modeled by including a random intercept per subject. The model formula was:

$$\mathbf{y \sim Group \times Entry + (1 \mid Subject)}$$

To avoid interpretations based on an arbitrary reference level, sum-to-zero contrasts were used, and inferences about fixed effects were evaluated using Type III ANOVA with a Satterthwaite approximation of the degrees of freedom. In line with the main objective of the study, the interpretation of the results focused on differences between groups within each room, estimated using estimated marginal means. Post-hoc differences also emerged between rooms within each group, attributable to the rooms' distinct characteristics and contents rather than to the experimental manipulation.

Post-hoc comparisons between groups for each entry were corrected for multiple comparisons using the Holm method. The main effects of Entry and comparisons between rooms are reported for descriptive purposes but are not the main focus of interpretation.

For the BATR index, Type III ANOVA revealed a significant main effect of Entry, F(6, 232.67) = 6.39, p < .001, while neither the main effect of Group, F(1, 41.24) = 1.92, p = .173, nor the Group × Entry interaction, F(6, 232.67) = 1.21, p = .303, were significant overall. The mean effect of Group, averaged across rooms, was not significant (p = .173).

However, post-hoc comparisons showed a significant difference between groups in Room 7, with higher BATR values in the experimental group than in the control group (Estimated difference = 0.45, p_{holm} = .026). In all other rooms, the differences between groups were not significant (Figure 16).

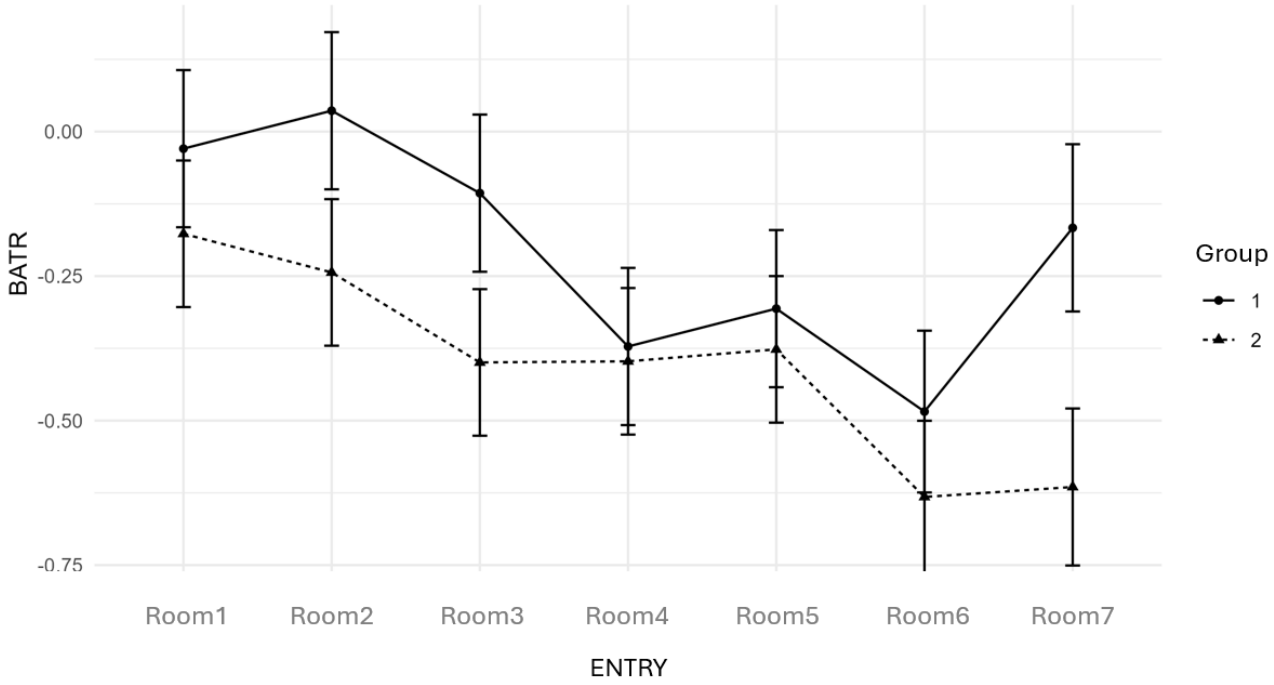

Figure 16. BATR: LMM between-group comparisons within each museum room.

For the FTA index, Type III ANOVA showed a significant Group × Entry interaction, F(6, 232.13) = 3.05, p = .007, while neither the main effect of Group, F(1, 40.91) = 2.09, p = .156, nor that of Entry, F(6, 232.13) = 1.20, p = .306, were significant. Post-hoc comparisons between groups within individual rooms revealed significant differences in favor of the experimental group in Room 6 (p = .026) and in Room 7 (p_{holm} = .045). No significant differences emerged in the other rooms (Figure 17)**.**

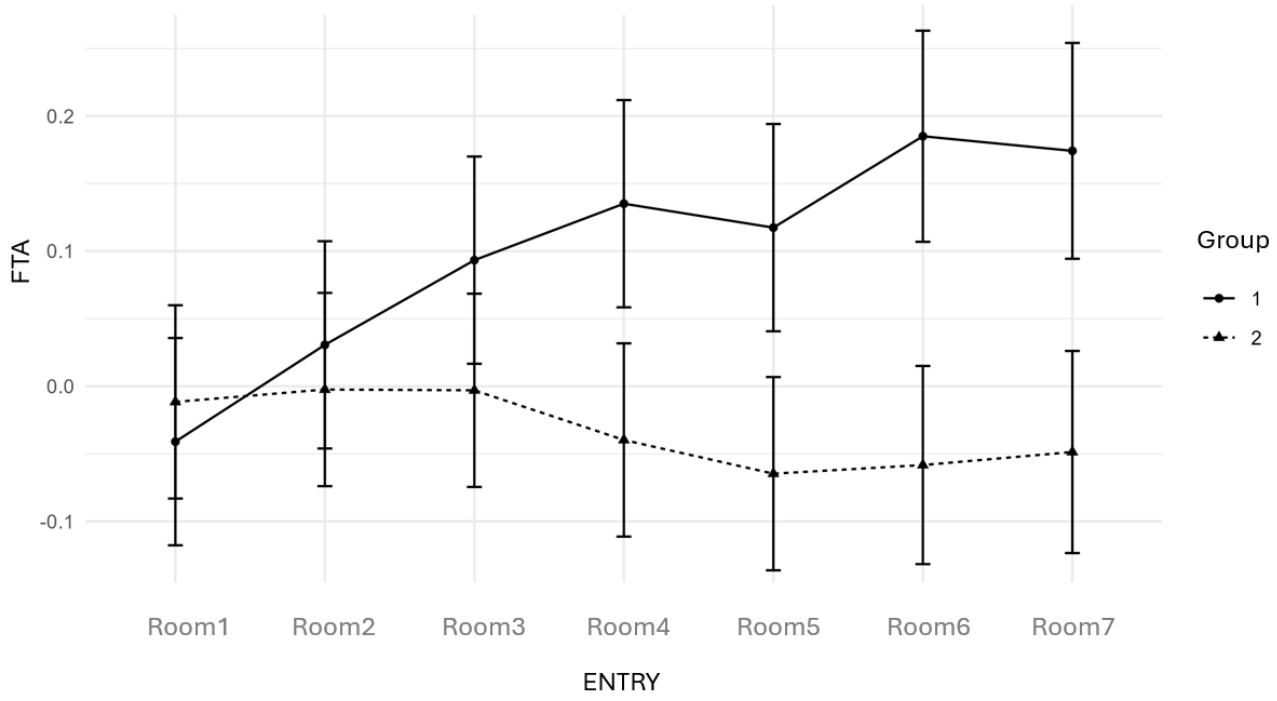

Figure 17. FTA: LMM between-group comparisons within each museum room.

For the WL index, ANOVA showed a marginal main effect of Group, F(1, 41.39) = 3.06, p = .087, and a significant main effect of Entry, F(6, 232.81) = 2.34, p = .033. The Group × Entry interaction did not reach significance, F(6, 232.81) = 1.61, p = .144. The overall mean effect of Group, averaged across rooms, was not significant (p = .087). However, post-hoc comparisons between groups within each room revealed a significant difference in Room 7, with significantly higher WL values in the control group than in the experimental group (Estimated difference = −0.45, p_{holm} = .0025). No other rooms showed significant differences between groups. This pattern suggests that the immersive AR/VR experience is associated with lower cognitive load than the traditional museum experience in the VR phase (Figure 18).

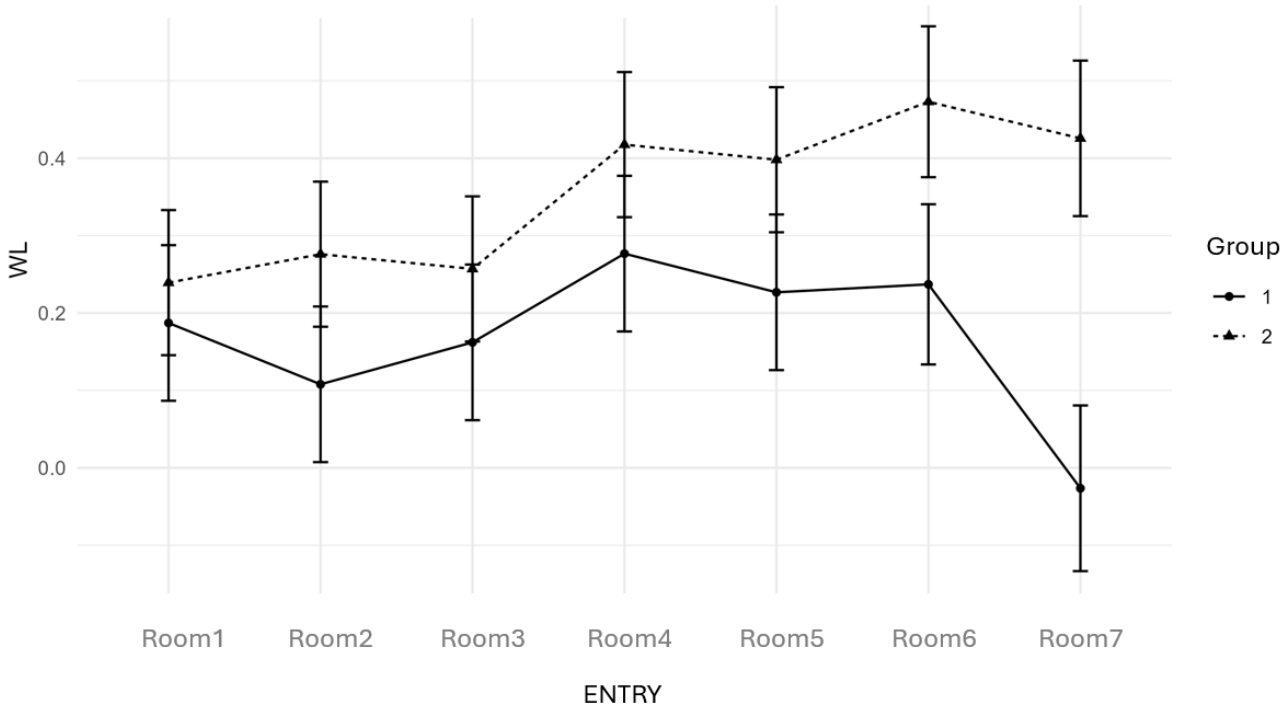

Figure 18. WL: LMM between-group comparisons within each museum room.

For the MI index, a strong main effect of Entry emerged, $F(6, 232.89) = 16.75$, $p < .001$, while neither the main effect of Group, $F(1, 41.35) = 0.50$, $p = .483$, nor the Group × Entry interaction, $F(6, 232.89) = 1.73$, $p = .116$, were significant overall.

The mean Group effect, averaged across rooms, was not significant ($p = .483$). However, post-hoc comparisons based on estimated marginal means revealed a significant difference between groups in Room 7, with significantly higher MI values in the control group than in the experimental group (Estimated difference = −0.48, $p_{holm} = .033$). No other rooms showed significant differences between groups. This result indicates that the AR/VR experience is associated with a lower demand for mnemonic and working memory resources, suggesting more fluent and less cognitively demanding processing than the traditional museum experience (Figure 19).

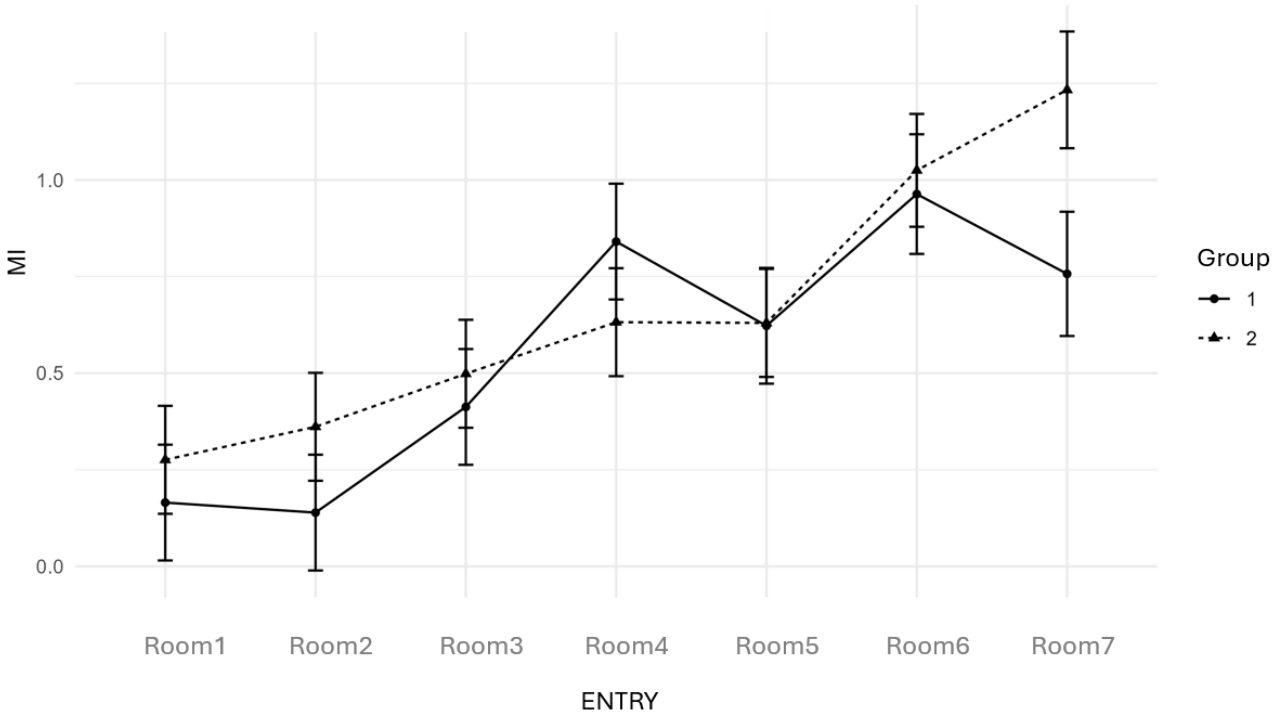

Figure 19. MI: LMM between-group comparisons within each museum room.

4.3.4 Neurophysiological results: Emotional Index

A linear mixed-effects model was estimated with Group, Entry, and their interaction as fixed effects and a random intercept per subject (y ~ Group × Entry + (1 | Subject)).For the EI index, Type III ANOVA showed a significant main effect of Entry, $F(6, 294) = 3.61$, $p = .0018$, indicating that the physiological emotional response varied according to the different rooms of the museum tour. In contrast, the main effect of Group was not significant, $F(1, 49) = 0.03$, $p = .870$, nor was there a significant Group × Entry interaction, $F(6, 294) = 0.46$, $p = .835$. The overall mean effect of Group, averaged across rooms, was not significant ($p = .870$). Furthermore, post-hoc comparisons between groups within each room did not reveal any significant differences for any entry after Holm correction.

The EI components (SC and HR) were then examined in more detail. No significant differences were found for SC, but a significant effect was found for HR. For this measure, ANOVA showed a significant main effect of Entry, $F(6, 294) = 3.02$, $p = .007$, indicating variations in cardiovascular response along the museum route. The main effect of Group was not significant, $F(1, 49) = 1.74$, $p = .194$, nor was the Group × Entry interaction, $F(6, 294) = 1.09$, $p = .367$. The mean Group effect, averaged across rooms, showed no significant differences ($p = .194$) (Figure 20).

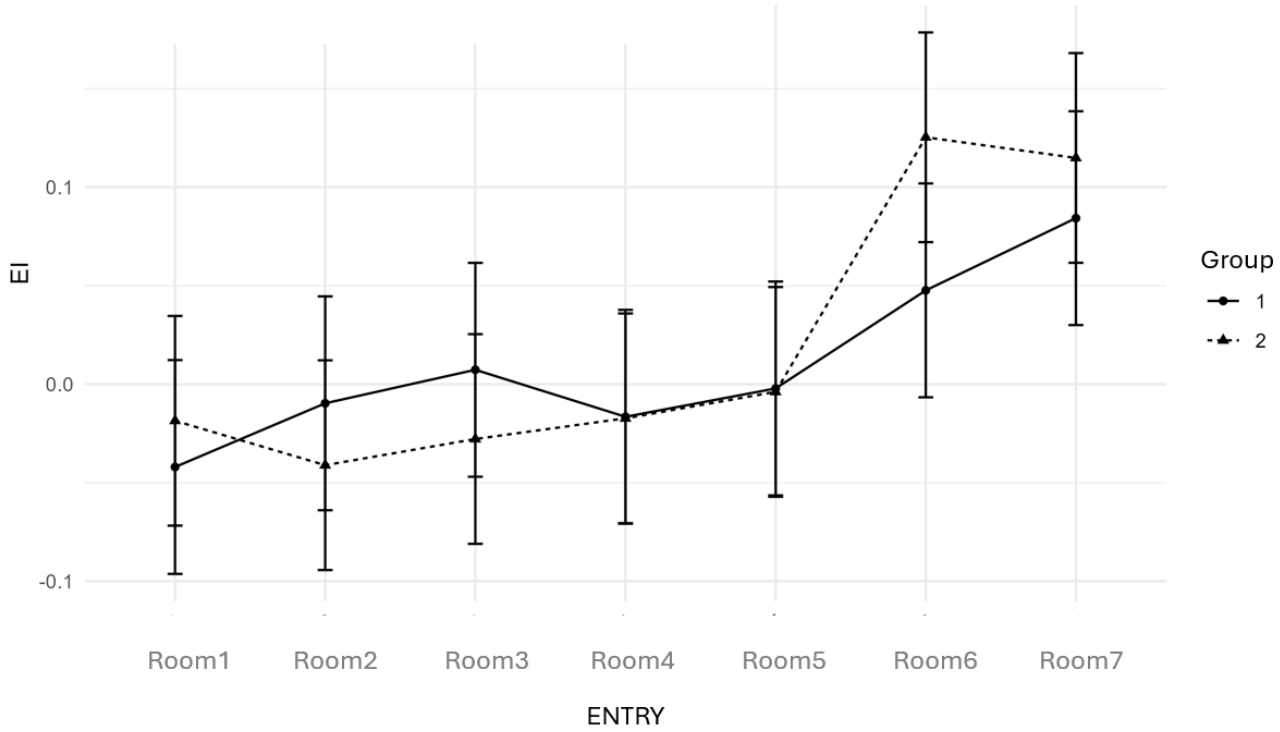

Figure 20. EI: LMM between-group comparisons within each museum room.

However, post-hoc comparisons between groups within each room revealed a significant difference in Room 7, with significantly higher HR values in the control group than in the experimental group (Estimated difference = −1.10, p_{holm} = .0104). No other rooms showed significant differences between groups (Figure 21).

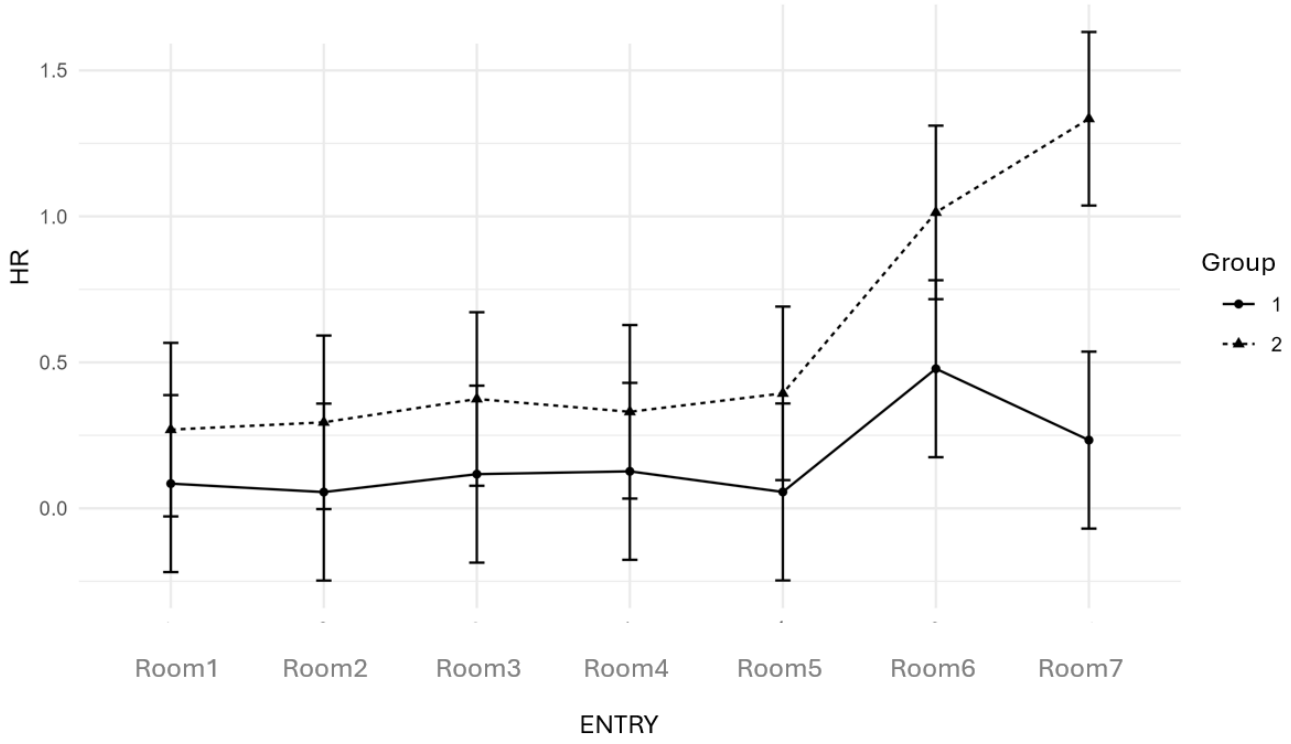

Figure 21. HR: LMM between-group comparisons within each museum room.

4.3.5 Neurophysiological results: Immersion

To assess how Immersion peaks differed across rooms, a linear mixed-effects model was estimated with Group, Entry, and their interaction as fixed effects and a random intercept per subject (y ~ Group × Entry + (1 | Subject)). Type III ANOVA showed a significant main effect of Group, $F(1, 48) = 107.01$, $p < .001$, a significant main effect of Entry, $F(6, 288) = 16.00$, $p < .001$, and a significant Group × Entry interaction, $F(6, 288) = 18.26$, $p < .001$.

The main effect of Group indicates that, on average, Immersion peak values were higher in the experimental group than in the control group. However, the presence of a strong interaction suggests that this difference varies substantially across rooms.

Post-hoc comparisons between groups within each room showed significant differences in favor of the experimental group in several conditions. In particular, the experimental group showed significantly higher Immersion peak values than the control group in Room 1 ($p = .0015$), Room 2 ($p = .0006$), Room 5 ($p = .0002$), Room 6 ($p = .0235$), and, most notably, in Room 7 ($p < .0001$). No significant differences between groups were observed in Rooms 3 and 4.

Analysis of comparisons between rooms within each group showed a clearly divergent pattern. In the control group, Room 7 was associated with significantly lower Immersion peak values than all other rooms ($p < .0001$), indicating a drastic decline in overall performance in this phase. In contrast, in the experimental group, Immersion peak values were stable and consistent throughout the entire route, with no significant differences between rooms, including Room 7 (Figure 22).

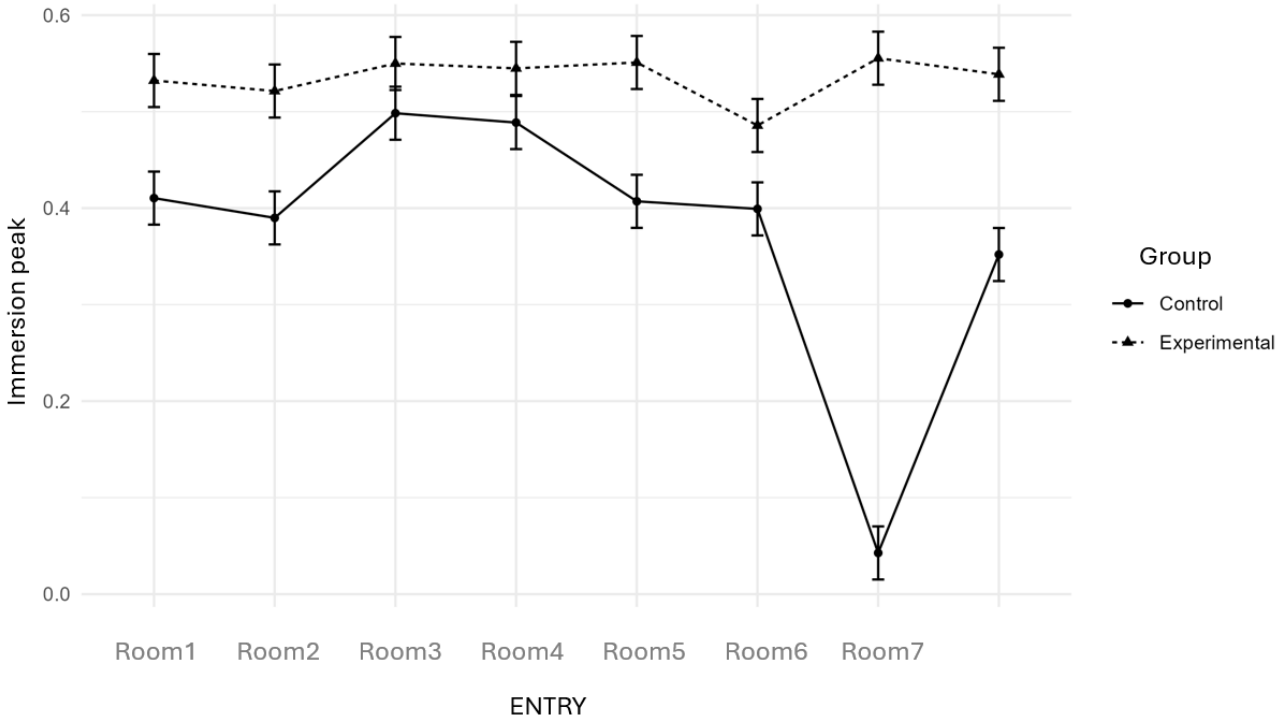

Figure 22. Immersion peaks: LMM between-group comparisons within each museum room.

4.3.6 Immersion peaks in the experimental and control groups

To verify the differences between the experimental group and the control group in terms of the overall Immersion levels of the experience, an independent sample t-test was conducted. The overall average of the Immersion peaks in the various rooms of the museum was used as the dependent variable.

A statistically significant difference emerged between the two groups ($p < .001$; $t(48) = -10.79$). The experimental group showed significantly higher Immersion peak scores ($M = 0.535$; $SD = 0.032$) than the control group ($n = 25$; $M = 0.379$; $SD = 0.065$).

Cohen's d ($d = -3.05$, $SE = 0.52$) showed a large effect size. The negative sign of d is due to the order of subtraction of the groups (control − experimental) and reflects the greater Immersion observed in the experimental group.

The Brown–Forsythe test suggested ($p < .05$) a violation of the assumption of homogeneity of variances. However, the large effect size and consistency of the differences observed indicate that the result can still be considered robust.

To support the robustness of the results, the distribution of standardized residuals was also examined using a Q–Q plot (Figure 23). Visual inspection of the graph shows that the points are mainly arranged along the theoretical diagonal, with limited deviations confined to the tails of the distribution, suggesting approximate normality of the residuals. Therefore, the trend of the Q–Q plot supports the appropriateness of using the t-test. Furthermore, Cohen's d shows a large effect size ($d = -3.05$). Therefore, the difference observed in Immersion levels

between the experimental group and the control group does not appear to be attributable to substantial deviations from statistical assumptions.

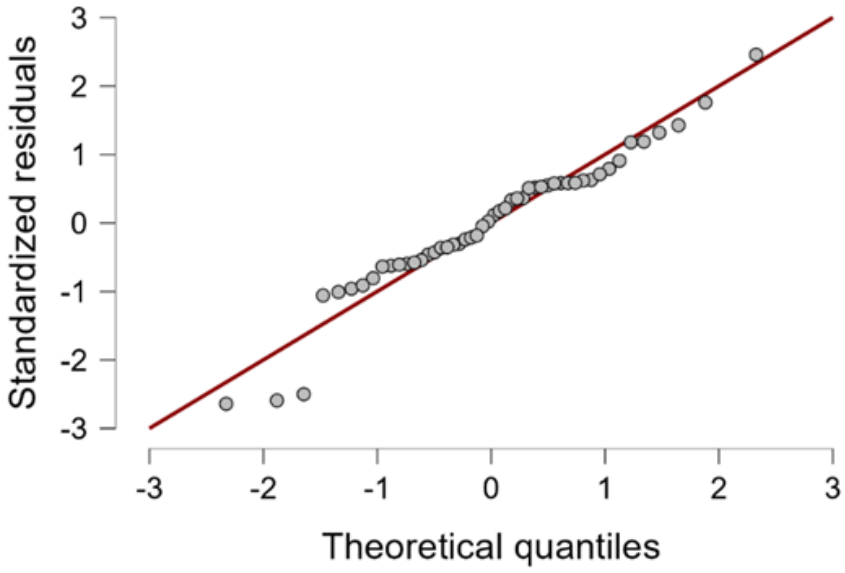

Figure 23. Q–Q plot of the distribution of data related to immersion peaks

Overall, these results support the hypothesis that the experimental experience elicited an increase in the magnitude of immersion peaks.

4.3.7 The effect of sex, age, and group on immersion

In order to verify whether the differences observed in Immersion levels were specifically attributable to the experimental condition rather than sociodemographic variables, a multiple linear regression was conducted. The dependent variable was the overall average of Immersion peaks during the entire experience. Age, gender, and group (control vs. experimental) were included as predictors.

The complete model (M_1) showed values that explained a large part of the variance in Immersion (R^2 = .716, adjusted R^2 = .691). An analysis of variance confirmed that the overall model was statistically significant, $F(4, 45) = 28.41$, $p < .001$.

Regarding predictors, the only variable that was statistically significant ($p < .001$) was group membership ($b = 0.156$; $SE = 0.015$; $t = 10.48$).

Neither age ($p = .465$) nor gender ($p > .52$) showed significance in the model. No multicollinearity problems were found among the predictors. Specifically, the VIF values were 1.03 for age, 1.02 for gender, and 1.01 for the experimental group, while the corresponding tolerance values were high (Tolerance = 0.97; 0.98; 0.99).

Therefore, the results suggest that Immersion peak scores related to the museum experience are attributable to the experimental manipulation rather than to individual differences in gender and age.

4.3.8 Donations between the two groups

Concerning the donations made to the museum at the end of the study, only two subjects in the experimental group donated €10. For this reason, the analysis of the data for the Italian sample focused mainly on the questionnaire subscale relating to the intention to donate. To verify the effect of the experimental manipulation on the latter, an independent-samples t-test was conducted comparing the experimental and the control group. The dependent variable was the difference score (post-minus-pre) relating to the intention to donate in support of cultural heritage over the following six months.

The intention to donate was measured using items adapted from the Assessment of Blood Donation Intention scale, developed according to the Theory of Planned Behavior (Faqah et al., 2015). The original items ("I will donate blood in the coming six months"; "I want to donate blood in the coming six months") were adapted to the topic covered by the present study. However, the time frame and the theoretical function of the behavioral intention to donate remained unchanged. The final items were therefore reformulated as follows: "I will donate to support cultural heritage in the next six months" and "I want to donate to support cultural heritage in the next six months."

The subscale was administered before and after the museum visit. The difference in post–pre scores was then calculated to understand whether the visit could have influenced the intention to donate in the two groups.

Consistent with the hypothesis that the experimental group would express a higher intention to donate than the control group, a one-tailed t-test was used. The results showed a statistically significant difference, $p = .027$, $t(47) = -1.97$.

The experimental group obtained a mean score for donation intention ($M = 0.64$; $SD = 1.07$) that was higher than that of the control group ($M = 0.06$, $SD = 0.98$). Cohen's d ($d = -0.56$; $SE = 0.30$) showed a moderate effect size. The negative sign of d is due to the order of subtraction of the groups, i.e., the scores of the control group subtracted from those of the experimental group.

These results indicate that the experimental condition showed higher levels of intention to donate than the control condition.

4.3.9 Mediation analysis between group, immersion, and donation intention

4.3.9.1 Model 1

To assess whether the effect of the experimental manipulation across the two groups on intentions toward donating over the subsequent six months (measured as the difference in post–pre questionnaire scores) was mediated by Immersion peaks (defined as the overall

average of peak Immersion across the experience), a mediation analysis was performed. The model was estimated using the maximum likelihood (ML) method.

The analysis of direct effects did not show a significant effect (p = .628) of Group on the intention to donate (b = 0.237; SE = 0.489; z = 0.48; 95% CI [−0.834, 1.116]). The level of Immersion was also not a significant predictor of donation intention, showing a positive coefficient but characterized by high variability (b = 2.172; SE = 2.631; z = 0.83; p = .409; 95% CI [−2.935, 7.549]).

In contrast, membership in the experimental group showed a significant effect on Immersion levels, indicating a marked difference between the groups in mean Immersion peaks observed (b = 0.156; SE = 0.014; z = 10.97; p < .001; 95% CI [0.128, 0.184]).

As for indirect effects (relating to the effect of Group on donation intention mediated by Immersion peaks), these did not reach statistical significance (b = 0.339; SE = 0.442; z = 0.77; p = .444; 95% CI [−0.457, 1.192]). The total effect of Group on donation intentions, on the other hand, was significant (b = 0.575; SE = 0.287; z = 2.00; p = .045; 95% CI [0.006, 1.125]).

Taken together, these results suggest that the level of Immersion peaks did not mediate the relationship between membership in the experimental group and donation intention. The model explains a high proportion of the variance in Immersion peaks (R^2 = .708), but not in donation intention (R^2 = .087).

4.3.9.1 Model 2

Given the results of the previous model, it was deemed appropriate to further investigate the data. In particular, changes in pre-post scores on the donation intention subscale and the various dimensions related to artistic engagement were explored in greater depth, using scores from the Arts Engagement Scale subscales.

With regard to the difference in post–pre visit scores on the TPB donation intention subscale, subjects were divided as follows: 0 = those who showed no difference between pre and post (17 participants); 1 = those who increased their score after the visit (21 participants); 2 = those who decreased their score after the visit (12 participants).

Next, the analysis examined which aspects of the artistic experience most differentiated the participants who increased their propensity to donate from those who reduced it.

One-way ANOVAs were performed across the three groups, using the Arts Engagement Scale subscales, calculated as post–pre differences, as dependent variables.

In the ‘Social’ subscale, a significant group effect emerged, F(2, 46) = 3.19, p = .050, with an effect size of η^2 = .122 and ω^2 = .082. Levene's test indicated that the assumption of homogeneity of variances was met (p = .682). A post hoc comparison with Bonferroni correction was then performed, which found a significant difference only between the group that increased its intention to donate and the group that decreased it (p_{Bon}f = .047).

A significant difference between the groups was also found in the Behavioral subscale of the Arts Engagement Scale ($F(2, 46) = 4.69$; $p = .014$; $\eta^2 = .169$; $\omega^2 = .131$). Again, Levene's test indicated that the assumption of homogeneity of variances was met ($p = .063$). The post hoc comparisons with Bonferroni correction revealed a significant difference between the group that had increased its intention to donate and the group that had decreased its score after the visit ($p_{Bonf} = .011$).

No significant differences emerged between the groups for the other subscales of the Arts Engagement Scale. In fact, the Cognitive ($F(2, 46) = 0.003$; $p = .997$), Affective ($F(2, 46) = 0.81$; $p = .452$), and Connection ($F(2, 46) = 0.64$; $p = .534$) dimensions did not show statistically significant differences.

Among these, the Behavioral subscale showed the most marked effect. The items that make up this subscale focus on concrete and observable behaviors (e.g., the frequency of participation in artistic events and the habit of taking part in cultural activities). The latter is also consistent with the donation intention subscale, which refers to a planned behavioral change (Faqah et al., 2015). Furthermore, Immersion is also a measure that can be traced back to the prediction of observable behaviors, rather than to purely cognitive or affective assessments (Rancati et al., 2025). For these reasons, the behavioral subscale was selected as a mediator in the subsequent model.

A linear mediation model was then estimated using the average of Immersion peaks as the independent variable, the difference in post–pre scores on the behavioral subscale of the Arts Engagement Scale as the mediating variable, and the post–pre difference on the intention-to-donate subscale over the next six months as the dependent variable. The analysis was conducted using maximum likelihood estimation, and confidence intervals were calculated using a bootstrap procedure with 5,000 resamples in order to obtain robust estimates of indirect effects.

The results showed a non-significant direct effect of Immersion on donation intention ($\beta = 1.57$; $SE = 1.42$; $z = 1.10$; $p = .270$; 95% CI [−1.20, 4.30]). Therefore, Immersion does not directly predict change in donation intention.

In contrast, the effect of Immersion on the subscale related to behavioral engagement in the arts was significant ($\beta = 2.97$; $SE = 0.96$; $z = 3.10$; $p = .002$; 95% CI [1.26, 5.05]), suggesting that higher levels of Immersion are associated with increased behavioral engagement in the arts. The latter, in turn, significantly predicted the change in donation intention ($\beta = 0.56$; $SE = 0.27$; $z = 2.12$; $p = .034$; 95% CI [0.06, 1.10]).

The indirect effect of Immersion on donation intention, mediated by behavioral involvement, was significant ($\beta = 1.67$; $SE = 0.83$; $z = 2.03$; $p = .043$; 95% CI [0.32, 4.36]). Therefore, the results suggest that Immersion influences the intention to donate mainly through increased behavioral involvement in the arts.

Finally, the total effect of Immersion on donation intention was significant ($\beta = 3.24$; $SE = 1.53$; $z = 2.11$; $p = .035$; 95% CI [0.22, 6.31]). From the model, therefore, it would appear that the

immersive experience, through an increase in behavioral involvement in the arts, is associated with an increase in the intention to donate, albeit indirectly.

The model explains 20.8% of the variance in the change in donation intention and 14.9% of the variance in behavioral engagement in the arts. In conclusion, the results show that Immersion does not automatically increase the intention to donate, but indirectly, through increased behavioral engagement with art.

4.4 Discussion: study results in Italy

4.4.1 Neurophysiological results

The museum experience in the present study is complex, ecological, and layered. In this context, the introduction of AR and VR content mostly produced only trends in EEG indices, often without reaching statistical significance.

In many previous studies on the use of VR and AR in the arts and culture, EEG neurometrics have been used in experimental contexts characterized by marked and clearly distinguishable differences between conditions, such as controlled tasks or completely virtual environments (Giorgi et al., 2023; Castiblanco Jimenez et al., 2023). The aim of the present study, by contrast, was not to compare two different environments, but to understand the added value of new technologies in this field, without creating virtual substitutes for what is already present. As is often the case in more ecological contexts, technologies such as AR in museums tend to produce qualitative and incremental changes in the experience, rather than a radical transformation of the perceptual scenario (Roussou & Katifori, 2018).

Therefore, the fact that the two conditions shared a substantial portion of the experience, namely the same museum rooms, may have made the variations introduced in the experimental group difficult to detect and diluted during the visit, reducing the discriminatory power of neurophysiological indices. Furthermore, in more ecological contexts, EEG may show lower discriminatory capacity due to greater noise, the presence of artifacts, and lower signal stability (Ronca et al., 2026).

This interpretation is further supported by the fact that neurometrics showed more evident differences in the last room of the museum tour, where the experimental manipulation was more pronounced. In this context, the experimental group was exposed to a highly immersive, narrative virtual reality experience, while the control group had no technological mediation or storytelling, and the clues for understanding the content of the room were reduced, resulting in a clear and structural difference between the two conditions. Furthermore, this room lacked interactive content for the control group.

In scenarios characterized by radical differences between conditions, the indices used proved capable of detecting the variations induced by the experience (Giorgi et al., 2023; Marín-Morales et al., 2019). Conversely, in rooms where AR and VR acted as integrative elements of a shared baseline experience, these metrics showed limited sensitivity in this study (Ronca et al., 2026).

In this context, Immersion peaks, designed to capture even smaller and qualitatively different variations, showed a greater ability to capture overall experiential differences between groups (Zak & Barraza, 2018; Merritt & Zak, 2024).

Taken together, these results suggest that, in complex experiential contexts such as museum visits, metrics oriented toward experiential value, such as Immersion, may be more sensitive than traditional neurophysiological indices. In fact, the latter are more focused on very specific cognitive or affective components whose incremental differences may have been difficult to detect with other measures (Ronca et al., 2026).

Therefore, these results could indicate that the impact of AR and VR technologies in the museum context does not necessarily manifest itself as a linear increase in individual neurocognitive processes, but as an integrated reorganization of the experience (Song & Evans, 2024; Rolla et al., 2022). In this sense, tools capable of capturing its value dimension are more appropriate than metrics designed to isolate specific processes.

Given this initial premise, with regard to the initial hypothesis H1, the results obtained indicate that only in the last room was a difference found between the experimental and control groups. In this room, the BATR index was higher in the experimental group. Although there was also a VR experience in Room 5, no differences emerged.

The reported results are consistent with the literature on cognitive engagement in virtual reality. In a study in which the beta band was used as an indicator of cognitive engagement, it was found to be associated with 'active mental processing and cognitive engagement' during the most active phases of the museum experience (Castiblanco Jimenez et al., 2023). In an article by Škola et al. (2020), the integration of 360° immersive storytelling into the VR experience produced a significant increase in the beta band, interpreted as a sign of increased cognitive processing and greater user engagement within the virtual narrative.

Since the BATR index in the present study depends directly on the modulation of beta activity, this evidence supports the interpretation that the last VR room, characterized by dynamic and narrative content, was able to elicit greater cognitive engagement than the previous VR in Room 5, where the static nature of the stimulus probably required less cognitive involvement, which may therefore have resulted in lower BATR values.

As for the FTA index, contrary to the initial hypothesis, a statistically significant difference was found in Room 6. This room had no AR or VR stimuli and was therefore the same for both groups. Nevertheless, the experimental group showed higher FTA levels. These results are consistent with those reported in a study by Li et al. (2020), which explored how the effects of the VR experience may not necessarily manifest during immersive interaction but may take the form of a carry-over effect that emerges in the subsequent minutes. In the study by Li et al. (2020), subjects explored an immersive natural VR environment. This setting is designed to induce soft fascination and relaxation, without demanding cognitive tasks. This type of experience can be compared to the Buddhist temple that the participants in the present study visited in Room 5. Subsequently, the paper shows that frontal theta oscillations appear only after the VR experience, during a subsequent task (Li et al., 2020). Another hypothesis could

be that, after the first VR experience, the participants in the experimental group experienced a sort of reorientation towards the real rooms of the museum. Therefore, the rapid reallocation of attention may have induced an increase in theta activity in the frontal regions (Lin et al., 2008).

The second VR experience, based on a dynamic 360° video, produced an immediate and significant orientation towards stimuli of interest, as indicated by the FTA index values. This dynamic is consistent with the findings of Škola et al. (2020), who reported that dynamic viewing of immersive and narrative 360° content causes an immediate increase in frontal theta power during the early stages of the experience. Therefore, the dynamic, novel, and salient nature of the VR video in the second condition, characterized by continuous visual flow, movement, and greater narrative richness, may have been a plausible factor in explaining the immediate increase in theta signal detected in the FTA, compared to the first static VR experience, which was perhaps less relevant and less engaging. Therefore, the experimental hypothesis (H2) can be confirmed only for VR content of a more dynamic and narrative nature.

Concerning the WL index, as hypothesized (H3), the experimental group did indeed experience lower overall levels of this indicator. Once again, however, only in the last room was there a significant difference between the two groups. In this regard, it should be noted that the experience in the last VR room was able to provide more consistent multisensory stimuli to the experimental group, facilitating understanding of the meaning of the space and reducing cognitive demand. Marucci et al. (2021) show that the presence of multisensory stimuli integrated into VR leads to a significant reduction in EEG-based workload compared to visual stimulation alone.

The same pattern emerges in the study by Giorgi et al. (2023), in which the real visit to the Sarcophagus of the Spouses induces a higher EEG workload than its VR experience ($p = 0.04$). The authors interpret VR as a more 'simplified' and perceptually guided environment, which requires fewer cognitive resources to be understood.

In line with these results and considering that the WL index was generally lower in the experimental group compared to the control group, it can be hypothesized that in this study as well, VR (and to a lesser extent AR) provided a more structured and semantically rich set of information, allowing participants to understand the environment with less cognitive effort. This is particularly evident for the control group in the last room (probably lacking cues and context), which showed a higher cognitive load.

Regarding to hypothesis H4, the results obtained for MI are consistent with those presented above. A difference between the experimental and control groups emerged only in the last room, where the working memory load was probably greater for the control group. Lower levels of MI (based on theta power in the left frontal area) for the experimental group, observed in the last VR room, are consistent with the EEG literature on working memory in immersive environments. For example, Kisker et al. (2021) show that, during memory retrieval, frontal theta oscillations reflect greater involvement of the working memory needed to reconstruct an episode. In their study, the VR condition shows an attenuation of the theta response and a disappearance of the classic old/new effect, interpreted as an indication of

more immediate, direct retrieval with less cognitive effort compared to content presented on a PC (Kisker et al., 2021). Therefore, the VR content may have reduced the demand on working memory during exploration of the room.

In another study, Škola et al. (2020) also show that VR environments with immersive storytelling produce more guided and semantic processing of the scene, reducing the need to actively maintain and organize information. Dynamic narration allows for a more structured flow of information, supporting the user and decreasing the executive load associated with autonomous context construction (Škola et al., 2020). Consequently, the combination of greater Immersion and storytelling may have reduced working memory demands, producing lower MI values while maintaining a high level of cognitive engagement.

As for EI, contrary to the initial hypothesis (H5), it did not show significant differences between the two groups in the various rooms of the museum. By contrast, a significant difference in HR was observed, once again, in Room 7. The latter could be due to the physical characteristics of the room itself, rather than its content and how it is experienced. The last room, in addition to being lacking orientation cues, was also much darker than all the others in the museum. It should be noted, however, that the experimental group experienced a different lighting condition in that area than the control group. The experimental group wore a headset that provided stable, artificial internal lighting independent of the real environment. Therefore, the two groups did not experience the same lighting conditions, as the control group was directly exposed to the physical room. As shown by Weijs et al. (2023), changes in brightness systematically alter HR and HRV, regardless of emotional content. VR provided internal artificial light, while the control group was immersed in the actual dark room. HR is very sensitive to ambient brightness (Weijs et al., 2023), so the difference in HR between groups could be due to a different light environment, not an emotional difference.

Therefore, the difference in HR between the two groups could be attributed to the effect of different light conditions and not to a difference in emotional response, as confirmed by EI, which showed no significant differences between groups.

4.4.2 Interpretation of the Immersion results

Hypothesis H6 can be considered for the most part confirmed. In fact, apart from two rooms, the experimental group showed higher levels of Immersion peaks than the control group. The greater Immersion detected for the experimental group can be interpreted in light of Zak's (2015) studies, according to which engaging and coherent narratives increase oxytocin levels and generate greater attention and engagement. Since the experimental group experienced storytelling during the visit, it underwent the effects of narrative engagement during the tour. This element is consistent with Zak's (2025) narrative immersion model, according to which high immersive engagement can be attributed to the presence of narrative content. Furthermore, some studies on the use of VR and AR in museums have shown a significant increase in self-reported immersion levels (Lee et al., 2019; Jangra et al., 2025).

The only two rooms in which no significant difference emerged from the control group were Rooms 3 and 4. In the present study, WL showed higher levels starting from Room 3, which

included three different AR contents. According to Buchner et al. (2022), when AR provides too much information at once, it increases the risk of overload, as the stimuli are numerous and require constant shifts in attention. As already mentioned, this room presented several AR stimuli in close proximity, with heterogeneous content. This high level of interactivity may have had the effect of reducing immersive engagement. In fact, a study on museum fatigue (Miao et al., 2024) found that dense exhibitions that are too rich in narrative content can exacerbate fatigue and reduce attentional capacity. This may have had a knock-on effect in Room 4 and probably resulted in a reduced effect, compared to the other rooms, in terms of Immersion, which nevertheless remains higher than in the control group.

In addition, Room 3 featured many interactive elements that were also accessible to the control group (e.g., the use of LED lights to determine whether an object was authentic and the use of microscopes). Therefore, the small difference in Immersion observed between the two groups can be interpreted in light of the fact that the room was already quite interactive (Allen, 2004). In fact, direct interaction with objects, supported by simple but culturally intelligible tools, can foster sustained engagement and promote a self-guided inquiry experience. Such conditions are known to support states of attentive absorption and active participation, which are fundamental elements of the immersive experience (Allen, 2004).

Similarly, in Room 4, participants in the control group also showed good levels of Immersion. Unlike the previous rooms, this room consisted solely of tapestries hanging on the walls, with no other elements of a different nature. Therefore, it presented itself as a single, coherent, and all-encompassing environmental stimulus, free of competing elements or demands for interpretation. In line with Forrest's study (2013), this configuration can promote a holistic and absorbing experience, in which the visitor's attention is captured by the environment as a whole rather than distributed among individual objects or tasks.

Subsequently, Room 5 introduced the experimental group to a unified and sensorially immersive VR experience. The literature notes that non-complex immersive experiences can reduce fatigue and increase concentration (Miao et al., 2024), restoring Immersion. This is perfectly consistent with the difference between the two groups in the levels of Immersion detected in Room 5, where there was a VR experience of a Buddhist temple. In contrast, the control group could only focus on the various elements present in the room. Therefore, the VR experience, being the first one carried out inside the museum, may have restored higher Immersion values, which were then maintained in Room 6.

The last VR room produced the highest levels of Immersion across the entire tour, a result that can be interpreted through the combination of storytelling and a multisensory experience. According to Zak, emotionally engaging narratives have an impact on the release of oxytocin, promoting sustained attention and empathy: “compelling narratives cause oxytocin release and have the power to affect our attitudes, beliefs, and behaviors” (Zak, 2015). Similarly, Uvnäs-Moberg et al. (2015) show that non-harmful, multimodal sensory stimulation, such as sound, light, and meaningful images, can activate sensory pathways that promote oxytocin release, supporting calmness and engagement.

The VR experience in African Room 7 combines both of these elements: an emotional narrative (the journey on the turtle) and an immersive multisensory environment (360° visuals, sounds, and a ritual atmosphere). According to the literature, this combination represents the ideal condition for the activation of oxytocinergic systems associated with Immersion, explaining the marked increase in engagement observed in the experimental group (Zak, 2015; Uvnäs-Moberg et al., 2015).

4.4.3 Overall Immersion levels of the experience

The adoption of immersive technologies such as virtual reality (VR) and augmented reality (AR) in museum contexts has been extensively studied in recent years, especially in relation to their potential to increase visitor engagement, the sense of presence, and the overall quality of the visitor experience. Numerous empirical studies and systematic reviews agree that augmented technologies promote experiences characterized by greater engagement, increasing Immersion, the sense of presence, and visitor agency (Innocente et al., 2023). However, most of these studies have investigated these effects through subjective measures, such as self-assessment questionnaires, post-visit interviews, or perceived experience scales, with the inherent limitation of relying on retrospective accounts and conscious cognitive processes (Dufresne-Tassé et al., 2022).

In particular, the museological literature has highlighted sometimes conflicting results on the effectiveness of immersive experiences. For example, Dufresne-Tassé and colleagues (2022) created immersive museum rooms using projectors in their study. These authors found no significant differences in self-reported immersion between more or less immersive exhibition conditions, suggesting that such outcomes may depend, at least in part, on the conceptual and methodological limitations of the measurement tools used (Dufresne-Tassé et al., 2022). Numerous studies on the use of VR and AR in museums have shown significant increases in visitor immersion, engagement, and satisfaction, but have operationalized these constructs mainly through standardized questionnaires (Lee et al., 2019; Jangra et al., 2025). In this vein, Lee and colleagues (2019) demonstrated that museum VR experiences increase the immersive dimensions of escapism and aesthetics, which in turn improve the overall experience and intention to revisit, while Jangra et al. (2025) highlighted significantly higher levels of immersion in fully immersive VR experiences compared to semi-immersive ones. However, in both cases, immersion was understood as a perceived experience and measured exclusively through self-report.

In light of these limitations, this study is based on a conception of immersion not as a simple subjective perception, but as a dynamic neuropsychological state characterized by the integration of attentional and emotional processes. As previously mentioned, according to the neurophysiological model proposed by Zak and Barraza (2018), immersion emerges from the combination of sustained attention, associated with dopaminergic mechanisms, and emotional involvement, mediated largely by oxytocin. This state is not fully accessible to individual awareness and is therefore difficult to measure using self-report instruments, which are known to be influenced by memory biases, social desirability, and individual differences in the interpretation of response scales (Zak & Barraza, 2018). The use of the Immersion

Neuroscience platform, on the other hand, allows Immersion to be measured as a continuous neurophysiological process, identifying specific Immersion peaks that reflect moments of high experiential value.

In this theoretical framework, the results obtained in the present study, which show significantly higher overall levels of Immersion peaks in the experimental group exposed to museum experiences with VR and AR compared to the control group, are fully consistent with the existing literature. Previous questionnaire-based studies have already documented significant differences in perceived immersion levels between traditional and technologically enriched museum experiences (Lee et al., 2019; Jangra et al., 2025); the present work extends this evidence by demonstrating that these differences also manifest at an objective neurophysiological level. The particularly high effect size observed (d = −3.05) is consistent with the hypothesis that immersive technologies simultaneously amplify visitors' attentional mechanisms and emotional engagement, producing more intense and consistent neurophysiological responses than traditional visits. Recent evidence also indicates that neurophysiologically measured Immersion peaks represent distinct and significant events, capable of predicting relevant psychological outcomes such as mood and subjective well-being with high accuracy (Merritt & Zak, 2024).

Therefore, the results of this study are not only consistent with the literature documenting the effectiveness of VR and AR in enhancing the museum experience, but also help to clarify the discrepancies that emerged in previous studies, showing how the adoption of neurophysiological measures allows researchers to capture dimensions of immersion that remain partially invisible to tools based exclusively on self-assessment. In this sense, the work provides an original contribution to the field, filling a significant methodological gap in the study of immersive technologies in museums.

4.4.4 The results of the two donation models

The literature highlights the role of immersive technologies, such as VR and AR, in promoting prosocial behavior by increasing experiential immersion. Previous studies show that VR is capable of generating higher levels of immersion than traditional formats, activating emotional processes that, in turn, increase the intention to donate time and money to a cause (Kandaurova & Lee, 2018). Similarly, experimental evidence based on actual donation behavior shows that immersive VR experiences produce significantly higher donation amounts than non-immersive content, suggesting that immersion reduces psychological distance and strengthens user engagement (Kristofferson et al., 2022). Furthermore, the neuroscientific literature on immersion indicates that experiences characterized by high attentional and emotional engagement can predict actions following the experience (Zak & Barraza, 2018).

Contrary to what is indicated in the literature, however, with reference to H7 and H8, only two people in the experimental group made a direct monetary donation to the museum. Therefore, these two hypotheses were rejected. Although H9 was confirmed, the same cannot be said for H10, as Immersion did not mediate the effect of the experimental condition on the intention to donate within 6 months.

In fact, in the present study, the experimental group obtained a statistically significant mean donation intention score that was higher than that of the control group. Furthermore, technological manipulation (VR/AR) seems to have produced an increase in neurophysiological Immersion (measured as the overall average of Immersion peaks). However, the latter was not significant in the first model tested, in which it was included as a mediator in relation to the intention to donate over the following six months.

Immersion was developed precisely to capture the neurophysiological value of socio-emotional experiences and to predict behavioral outcomes (Rancati et al., 2025). Therefore, at a theoretical level, the results of some studies in which this measure was used could suggest that it could potentially serve as a mediator in the relationship between the museum visit experience and the TPB subscale on the intention to donate within six months.

Immersion has been validated as a neurophysiological indicator capable of predicting behavioral outcomes observable in free-choice contexts (Lin et al., 2022; Rancati et al., 2025). The fact that the first mediation model tested in the present study was not statistically significant helps to more precisely delimit the scope of Immersion's influence, highlighting its boundaries with respect to longer-term intentional constructs. Neurophysiological Immersion has been shown to predict observable and discretionary behaviors in the short term, such as persistence in the experience, exposure time, or the choice to take immediate action, but it has not been tested on medium- or long-term intentional assessments (Lin et al., 2022; Zak & Barraza, 2018).

Therefore, testing whether the level of Immersion peaks could play a mediating role in the intention to donate addressed the need to verify whether a high-neurophysiological-value experience could also have an effect on medium-term prospective assessments. The results suggest that this time lag is a critical element.

The lack of statistical significance of the first model and the hypothesis that Immersion was not significant because the outcome refers to a medium-term timeframe is in line with some key aspects of the TPB. Because it refers to a relatively broad time horizon (“in the next six months”), it reflects a more deliberative and multi-determined decision-making process than the immediate neurophysiological response to the experience (Faqah et al., 2015).

In the present study, Immersion appears to capture the value of the experience, but it is not sufficient on its own to translate into a direct change in the intention to donate within six months, which by definition requires the integration of feasibility assessments and norms, as well as motivations (Faqah et al., 2015).

By contrast, the second model tested (Immersion → behavioral engagement → intention to donate within six months) is more aligned with both the nature of Immersion and the conceptualization of arts engagement. Kemp (2015) defines arts engagement as a set of responses evoked by the artistic experience (affective, cognitive, behavioral, social, and connection-related) and explicitly emphasizes that when engagement is strong, it manifests in behavioral actions, such as participation and volunteering.

In this context, Immersion can be interpreted as a neurophysiological condition that signals high experiential value and, as indicated in the literature, can predict the adoption of observable behaviors (Rancati et al., 2025). According to the TPB, however, the intention to donate can be influenced by many factors, many of which are related to perceived behavioral control (Ajzen, 1991). In the Italian context, donating is not as widespread a behavioral norm as in other countries, such as the United States.

Consequently, it is plausible that the effect of the immersive experience was expressed in terms of behavioral dispositions towards art (a greater propensity to 'do', i.e., participate, support, and attend), and that only subsequently did this translate into a greater explicit intention to donate in the medium term. This interpretation is also consistent with the evidence that, when observing costly outcomes such as donations, neurophysiological signals of value tend to influence behavior through more proximal intermediate steps (e.g., greater persistence/time on task) (Lin et al., 2022), making this second model theoretically more appropriate than a direct link between Immersion and the intention to donate within six months.

In light of these results, the comparison between the two models tested allows the theoretical framework to be refined, showing that in certain cases the effect of the immersive experience can be expressed through behavioral mediators consistent with the neurophysiological nature of the Immersion measure, as already highlighted by studies showing how Immersion influences behavior through proximal intermediate steps (e.g., greater engagement, persistence, or interaction time), rather than through a direct impact on intentional decisions at longer time horizons (Rancati et al., 2025; Merritt & Zak, 2024).

4.5 Conclusions of the study in Italy

Overall, the study conducted in Italy indicates that the introduction of AR/VR content within a museum tour can increase levels of neurophysiological Immersion in the experimental group. In line with the hypotheses formulated, the manipulation is therefore effective in modifying the experience in an immersive sense at a neurophysiological level, consistent with previous studies that relied on self-report measures, which may be subject to self-report biases.

However, the results suggest a more complex picture. In the first mediation model, Immersion peaks did not mediate the intention to donate within the following six months. In particular, the direct effect of Group on intention was not significant, and the indirect effect of Immersion peaks also failed to reach significance. This pattern, together with the low explained variance of donation intention (R^2 = .087) and the high explained variance for Immersion peaks (R^2 = .708), indicates that AR/VR robustly modifies the experience, but this increase does not automatically translate into a linear and direct change in medium-term intentions.

The second proposed model allows for a more precise understanding of the mechanism. In fact, the effect of Immersion seems to be expressed more consistently when considering an intermediate behavioral step, namely an increase in behavioral engagement in the arts, which in turn is associated with a greater intention to donate in the medium term. This interpretation is in line with a conceptualization of arts engagement as a multidimensional construct that,

when consolidated, tends to manifest in actions and behavioral dispositions (Kemp, 2015), and with the idea that neurophysiological signals of experiential value influence outcomes such as donations through more proximal intermediate steps (Lin et al., 2022). From an applied perspective, these results suggest that immersive technology can contribute to the sustainability of museums, especially when the experience is designed to transform the immediate impact (Immersion) into a greater willingness to act and a more stable connection with cultural and supportive practices.

Finally, regarding EEG measurements, in an ecological and layered museum context, differences between conditions tend to emerge predominantly as trends and are more evident when the experimental manipulation is more distinct. For example, in the last room, with highly immersive narrative VR, several significant differences emerged across the EEG indices. In this room, the two groups experienced more markedly different experiences than in the previous environments, where AR and VR had been implemented more as support for the visit. This is consistent with the idea that neurophysiological indices are more discriminative in the presence of marked contrasts between conditions and more attenuated when AR/VR operate as incremental elements of a shared experiential baseline (Marín-Morales et al., 2019; Roussou & Katifori, 2018).

4.6 Limitations of the Italian study

A first significant limitation concerns the potential reduction in ecological validity due to the combined use of neurophysiological instruments, especially EEG and Shimmer. Although these measures increase the objectivity of the experiential assessment, their presence may have made the visit feel more like an experimental situation than a spontaneous museum experience. In this context, it is plausible that participants modulated their post-visit behavior, particularly their immediate donation, due to their awareness of being in an experimental setting, thereby diminishing the naturalness of the decision. This interpretation is consistent with the observed outcome, as only two people actually made a donation.

Furthermore, the study was unable to systematically monitor whether the participants' stated intention to donate translated into actual donations in the weeks or months following the visit. As a result, the main outcome remains an intentional rather than behavioral indicator, with an inevitable limitation in terms of predictive validity for actual financial support for the museum.

A further limitation concerns the duration and complexity of the experimental protocol, carried out in a museum divided into seven rooms and characterized by a long overall visit. Prolonged exposure can lead to fatigue and lapses in attention, increasing intra-subject variability and making neurophysiological indicators less stable over time. In addition, the length of the protocol increased the likelihood of technical issues typical of wearable devices in field settings (e.g., device disconnections, loss of recording segments), resulting in reduced data completeness and possible attenuation of statistical sensitivity in detecting differences between conditions.

In addition, some characteristics of the museum may have reduced the discriminatory power of the neurophysiological measures. The selected museum already included rooms with

interactive features shared by both groups. This may have reduced the effective contrast between the classic visit and the AR/VR-mediated visit, producing a common experiential baseline and limiting the ability of neurophysiological indices to discriminate between conditions when the manipulation is grafted onto an already stimulating experience. In other words, in an environment already rich in stimuli, neurophysiological indices may have been less sensitive given the insufficiently marked differences between conditions.

In light of these elements, a further limitation concerns the adequacy of the measurement strategy in relation to the objective of the work. Since the study aims to evaluate the introduction (and not the replacement) of museum visits through technological tools, a broad neurophysiological battery may have represented a high methodological cost in terms of intrusiveness and operational complexity, without a proportional gain in explanatory power regarding prosocial outcomes. In this sense, a single, more parsimonious measure directly linked to the quality of the experience, such as Immersion, would perhaps seem more appropriate for capturing the relevant neurophysiological impact of museum visits in naturalistic settings, while reducing threats to ecological validity.

Chapter 5: the experiment in the United States

5.1 Introduction and hypotheses

A second study was conducted in a cultural context different from that of Italy, namely the United States. The purpose of this replication was to assess similarities or differences between the results obtained in Italy, in order to determine whether they could be generalized to a different context. As in the Italian context:

H1. The experimental group is expected to show higher overall levels of Immersion peaks than the control group.

As demonstrated previously, it is plausible in this case too to expect higher levels of Immersion peaks in the experimental group than in the control group. As previously stated, in addition to the experiment presented above, other studies on VR/AR in museums report significant increases in immersion (Lee et al., 2019; Jangra et al., 2025), and neurophysiologically measured Immersion peaks are higher when participants undergo an engaging experience (Zak, 2015).

Furthermore, with regard to the previous hypothesis that was rejected in the Italian context, it is expected that in the U.S. context, a higher level of Immersion peaks will lead to direct donations, as hypothesized in the first model. This is because the United States is a country where it is very common to leave a tip or a small monetary donation after using a service. This practice is more regulated and socially expected than in other European contexts, including Italy (Smith, 2023). Therefore, this would suggest that cultural learning of this practice could act as a key determinant of the outcome.

H2. The experimental group is expected to make more direct donations to the museum than the control group.

Consequently, contrary to what emerged in the Italian context, Immersion peaks may be associated with the probability of donating immediately after the experience. This hypothesis is in line with previous literature, in which studies have been conducted on donations in the U.S. context and according to which Immersion is able to predict donation behavior (Zak & Barraza, 2018; Lin et al., 2022).

H4. It is hypothesized that higher levels of Immersion predict a greater likelihood of making direct donations to the museum and that Immersion mediates the effect of the experimental condition on donations.

Furthermore, as mentioned above, the literature suggests that immersive and narrative experiences can promote a more lasting predisposition to prosocial behavior (Zak, 2015; Zak, 2022). Accordingly, the intention to make future donations may also be affected, if individuals perceive themselves to be in tune with perceived norms and feasibility assessments, as posited by the TPB (Faqah et al., 2015). Therefore, in this case, immersive experiences could effectively increase awareness and openness to support and donation practices (Pitsillides et al., 2022).

H5. The experimental group is expected to report a greater intention to donate over the next six months than the control group.

In the study conducted in Italy, experiencing higher levels of Immersion was not sufficient to translate into a direct change in the intention to donate within six months. This is because, in accordance with the TPB, this would require the integration of feasibility assessments and norms, as well as motivations (Faqah et al., 2015). In this regard, it is hypothesized that the U.S. sample, having already culturally internalized certain norms and given that donation is a frequently practiced behavior in this country, will not need to show greater behavioral engagement as an intermediate step.

H6. It is hypothesized that higher levels of Immersion predict a greater intention to donate over the next six months, and that Immersion mediates the effect of the experimental condition on this intention.

5.2 Method

5.2.1 Participants

For this study, 50 participants were also recruited. This is consistent with the sample size previously used for measures such as Immersion Neuroscience (Lin et al., 2022) and other neurophysiological data (Garczarek-Bąk et al., 2021; Fici et al., 2024).

Furthermore, a sensitivity analysis was conducted in G*Power (Faul et al., 2009; $\alpha = .05$; $1-\beta = .80$; two-tailed test; $n_1 = n_2 = 25$). The analysis indicated a detectable effect size of Cohen's $d = 0.81$, corresponding to a medium-to-large effect for the experimental versus control group comparison (Cohen, 2013). An additional sensitivity analysis was performed in G*Power using an F-test ($\alpha = .05$; $1-\beta = .80$) to evaluate a linear regression model with two predictors (group and Immersion).

This analysis yielded a moderate effect size ($f^2 = 0.164$; Cohen, 2013). Accordingly, the proposed sample size appears sufficient to detect a unique effect of the mediator Immersion on the donation outcome, controlling for group.

This study was approved by the Institutional Review Board of Claremont Graduate University, and all participants provided written informed consent before being included in the study.

5.2.2 Materials

A brief review was conducted on museum attendance to understand which type of museum would be most appropriate for the present study. The review took into consideration museums in California, the state where the experiment took place. Although the California Science Center in Los Angeles is the most visited museum in California, with approximately 1,700,000 visitors according to the TEA Global Experience Index™ (Theme Index and Museum Index 2024), a more detailed analysis of museum attendance, which explored the museums next in the rankings of the most visited, showed that the largest overall number of visitors is

concentrated in art museums. In fact, the data indicate that the J. Paul Getty Museum recorded 1,301,332 visitors, the Los Angeles County Museum of Art (LACMA) 873,825 visitors, and The Broad 846,500 visitors (Cheshire & Goukassian, 2025). The total attendance of these three art museums therefore amounts to 3,021,657 visitors. These results suggest that overall cultural demand is directed toward art museums when considering aggregate visits to multiple institutions. For methodological reasons related to the limitations highlighted in the study conducted in Italy, a small-scale art museum was sought. The Claremont Lewis Museum of Art was therefore selected.

The AR content was accessible exclusively to participants assigned to the experimental condition, who interacted with it via a Lenovo Tab M10 tablet. Access to the AR experiences was provided through the ARLOOPA application (ARLOOPA, Inc.), which allowed AR videos to be activated by scanning dedicated markers placed in the three museum rooms.

The two virtual reality experiences were carried out using a Meta Quest 3 headset. The first VR experience, in the first room of the exhibition, consisted of a 360° video in which the gallery changed color, in line with the main theme of the museum exhibition (Complications in Color). The experience was created using an Insta360 One X2 camera and edited using DaVinci Resolve Studio version 20 software. This made it possible to insert the effect whereby the room changed color during the video, creating new tones and contrasts compared to the original paintings in the first room.

The last VR experience, located in the last room, was created using Blockade Labs' Skybox AI platform. This consisted of a 'stepping inside the artwork's experience. Specifically, the interior of a sculpture that was present in the last room of the museum was reproduced according to the artist's symbolic meaning. Participants therefore had the sensation of being inside the artwork. Both VR experiences included sound, and each featured a changing landscape. All AR and VR content was produced under the supervision of the museum director.

5.2.3 Experimental conditions

The experimental design was between-subjects. Again, the experimental group completed the visit with AR/VR content and the control group completed a traditional visit. The sample consisted of 50 participants, 25 participants per group. Group assignment was carried out through partial randomization, considering participants' gender and age.

The inclusion criteria were the same as those used in the study previously conducted in Italy and included: being at least 18 years of age, no history of neurological, psychiatric, or neurodevelopmental disorders, and the ability to use a smartphone or tablet independently on a daily basis. Participants who did not meet one or more of these criteria were excluded from the study. Since no ET was used in this study and the Meta Quest 3 headset allows the use of personal eyeglasses or, alternatively, the insertion of corrective lenses, wearing eyeglasses was not considered an exclusion criterion. The museum was equipped with high-definition cameras, which made it possible to estimate event timing for marker insertion without the need for an ET.

Participants assigned to the experimental group visited the museum with the addition of AR and VR content. AR content was present in all three rooms. It was video-based and aimed to present specific content. After each AR experience, the participant could visit the room normally.

Two rooms of the museum (the first and last) featured VR experiences. The first consisted of the 360° video described above, in which the museum room changed color. The second, the "stepping inside the artwork" described above, was in the last room.

Participants in the control group visited the same rooms in the same order, but without the use of AR/VR.

5.2.4 Instruments

In the second study, it was decided to use only the Immersion measurement device in order to reduce the experimental friction observed in the Italian study. Furthermore, as previously highlighted, the neurophysiological indices obtained from EEG and Shimmer were not particularly useful in discriminating between the two experimental conditions. In addition, in line with Kleckner et al. (2021), the use of multiple sensors can sometimes increase participant burden and compromise the feasibility and overall quality of the experience, especially in field studies. Furthermore, the use of more or less invasive instrumentation in naturalistic contexts can reduce ecological validity and alter the behaviors under study (Janssen et al., 2021). Considering the results of the Italian study and given that the main objective of the experiment was to understand whether AR and VR could increase levels of Immersion, which in turn could predict real prosocial behavior (donation) in a museum setting that was as natural as possible, reducing the amount of instrumentation was considered the most appropriate choice.

As in the Italian study, measures of Immersion responses were collected using the Immersion Neuroscience platform (Henderson, NV). Participants were asked to wear a Scosche Rhythm+ device (Scosche Industries, Oxnard, CA), equipped with PPG sensors, on their non-dominant forearm (Rancati et al., 2025). The device is capable of measuring changes in peripheral blood flow using LED technology and a heart cycle detection algorithm (Nitzan & Ovadia-Blechman, 2022). The cardiac signals acquired and transmitted to a cloud server were then processed using an algorithm that allows cranial nerve activity to be inferred (Barraza & Zak, 2009; Zak, 2022). The final output consisted of a file containing data that had already been filtered and processed.

Compared to the Italian results, Immersion proved to be sensitive to experiential impact and capable of predicting prosocial behaviors and behavioral changes toward art. As already highlighted, the literature suggests that this indicator may be able to predict the likelihood of donation (Lin et al., 2022). Therefore, in the present study, Immersion was used as a key measure to investigate the link between the museum experience and donation behavior.

5.2.5 Self-report measures

As in the Italian study, participants were asked to complete questionnaires before and after their visit to the museum. The questionnaires used were the same as those in the previous study and allowed us to gather participants' opinions on art and donations to the cultural sector. They also allowed us to identify any changes after the visit. For each of these, a 6-point Likert scale (1=completely disagree; 6=completely agree) was used to avoid neutral responses (Kankaraš et al., 2024).

Arts Engagement Scale

The Arts Engagement Scale questionnaire (2015) was administered in its original form before and after the visit. The questionnaires had already been validated in English, and the items were not modified. As previously stated for the Italian sample, the scale conceptualizes artistic engagement through five dimensions: affective, cognitive, behavioral, social, and connection/identity.

Charitable attitude toward cultural organizations (ACO)

As in the Italian study, an adaptation of the Attitude toward Charitable Organizations Scale developed by Webb et al. (2000) was used. Again, the original items were adapted to the context of cultural institutions, replacing references to charitable organizations with references to cultural organizations and cultural heritage. The items used were as follows:

- *The money given to cultural organizations goes for good causes.*
- *Much of the money donated to cultural organizations is wasted.*
- *My image of cultural organizations is positive.*
- *Cultural organizations have been quite successful in supporting cultural heritage.*
- *Cultural organizations perform a useful function for society.*

Attitude toward donating to museums (ATD)

In this study, the items of the ATD scale by Chen et al. (2022), as in the Italian version, were semantically adapted to the context of donations to interactive and innovative museums, while maintaining the conceptual structure of the original scale unchanged. The items used were as follows:

- *Donating to interactive and innovative museums is something that can help address issues related to cultural heritage.*

- *Donations to interactive and innovative museums are worth making to support cultural heritage.*
- *Donating to interactive and innovative museums is something I would like to do to support cultural heritage.*

Intention to donate (ID)

The two items originally used to assess intention to donate blood (Faqah et al., 2015) were adapted as follows for the present study:

- *I will donate to support cultural heritage over the next six months*
- *I want to donate to support cultural heritage over the next six months*

5.2.6 Procedure

Participants were recruited through flyers and word of mouth. As in the Italian study, they were healthy volunteers with no history of neurological, psychiatric, or neurodevelopmental disorders. During recruitment, all participants stated that they used smartphones or tablets on a daily basis and were able to use them independently.

The experimental sessions were planned by assigning each participant a specific time slot, during which the visit was carried out individually. The museum selected for the experiment was the Claremont Lewis Museum of Art in California.

Once inside, the participants signed the informed consent form and then completed the pre-visit questionnaires. The latter also included demographic questions (gender, age, number of children, level of education, occupation, and income).

They were then asked to wear the wearable device connected to the Immersion Neuroscience platform. Once equipped, participants in the control group were allowed to enter the first room. Participants in the experimental group, on the other hand, completed a short training session on how to use the tablet with the ARLOOPA augmented reality software before starting the visit. In addition, they were given instructions regarding the AR and VR content in the museum. They were told that in each room (three in total) they would find symbols/markers that they could scan with the tablet using the ARLOOPA application, as they had done during the training. Each marker would activate a short introductory video about the room they were in. Participants were also informed that they would find a Meta Quest 3 headset in the first and last rooms. All they had to do was put it on and sit in the chair in front of them to experience the VR content. After these VR/AR experiences, participants were free to explore the museum room as usual. Once all the explanations were completed and the participants had become familiar with the use of AR, participants in the experimental group could also begin their visit. Both the experimental and control groups visited the three rooms of the museum in the same order.

All three rooms of the museum shared the same theme, and many of the works displayed across spaces were by the same artists. The exhibition was entitled “Complications in Color” and explored the role of color and abstraction in late 20th-century Californian art, with works by several generations of artists associated with the hard-edge painting movement. Through paintings and sculptures, the exhibition presented geometric forms and color fields. The exhibition focused in particular on the relationships between color, space, and perceptual dynamics. The works belonged to five artists active in different contexts and periods. Karl Benjamin was one of the leading exponents of Californian hard-edge painting, known for his rigorous use of geometric shapes and pure color fields. Florence Arnold and June Harwood produced works that focus on geometric abstraction and the exploration of the dynamics between color and space. Rachel Lachowicz produced abstract works using materials such as eye shadow and lipstick, linked to themes of gender and identity. Finally, Terry O'Shea's works were resin sculptures that emphasized the perceptual and sensory aspects of color and light.

The first room featured geometric works characterized by pure color fields and clean shapes. The exhibition space encouraged a visual experience focused on the perceptual relationships between color, form, and light (Figure 24).

Figure 24. The first room of the Claremont Lewis Museum of Art.

The second room contained abstract works characterized by simple geometric compositions and sharp color contrasts. These were all arranged along the walls (Figure 25).

Figure 25. The second room of the Claremont Lewis Museum of Art.

The third room was characterized by a large, open space that housed large abstract works, arranged along the perimeter to encourage a distanced view. The only element present in the center was a monochromatic sculpture (Figure 26).

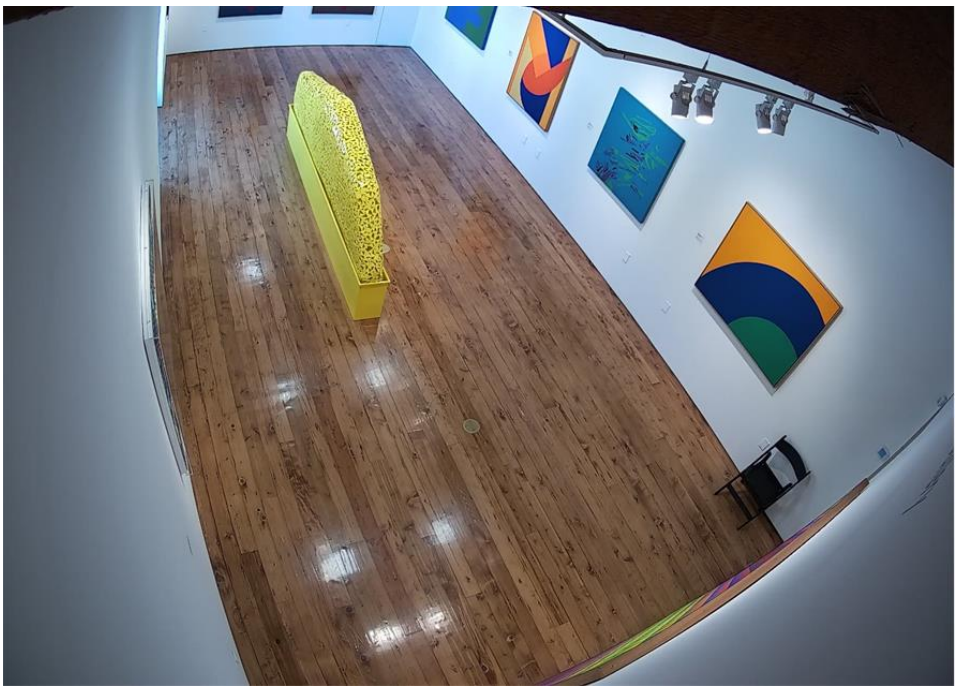

Figure 26. The third room of the Claremont Lewis Museum of Art.

At the end of the experiment, participants received $10 in compensation, provided as two $5 bills, consistent with the value of the complimentary museum ticket in Italy.

5.2.7 Computation of immersion peaks

As in the previous study, neurophysiological Immersion was measured using a wearable device connected to the Immersion Neuroscience platform, which returns a 1 Hz time series of a synthetic index derived from peripheral nervous system signals associated with attention and emotional resonance. This measure was developed specifically to predict behavior and has proven particularly suitable for field studies due to its non-invasive nature (Zak, 2022; Rancati et al., 2025).

For this study, the museum was much smaller and consisted of only three rooms. For this reason, there were no substantial variations between subjects in the time spent in each room. The average time spent in each room was 4.62 minutes for Room 1, 2.96 minutes for Room 2, and 5.56 minutes for Room 3. The average duration of the visit was 13.14 minutes (SD = 6.64). These times are in line with those reported by Rancati et al. (2025). Therefore, the formula from the aforementioned study was used to calculate Immersion peaks.

As already mentioned, Immersion peaks capture moments of maximum neurophysiological engagement during an experience. Following the method proposed by Rancati et al. (2025), Immersion peaks are defined as the share of total Immersion attributable exclusively to values exceeding an individual threshold, normalized with respect to the overall Immersion of the experience. Following the study's guidelines, Immersion peaks were calculated using the following formula:

$$\text{Peak Immersion}_i = \frac{1}{I_i} \int_{t=0}^{T} 1(n_{it} > M_i)\, n_{it}\, dt$$

where $n_{i,t}$represents the neurophysiological Immersion value of individual $i$at time t, Tindicates the duration of the experience, $M_i$is the individual threshold defined as the median Immersion plus 0.5 standard deviations, $I_i$is the total Immersion accumulated during the entire experience, and $1(\cdot)$is an indicator function that takes the value 1 when the condition is satisfied and 0 otherwise. In conceptual terms, this measure exclusively accumulates Immersion values that exceed the threshold $M_i$and normalizes them with respect to total Immersion, allowing control for differences in the duration of the experience (dwell time).

Immersion peaks were calculated separately for each room (Room 1, Room 2, Room 3) and for each participant. For each room, only the Immersion values recorded during the participant's stay in that specific environment were selected. Within each segment, a local threshold $M_{\text{room}}$was calculated, defined as the median Immersion in the room plus 0.5 standard deviations. Subsequently, all Immersion values above this threshold were summed, and the

result was normalized with respect to the total Immersion within the same room. This process produced three distinct measures of Immersion peaks, one for each room. Subsequently, an overall average of the Immersion peaks for each participant was derived by averaging these three values.

This approach allows for the sensitive capture of dynamic fluctuations in Immersion along the museum route, respecting the neurophysiological assumption that brain activity tends to return quickly to baseline levels and that, in prolonged or segmented experiences, Immersion peaks are more informative indicators of engagement than average values (Merritt et al., 2023; Rancati et al., 2025).

5.3 Results

5.3.1 Reliability of self-report measures

Concerning the Arts Engagement Scale, although the items were kept in their original wording, the change in the Likert scale (from 5 to 6 points) made it necessary to calculate reliability. Therefore, Cronbach's alpha coefficients were calculated separately for each subscale in the pre-visit and post-visit phases. The reliability values of the subscales administered before the visit were as follows: $\alpha = 0.786$ for affective engagement, $\alpha = 0.904$ for cognitive engagement, $\alpha = 0.693$ for behavioral engagement, $\alpha = 0.914$ for social engagement, and $\alpha = 0.881$ for the connection/identity dimension. Similarly, in the post-visit phase, the subscales showed good reliability (Taber, 2018), with values of $\alpha = 0.763$ for affective engagement, $\alpha = 0.930$ for cognitive engagement, $\alpha = 0.766$ for behavioral engagement, $\alpha = 0.959$ for social engagement, and $\alpha = 0.894$ for the connection/identity dimension.

For questions related to ID, in the U.S. sample the inter-item correlation was significant (Eisinga et al., 2013) both in the pre-visit phase ($r = 0.686$, $p < .001$), corresponding to a Spearman–Brown reliability of 0.814, and in the post-visit phase ($r = 0.875$, $p < .001$), with a Spearman–Brown reliability of 0.933. The internal consistency of the ATD measure, consisting of three items, was also high, with a Cronbach's alpha coefficient of $\alpha = 0.885$, indicating a good level of reliability for the scale in the context of the present study. Finally, the ACO scale, consisting of five items, showed adequate internal consistency (Taber, 2018), with a Cronbach's alpha coefficient of $\alpha = 0.713$.

5.3.2 Demographic characteristics: comparison of the Italian and U.S. samples

Some comparisons were made between the Italian and US samples in order to verify any differences in the main demographic variables. Regarding gender, the distribution of participants did not show significant differences between the two samples, $\chi^2(1, N = 100) = 1.45$, $p = .229$, indicating a comparable composition of the groups with respect to this variable. The Italian sample was composed of 52.0% men and 48.0% women, while the US sample had a higher percentage of women (60.0%) than men (40.0%) (Table 1).

Gender	Italy (n=50)	United States (n=50)
Female	24 (48.0%)	30 (60.0%)
Male	26 (52.0%)	20 (40.0%)

Table 1. Gender Distribution by Country

Since normality tests (Shapiro–Wilk test) showed significant deviations from normal distribution for the remaining demographic variables ($p < .001$), comparisons between groups were performed using nonparametric Mann–Whitney U tests. No significant differences were observed in monthly income, $U = 1360.50$, $p = .423$. The mean scores were comparable between the Italian sample ($M = 2.20$, $SD = 1.28$) and the US sample ($M = 2.10$, $SD = 1.40$). In both groups, most participants reported an income of less than €1,500/$1,500 per month, with comparable percentages in the different income brackets, suggesting substantial economic homogeneity between the samples (Table 2).

Monthly income	Italy (n = 50)	United States (n = 50)
Under 1,000	25 (50.0%)	23 (46.0%)
1,000–1,500	18 (36.0%)	12 (24.0%)
2,000–3,000	8 (16.0%)	6 (12.0%)
3,000 or more	5 (10.0%)	9 (18.0%)

Table 2. Monthly income by Country

A significant difference emerged between the groups in terms of age ($U = 1543.00$, $p = .043$). Specifically, the Italian sample was older on average ($M = 32.80$, $SD = 13.49$) than the US sample ($M = 27.84$, $SD = 11.15$). Consistently, the mean rank was higher for the Italian group (Mean Rank = 56.36) than for the US group (Mean Rank = 44.64).

Regarding marital status (Table 3), both samples are predominantly composed of single participants. This characteristic is more pronounced in the US sample (94.0%) than in the Italian sample (72.0%). A higher proportion of Italian participants are married or cohabiting (28.0%) than in the US sample (2.0%). The categories of separated/divorced and widowed are marginal and present only in the US sample. The Mann–Whitney U test indicated a statistically significant difference between the two groups ($U= 871.00$, $p < .001$).

Marital status	Italy (n=50)	United States (n=50)
Single	36 (72.0%)	47 (94.0%)
Married/Cohabiting	14 (28.0%)	1 (2.0%)
Separated/Divorced	0 (0.0%)	1 (2.0%)
Widowed	0 (0.0%)	1 (2.0%)

Table 3. Marital Status Distribution by Country

In terms of education level (Table 4), the US sample has a significantly higher percentage of participants with postgraduate degrees (50.0%) than the Italian sample (18.0%). Conversely, Italian participants are more likely to have a high school diploma (38.0%) or a bachelor's degree (44.0%) than US participants. Therefore, a significant difference was observed in the level of education ($U = 862.00$, $p = .005$).

Educational qualification	Italy (n=50)	United States (n=50)
High school diploma	19 (38.0%)	11 (22.0%)
University/Bachelor’s degree	22 (44.0%)	14 (28.0%)
Postgraduate degree	9 (18.0%)	25 (50.0%)

Table 4. Education level by Country

In terms of occupational status (Table 5), the US sample consists largely of students (86.0%), while the Italian sample shows a more heterogeneous distribution of employment categories, with a greater representation of self-employed workers (20.0%), employees (14.0%), and other occupations (24.0%). This variable also proved to be significant between the groups ($U = 1810.00$, $p < .001$).

Occupational status	Italy (n=50)	United States (n=50)
Student	18 (36.0%)	43 (86.0%)
Employee	7 (14.0%)	3 (6.0%)
Self-employed	10 (20.0%)	0 (0.0%)
Unemployed	2 (4.0%)	1 (2.0%)
Retired	1 (2.0%)	1 (2.0%)
Part-time	0 (0.0%)	1 (2.0%)
Other works	12 (24.0%)	0 (0.0%)

Table 5. Occupational Status by Country

5.3.3 Pre-visit questionnaire results: a comparison of the Italian and U.S. samples

Preliminary comparisons were made between the Italian and US samples on the measures administered prior to the visit. Q–Q plots indicated an approximately normal distribution of the variables considered. Therefore, independent-samples t-tests were used to conduct the analyses.

With regard to the subscales of the Arts Engagement Scale, no statistically significant difference emerged for the affective dimension, $t(98) = -1.89$, $p = .061$, although the US sample reported a slightly higher mean value (US: $M = 5.27$, $SD = 0.72$; ITA: $M = 4.93$, $SD = 1.05$).

In contrast, significant differences were found in favor of the US sample for the cognitive dimension, $t(98) = -2.19$, $p = .031$ (US: $M = 5.40$, $SD = 0.72$; ITA: $M = 4.96$, $SD = 1.21$), for the behavioral dimension, $t(98) = -3.39$, $p = .001$ (US: $M = 3.41$, $SD = 1.03$; ITA: $M = 2.64$, $SD = 1.25$), for the social dimension, $t(98) = -2.74$, $p = .007$ (US: $M = 4.26$, $SD = 1.29$; ITA: $M = 3.51$, $SD = 1.43$), and for the connection dimension, $t(98) = -2.06$, $p = .042$ (US: $M = 4.59$, $SD = 1.33$; ITA: $M = 3.99$, $SD = 1.58$).

With regard to the donation subscales, ID was significantly higher in the US sample than in the Italian sample, $t(98) = -2.85$, $p = .005$. US participants reported a mean of $M = 3.45$ ($SD = 1.40$), while Italian participants reported a mean of $M = 2.69$ ($SD = 1.27$).

In addition, significant differences were found in both the ACO scale and the AD scale. Specifically, prior to the visit, the US sample showed higher mean ACO scores ($M = 4.88$, $SD = 0.67$) than the Italian participants ($M = 3.98$, $SD = 0.79$). The comparison revealed statistical significance in the t-test, $p < .001$, $t(98) = -6.11$. Similarly, a significant difference was also found in AD, $t(98) = -2.66$, $p = .009$ (Figure X), where the US sample had a higher mean ($M = 4.65$, $SD = 1.02$) than the Italian sample ($M = 4.09$, $SD = 1.09$).

These results suggest a greater propensity to donate observed in the US sample and a more positive attitude towards cultural institutions and donation in general from the outset.

5.3.4 The U.S. sample: experimental and control groups

The U.S. sample consisted of 50 participants, 30 female (60.0%) and 20 male (40.0%). The mean age was 27.84 years (SD ≈ 11.26). No significant differences were found between the experimental and control groups in age ($t(48) = 0.15$, $p = .881$) or gender distribution ($\chi^2(1, N = 50) = 0.00$, $p = 1.000$).

A series of Mann–Whitney U tests was also conducted on the main sociodemographic variables. No significant between-group differences emerged for marital status ($U = 325.00$, $p = .572$), number of children ($U = 312.00$, $p = 1.00$), educational level ($U = 382.50$, $p = .142$), employment status ($U = 299.00$, $p = .676$), or monthly income ($U = 312.00$, $p = 1.00$).

Regarding country of origin, most participants were born in the United States (n = 34; 68.0%). The remaining 16 participants (32.0%) were born in various countries, including India (n = 4), China (n = 2), South Korea (n = 2), Belgium (n = 1), Colombia (n = 1), Botswana (n = 1), Haiti (n = 1), Kenya (n = 1), Turkey (n = 1), Peru (n = 1), and Nepal (n = 1). No statistically significant difference between the experimental and control groups was observed for geographic origin ($U = 325.00$, $p = .777$), indicating comparable distributions of U.S.-born and non-U.S.-born participants across conditions.

Although a subset of participants was born outside the United States, all had resided in the U.S. for at least one year at the time of data collection and reported fluent English proficiency. National data on U.S. higher education indicate that approximately 32% of university students have a migrant background (Higher Education Immigration Portal, 2025). In the general U.S. population, foreign-born residents account for approximately 14% (U.S. Census Bureau, 2024). Accordingly, the proportion of participants born abroad in the present sample is consistent with the typical demographic composition of university settings and young-adult populations.

Regarding the Arts Engagement Scale, no differences emerged between the groups in the subscales: affective ($t(48) = -0.15$, $p = .884$); cognitive ($t(48) = 0.83$, $p = .410$); behavioral ($t(48) = 0.00$, $p = 1.000$); social ($t(48) = 1.65$, $p = .106$) and connection ($t(48) = 1.74$, $p = .088$). Similarly, no significant differences were observed between the groups for measures related to donation: ATD ($t(48) = 0.37$, $p = .714$); ID ($t(48) = 0.76$, $p = .453$) and ACO ($t(48) = 1.15$, $p = .258$).

Overall, the results suggest that the two groups started from comparable characteristics.

5.3.5 Differences in immersion peaks between the experimental and control groups in the U.S. sample

To verify the differences in the average Immersion peaks across the three museum rooms between the experimental group and the control group, an independent-samples t-test was conducted.

The results showed a statistically significant difference between the two groups, $t(48) = 2.10$, $p = .041$. In particular, the experimental group (n = 24) reported higher mean values (M = 0.153,

SD = 0.034) than the control group (n = 26), which showed a lower mean (M = 0.130, SD = 0.042).

The Brown–Forsythe test did not indicate a violation of the homogeneity-of-variance assumption (p = .989), suggesting that the use of the Student's t-test was appropriate.

Regarding the normality assumption, the Shapiro–Wilk test applied to the standardized residuals was significant (W = 0.925, p = .004), indicating a deviation from normality. However, visual inspection of the Q–Q plot (Figure 27) shows that the points lie predominantly along the theoretical diagonal, with more noticeable deviations only in the distribution tails. This pattern suggests approximate normality of the residuals, consistent with the robustness of the t-test, especially with similarly sized groups.

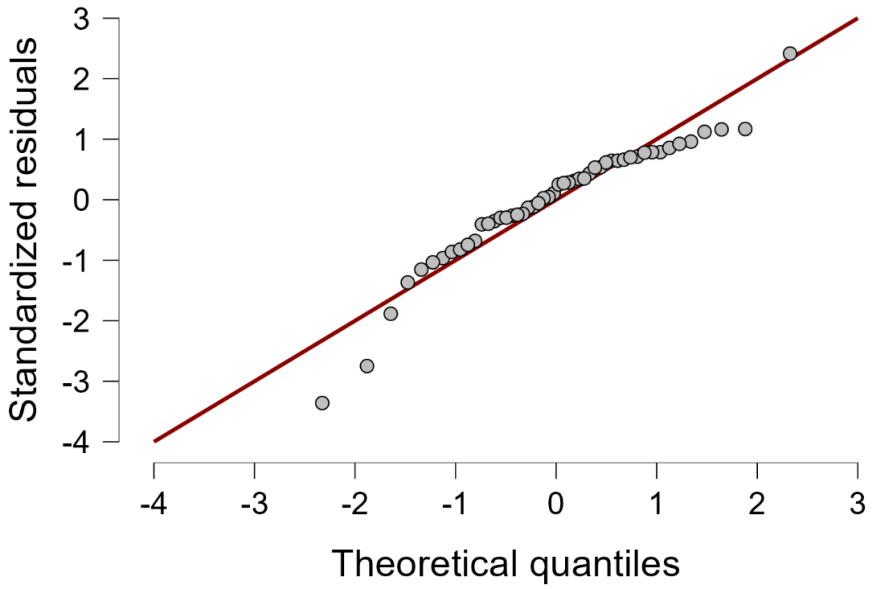

Figure 27. Q–Q plot of the distribution of standardized residuals for the mean immersion-peak variable

Therefore, the convergence of the descriptive results, the absence of heteroscedasticity, and the Q–Q plot pattern support the robustness of the t-test findings.

5.3.5.1 The effect of sex, age, and group on immersion peaks in the U.S. sample

In order to assess whether the differences observed in the previous t-test, namely the higher mean Immersion peak values in the experimental group compared with the control group, were specifically attributable to group membership rather than to sociodemographic variables, a multiple linear regression was conducted. The dependent variable was the overall mean of Immersion peaks. Age, gender, and group were included as predictors.

The full model (M_1) explained 15.6% of the variance in the dependent variable (R^2 = .156; adj. R^2 = .099). The ANOVA indicated that the overall model did not reach statistical significance, $F(3, 45) = 2.77$, $p = .053$.

Regarding the individual predictors, group was the only statistically significant predictor in the model ($b = -0.023$; $SE = 0.011$; $t = -2.10$; $p = .042$). The negative sign of the coefficient reflects the coding of the group variable (1 = experimental; 2 = control) and indicates that the control group showed significantly lower mean Immersion peak values than the experimental group.

Gender did not reach statistical significance ($p = .094$), and age was not significantly associated with the dependent variable ($p = .594$).

Overall, these results suggest that the observed differences in mean Immersion peaks are primarily attributable to group membership rather than to individual sociodemographic differences.

5.3.6 Differences in donations between the experimental and control groups in the U.S. sample

In light of the results previously obtained with the Italian sample, this study evaluated actual donation behavior, expressed both as the amount of money donated and as a dichotomous choice to donate or not to donate. This methodological choice was guided by the need to analyze an immediate behavioral outcome with respect to peak Immersion values.

Since the donation variable had a non-normal distribution and numerous zero values, a nonparametric Mann–Whitney U test was used to compare the experimental group and the control group. Consistent with the directional hypothesis, according to which the experimental group would show higher donation levels than the control group, a one-tailed alternative hypothesis was adopted.

The results showed a statistically significant difference in the amount donated between the two groups ($U = 391.0$, $p = .045$). In particular, the experimental group ($n = 25$) reported a higher mean amount donated ($M = 4.72$; $SD = 4.69$; mean rank = 28.64) than the control group ($n = 25$; $M = 2.60$; $SD = 4.11$; mean rank = 22.36).

The same test was also applied to the dichotomous variable donor/non-donor, coded as 1 = donor and 0 = non-donor. Again, a statistically significant difference emerged between the groups ($U = 387.5$, $p = .046$). The experimental group showed a higher proportion of donors ($M = 0.56$; mean rank = 28.50) than the control group ($M = 0.32$; mean rank = 22.50).

In the experimental group ($n = 25$), 11 participants (44%) did not make any donation. Among the remaining participants, 1 participant (4%) donated $3, 3 participants (12%) donated $5, and 10 participants (40%) donated $10. Overall, 14 out of 25 participants (56%) made a donation. In the control group ($n = 25$), 17 participants (68%) did not make any donations. Among the donors, 3 participants (12%) donated $5 and 5 participants (20%) donated $10. Overall, 8 out of 25 participants (32%) made a donation.

With regard to the dichotomous variable donor/non-donor, in the experimental group, 14 participants (56%) were classified as donors, while 11 participants (44%) were classified as non-donors. In the control group, 8 participants (32%) made a donation, while 17 participants (68%) did not donate.

5.3.7 Estimation of the relationship between Immersion and donation behavior

The variable referring to the amount of money donated was characterized by a marked concentration of zero values and by discrete amounts ($0, $3, $5, $10). Therefore, in the US sample, donation behavior was analyzed using the dichotomous variable donor vs. non-donor.

To test whether Immersion mediated the effect of the experimental condition on the probability of donating, a logistic mediation model was estimated in R with nonparametric bootstrap (5,000 resamples). In the analyzed sample (N = 49; 1 null), 22 participants (44.9%) were donors and 27 (55.1%) were non-donors.

In the mediator model (path a), the experimental condition significantly predicted Immersion, b = −0.023, SE = 0.011, t(47) = −2.10, p = .041, with an explained variance of R^2 = .086 (adjusted R^2 = .066). The negative coefficient is due to the fact that the control group was used as the reference, indicating higher Immersion levels in the experimental group.

In the outcome model (path b), estimated via binomial logistic regression, Immersion significantly predicted the probability of donating (b = 47.96, SE = 17.09, z = 2.81, p = .005), whereas the direct effect of Group on the outcome was not significant (b = −0.80, SE = 0.69, z = −1.16, p = .244). The logistic model showed an adequate fit to the data (AIC = 56.24) and an explanatory power (McFadden R^2 = .255) consistent with what is typically observed in models of discretionary behavior (Hauber et al., 2016).

The mediation analysis revealed a significant indirect effect of the experimental condition on the probability of donating through Immersion (mean ACME = 0.175), 95% CI [0.024, 0.324], p = .020, whereas the direct effect was not significant (mean ADE = 0.124), 95% CI [−0.076, 0.338], p = .233.

The total effect was statistically significant (Total Effect = 0.298, 95% CI [0.046, 0.520], p = .019). In addition, a significant proportion of the total effect was mediated by Immersion (proportion mediated = 0.585), 95% CI [0.113, 1.656], p = .031 (Table 6).

Effect	Estimate	95% CI	p
Indirect effect (ACME)	0.175	[0.024, 0.324]	.020
Direct effect (ADE)	0.124	[−0.076, 0.338]	.233
Total effect	0.298	[0.046, 0.520]	.019
Proportion mediated	0.585	[0.113, 1.656]	.031

Table 6. Results of the logistic mediation analysis

5.3.8 Mediation analysis of donation intention

A paired-samples t-test was conducted to compare intention-to-donate scores before and after the museum visit. The results showed a statistically significant difference between the two measurements, $t(49) = -4.56$, $p < .001$, indicating a significant increase in scores after the intervention. Specifically, the mean score in the pre-visit phase ($M = 3.45$, $SD = 1.40$) was significantly lower than in the post-visit phase ($M = 3.99$, $SD = 1.45$).

Despite this, an independent-samples t-test comparing the post–pre difference score for 6-month donation intention between the experimental and control groups did not show a statistically significant group difference, $t(48) = -0.50$, $p = .620$.

Nevertheless, mediation analyses were conducted to test whether higher Immersion levels could predict a greater likelihood of making direct donations to the museum, and whether Immersion mediated the effect of the experimental condition on donation-related outcomes.

The model showed that Group did not significantly predict change in 6-month donation intention ($b = 0.023$, $SE = 0.241$, $z = 0.097$, $p = .923$, 95% CI [−0.449, 0.495]). However, Group had a significant effect on Immersion ($b = -0.024$, $SE = 0.011$, $z = -2.160$, $p = .031$, 95% CI [−0.045, −0.002]). The indirect effect of Group on donation intention through Immersion was not significant ($b = 0.097$, $SE = 0.084$, $z = 1.144$, $p = .253$, 95% CI [−0.069, 0.262]), indicating that Immersion did not mediate 6-month donation intention.

In light of these results, it has been tested whether the mediation mechanism observed in the Italian sample was replicable in the US sample. A linear mediation model was therefore estimated using the overall mean of Immersion peaks as the independent variable, the post–pre difference on the Behavioral Engagement subscale of the Arts Engagement Scale as the mediator, and the post–pre difference in 6-month donation intention as the dependent variable. The model was estimated using maximum likelihood (ML) with 95% confidence intervals.

The results did not show a significant direct effect of Immersion on change in donation intention, $b = -3.91$, $SE = 2.99$, $z = -1.31$, $p = .192$, 95% CI [−11.04, 1.08]. Consistently, the total

effect of Immersion on donation intention was also not statistically significant, b = −4.15, SE = 2.91, z = −1.42, p = .155, 95% CI [−11.74, 1.34].

Regarding the mediation pathways, Immersion did not significantly predict change in behavioral engagement in the arts, b = −0.55, SE = 2.23, z = −0.25, p = .805, 95% CI [−6.38, 2.59]. In turn, behavioral engagement did not significantly predict change in donation intention, b = 0.44, SE = 0.24, z = 1.81, p = .071, 95% CI [−0.07, 0.84]. Consequently, the indirect effect of Immersion on donation intention mediated by behavioral engagement was not significant, b = −0.24, SE = 0.92, z = −0.26, p = .793, 95% CI [−4.12, 0.62].

In terms of explained variance, the model explained 13.4% of the variance in the change in donation intention (R^2 = .134), whereas the explained variance in behavioral engagement was negligible (R^2 = .001).

5.3.9 Additional analyses

In order to clarify why behavioral engagement mediated the effect of immersion on 6-month donation intention in the Italian sample but not in the US sample, the association between immersion level (measured as the overall mean of immersion peaks) and the post–pre change in behavioral engagement in the arts was examined separately by country.

In the Italian sample, a positive and statistically significant correlation emerged between immersion and change in behavioral engagement (r = .389, p = .006), indicating that higher immersion levels were associated with a greater increase in behavioral engagement after the visit. In contrast, in the US sample this association was not significant (r = −.038, p = .797), suggesting no relationship between immersion and change in behavioral engagement.

These results indicate that the immersion–behavioral engagement link was present exclusively in the Italian sample. In the US sample, behavioral engagement does not appear to be influenced by the immersive experience and, consequently, cannot function as a mediator.

Overall, this pattern suggests that in the US sample immersion neither directly nor indirectly influenced donation intention via behavioral engagement. This differs from the Italian sample and implies that the mechanism by which immersive experiences translate into prosocial outcomes may vary as a function of cultural context (Table 7).

	ITA	**USA**
Actual donation	Nearly absent	Frequent
Donation intention	Differs between groups	No difference between groups
Effect of Immersion	Indirect (via behavioural engagement)	Direct (behavior)

Table 7. Summary of model results across the two countries

5.4 Discussion of the study results in the United States

The results of the present study showed that manipulating the museum environment through VR and AR experiences produced higher levels of Immersion peaks in the experimental group. For this reason, in line with the results already presented for the Italian context, hypothesis H1 is supported.

As described above, this outcome is consistent with the literature, according to which museum experiences enriched by immersive technologies can significantly increase both perceived and neurophysiologically measured Immersion (Jangra et al., 2025; Lee et al., 2019). Furthermore, the presence of storytelling elements may have amplified engagement. As already mentioned, according to some authors, coherent and engaging narratives promote engagement and immersive states (Zak, 2015; Zak & Barraza, 2018). As was the case in the Italian context, Immersion in this study was measured at the neurophysiological level and not with self-report questionnaires as in the past. This made it possible to validate, even in different cultural contexts, that the use of AR and VR can be a strategy capable of making the museum experience more immersive and meaningful, beyond self-reported measures that can often be subject to various types of bias (Zak & Barraza, 2018).

Hypothesis H2, unlike what was observed in the study conducted in Italy, can also be considered accepted. In fact, the experimental group made more direct monetary donations to the museum than the control group.

About hypotheses H3 and H4, no evidence was found in the US sample to indicate that Immersion is a factor capable of predicting the intention to donate. Nor did the mediation model identified in the Italian sample (Immersion → behavioral engagement → intention to donate at 6 months) produce statistical significance in the US sample.

Regarding these results, a first crucial interpretative element concerns the baseline differences between the two samples even before the museum experience. Pre-visit comparisons indicate that the US sample started out with more favorable attitudes toward donations, as highlighted by the ACO, ATD, and ID subscales compared to the Italian sample. These differences could suggest that, for the US sample, the act of donating was more normatively legitimized and mentally available from the outset, thus probably reducing the need for the experience to operate through a process of gradual transformation.

On the Arts Engagement Scale, the US sample showed significantly higher pre-visit values on the cognitive, social, connection, and, above all, behavioral subscales. This could indicate a higher average level of cultural engagement and a greater orientation toward active engagement even before the intervention.

From a theoretical point of view, these data are consistent with the TPB. Specifically, TPB posits that intentions depend not only on attitude, but also on subjective norms (perceived social pressure) and perceived behavioral control, understood as the perceived ease or difficulty of performing the action (Ajzen, 1991).

Therefore, when a behavior is relatively simple, under the control of the individual, and part of stable contexts, experience tends to translate more easily into immediate action.

Conversely, medium-term intentions (e.g., “in the next six months”) reflect more deliberative and multidetermined processes, which are more exposed to situational barriers, planning, and contextual variability, contributing to a phenomenon known as the intention–behavior gap (Sheeran, 2002). Therefore, when a behavior is already culturally feasible and socially expected, such as tipping in the US, the experience can more easily translate into immediate action, while medium-term intentions (e.g., “in the next six months”) tend to reflect a more deliberative process involving multiple variables (Sheeran, 2002).

Therefore, it is plausible to assume that a behavior such as donating emerges more easily if it is socially and culturally practiced, as is the case in the US, where there is greater familiarity with small cash payments, such as tipping. This would therefore make it more natural to convert a prosocial impulse into an immediate, concrete choice. Conversely, in contexts such as Italy, where tipping or monetary rewards are less common, the change takes place at a more internalized level and translates into intention. In this regard, surveys on tipping norms show that the intensity and probability of leaving a tip vary considerably between countries and that the US presents a context in which immediate monetary gratification is more normalized than in other European contexts, including Italy (Smith, 2023). In fact, only two people in the Italian sample donated to the museum at the end of their visit.

The literature on VR and immersive environments indicates that an immersive state can increase engagement and emotional and cognitive processing. These processes, for example through mediators such as empathy and moderators such as guilt, can support altruistic responses (Liao, 2025). According to Liao (2025), Immersion acts as a trigger that can make prosocial action more salient, but it cannot specify when and how that action will be implemented. In this regard, a meta-analysis of tipping shows that tipping is a highly socially regulated behavior: people tip not only out of personal preference, but also due to social pressure and a sense of moral obligation (Lynn et al., 2015). Differences between countries therefore reflect systematic differences in attitudes toward giving and sensitivity to social norms, duties, and expectations (Lynn et al., 2015).

Furthermore, in support of the idea that donation mechanisms are sensitive to cultural context, a study comparing a Chinese sample with a US sample showed that the psychological processes driving prosocial decisions differed between cultures (Wang et al., 2015). For example, differences in emotions, norms, and processing styles were found between the two groups. Finally, the study highlighted how culture can modify the relationship between the salience of the experience and the choice to donate (Wang et al., 2015).

Therefore, in light of the data from the present study and the literature reviewed, it is plausible to assume that in the US sample, the act of donating may be more readily available even before the experience, while in Italy, the experience must first build a motivational/behavioral bridge (engagement) that makes future planning plausible. In this sense, Immersion is not less effective in either context. What differs is the trajectory by which experiential activation is translated. Therefore, Immersion seems to act as a general motivational amplifier, whose behavioral outcome depends on the normative availability and the ease of implementation of the action in the reference context.

5.4.1 Demographic differences between the samples and their implications

In this study, the US sample is younger on average, consisting mainly of students, with a higher level of education and a significantly higher proportion of single participants than the Italian sample. No significant differences emerged between the two samples in terms of monthly income, suggesting relative economic homogeneity between the two groups.

The literature on giving shows mixed results regarding age (Best & Freund, 2021). Nevertheless, numerous studies and meta-analyses suggest that, on average and especially for monetary donations, older individuals tend to give more frequently and donate larger amounts than young adults (Sparrow et al., 2021; Wiepking & James, 2013). This pattern has been interpreted as the combined result of greater availability of economic resources and motivational changes associated with adult development, such as increased generativity and orientation toward ego-transcendent goals (Best & Freund, 2021; Sparrow et al., 2021). Sparrow et al. (2021) show a positive effect of age on altruism, but point out that this relationship is moderated by the availability of resources (e.g., income, education) and tends to diminish in older age groups.

However, more recent studies suggest that the association between age and donation depends largely on the type of prosocial behavior considered (Best & Freund, 2021). In particular, older adults are more likely to make monetary donations, while young adults tend to report relatively higher levels of non-monetary forms of prosociality, such as direct or situational help, for which the subjective cost is comparable or lower (Best & Freund, 2021; Nakamura et al., 2025). These findings support the hypothesis that age-related differences reflect, at least in part, variations in the availability of resources and the perceived costs of different forms of prosocial behavior (Best & Freund, 2021).

The US group was rewarded for participating in the study with $10, while the Italian group received a museum gadget and a free ticket to revisit the museum. The greater immediate availability of economic resources and a lower perceived subjective cost may have facilitated the act of donating, in line with evidence indicating that the probability of donating increases when the perceived cost of the action is reduced (Bekkers & Wiepking, 2011; Sparrow et al., 2021).

Therefore, monetary availability may have influenced donation behavior despite the US sample having a lower average age than the Italian sample.

Furthermore, the latter consisted mainly of university students. Although university students generally have limited financial resources, numerous studies show that individuals with higher levels of education also tend to have higher levels of cultural capital, greater openness to artistic experiences, and greater sensitivity to social and collective issues (Bekkers & Wiepking, 2011; Wiepking & James, 2013). Moreover, education is one of the strongest predictors of the propensity to donate, especially when the donation is associated with symbolic, cultural, or identity values and psychological and value-based benefits, rather than direct material benefits (Bekkers & Wiepking, 2011; Wiepking & Maas, 2009).

This profile is consistent with the pre-visit results, which show higher scores in the behavioral, cognitive, and social dimensions of the Arts Engagement Scale in the US sample, as well as higher scores for ACO, ATD, and donation intention. In this context, the immersive experience may have acted as a catalyst for an already existing disposition, facilitating the direct transition from experiential activation to immediate donation behavior.

Marital status also differed between the two samples and may indirectly help explain the results. Some authors point out that married people or those in a family unit tend, on average, to donate more frequently and give larger amounts than single people, especially when the donation is intended as a planned decision and integrated into the management of the family budget (Wiepking & Bekkers, 2012). On the other hand, when it comes to small, situational donations (e.g., collections, street donations, or contributions linked to specific experiences), the decision is more often made at the individual level, even within couples, and is less constrained by shared planning processes (Wiepking & Bekkers, 2010, 2012). In this sense, the higher prevalence of single participants in the US sample may not indicate a greater general propensity to donate, but rather a greater likelihood that the immersive experience will trigger an immediate donation response, as a contextual and situational gesture, rather than a planned medium- or long-term decision.

Finally, it is important to note that the analyses conducted show that age and gender do not predict levels of neurophysiological Immersion, which are instead mainly attributable to the experimental manipulation. This result is consistent with recent evidence on immersive experiences and presence, according to which levels of presence and Immersion are not systematically associated with the age or gender of users, but depend mainly on the characteristics of the experience and the immersive context (Martingano et al., 2023). This evidence reinforces the interpretation that Immersion represents an experiential state that is relatively independent of the sociodemographic characteristics of participants.

However, demographic variables may have played a significant role in how Immersion translates into prosocial outcomes. In line with the TPB, the intention to donate in the medium term requires the integration of feasibility assessments, subjective norms, and perceived behavioral control, while immediate behavior is more sensitive to situational and normative factors (Sheeran, 2002). Therefore, in a young, highly educated, and culturally predisposed sample such as the US sample, Immersion probably translated more easily into immediate donation behavior. In contrast, in the Italian sample, the immersive experience can be interpreted as the activation of a more gradual process, mediated by increased behavioral involvement in the arts, which in turn supports the formation of a future intention, consistent with the distinction between determinants of immediate action and determinants of planned intention (Sheeran & Webb, 2016).

5.5 Conclusions for the U.S. study

The study replicated the experimental design in a different cultural context, namely the United States, with the aim of verifying the robustness of the results obtained in Italy and their potential generalizability. In line with the initial hypotheses, the visit enriched with AR/VR

content produced higher overall Immersion peaks in the experimental group than in the control group, suggesting that the integration of immersive experiences can increase the neurophysiological value of the museum experience even in a different context.

Furthermore, in the US sample, the experimental group made more direct donations to the museum than the control group, both in terms of the amount donated and the probability of donating (donor vs. non-donor). Specifically, 56% of participants in the experimental group donated, compared to 32% in the control group, with significant differences in non-parametric tests.

In this regard, a logistic mediation analysis was performed to understand the impact of Immersion peaks on direct donations. The experimental condition predicted Immersion (path a), and Immersion significantly predicted the probability of donating (path b). The indirect effect (ACME) was significant, while the direct effect of Group on the outcome was not, indicating that the increase in donations is mainly explained by the increase in Immersion peaks.

Overall, these results support the idea that, in the US context, Immersion may function as a proximal signal of experiential value that can translate directly into immediate prosocial behavior (Zak, 2015; Zak & Barraza, 2018; Lin et al., 2022).

In terms of attitude, however, the evidence does not indicate a differential change between groups in their intention to donate. In other words, the experience seems to affect immediate behavior rather than medium-term intentional planning. The different results that emerged in the Italian and US contexts are consistent with the literature. In this regard, in a cultural environment where donating money or leaving a tip is more normatively regulated and socially expected, prosocial action may be more readily available and easily implemented immediately after the experience, without necessarily requiring intermediate steps related to engagement or longer-term intention formation (Faqah et al., 2015; Lynn et al., 2015; Wang et al., 2015).

5.6 Limitations of the U.S. study

A first limitation concerns generalizability. Specifically, this study was conducted in a museum that only housed modern art. Unlike the study conducted in Italy, where the museum had rooms with heterogeneous content, the study conducted in the US only considered paintings and sculptures of a single type. In the absence of counterbalancing, it is not possible to completely rule out effects due to the specific works and environments of the rooms, which all focused on the theme of color in modern artworks.

Secondly, the composition of the sample, which had potentially specific sociodemographic characteristics (such as the large proportion of students), may limit the generalizability of the results to more heterogeneous museum populations.

A further limitation concerns possible economic and situational confounders: participants in the US sample were rewarded with $10, a condition that may have reduced the subjective cost of donating and facilitated immediate action, making it more difficult to isolate the proportion of the effect attributable exclusively to the immersive experience (Bekkers & Wiepking, 2011).

Furthermore, donation was measured as a discrete and immediate behavior, with limited amounts ($0, $3, $5, $10). This increases the ecological validity of the behavioral outcome but reduces the granularity of the data, which led to the decision to model the outcome as a dichotomous variable (donor/non-donor).

From a methodological point of view, although it increased feasibility in the field, the exclusive use of the neurophysiological measure of Immersion implies a trade-off. On the one hand, it reduces the experimental burden observed in the previous study (and thus supports ecological validity), but on the other hand, it limits triangulation with other neurophysiological components or with richer convergent measures, or, more simply, a more in-depth comparison with the Italian data (Kleckner et al., 2021; Janssen et al., 2021). In this sense, the choice to use only Immersion is consistent with the need to reduce experimental friction, but restricts inferences to what the metric is able to capture.

Finally, as was also the case in the experiment in Italy, it was not possible to monitor longitudinally whether any stated intentions translated into subsequent donations to the museum (in the weeks or months after the visit). This limits the ability to distinguish between an immediate situational effect and a more stable impact on practices of economic support for cultural institutions.

General conclusion and practical implications

This study addressed a central issue in cultural economics, namely whether the implementation of VR and AR experiences can encourage economic support behaviors such as donations. In this perspective, these technologies were considered not as substitutes for visits, but as additions capable of increasing experiential involvement and activating motivational levels typical of prosocial behavior. The results obtained in the two studies suggest that the use of immersive technologies (AR/VR) in museums can have significant practical implications in terms of experience design, fundraising, and the sustainability of cultural institutions. In fact, the data supports the idea that tools such as AR and VR can have an impact on the economic sustainability of museums if the content is designed and targeted to build meaning, proximity, and connection. Therefore, the goal should not be just to amaze visitors, but to elicit and foster engagement with the cultural institution.

Overall, the results of the two studies converge on one key point: AR/VR can significantly increase Immersion during visits. However, the relationship between Immersion and economic support is neither automatic nor identical in every context. In the Italian case, increased Immersion does not directly translate into a linear increase in the intention to donate. Rather, a more mediated picture emerges, in which the experience seems to have an impact when it transforms into greater behavioral engagement with the arts, which acts as an intermediate step toward the intention to support them through donations. This result suggests that, in the Italian museum context, VR and AR experiences could increase engagement without immediately generating sufficient motivational change, except through more gradual processes that pass through behavioral engagement (Kemp, 2015; Lin et al., 2022).

Therefore, similar AR/VR interventions can yield different outcomes depending on the habits of the population under consideration. For example, in Italy, donating small amounts of money is less common than in other countries, such as the US. For this reason, the use of AR/VR in contexts such as Italy could be more beneficial if used to activate visitors' behavioral engagement (participation, return visits, involvement in cultural activities), which constitutes a bridge to future financial support. In this case, therefore, the use of AR and VR should be associated with an initial call to action that is not necessarily monetary (newsletter subscription, membership, participation in events, return to the museum). Subsequently, once visitor engagement has been established, it would be appropriate to trigger a series of post-visit contacts that transform interest into a willingness to support and donate to the cultural institution.

The study conducted in the United States offers a complementary perspective. In a cultural context where donating is a common practice, Immersion is more clearly linked to immediate direct donation behavior. In this context, the effect of the immersive experience on donations appears to be explained mainly by the increase in Immersion, consistent with the idea that emotionally meaningful experiences can encourage prosocial actions in the here and now when the act is simple, available, and socially compatible (Zak, 2015; Zak & Barraza, 2018).

In contexts where the act of donating is more socially and normatively common, museums can maximize the effect of the experience by including immediate, simple, and contextual

donation requests. In this study, for example, the donation box was visible at the end of the visit. Other suggestions could be to make donations available through various payment methods (such as online giving via mobile and other contactless or mobile-enabled payment systems) combined with messages delivered immediately after the visitor has finished the experience, as also highlighted in the study of Cawston (2018).

Taken together, the two studies indicate that the introduction of AR and VR experiences in museums can contribute to their sustainability, but through different mechanisms depending on the cultural context: sometimes more indirect and linked to behavioral engagement (Italy), sometimes more immediate (the United States). From a theoretical point of view, this evidence supports an interpretation consistent with behavioral economics and experiential value. In fact, this study shows that the decision to donate depends on how the experience is perceived and how much it can be transformed into stable involvement or immediate action, including through social norms, ease of action, and decision-making (Bekkers & Wiepking, 2011).

The results also suggest that, considering the cultural context, it would be better not to evaluate the effectiveness of AR/VR using a single indicator referring to immediate economic return. In the Italian case, limiting oneself to the final outcome of immediate donation risks underestimating the value of the intervention, because the effect emerges mainly on intermediate variables (behavioral engagement, intention). Consequently, the evaluation should include various types of indicators, such as return visits to the museum, newsletter or membership subscriptions, and participation in events.

Furthermore, regarding AR/VR content design, the increase of the Immersion level in this study is also interpreted in light of the presence of coherent and engaging storytelling. AR/VR works best when it builds meaning and proximity, as suggested by other previous studies (Benghadbane et al., 2025; Pantile et al., 2016; Zak, 2015; Zak & Barraza, 2018). In practical terms, this implies that museums should invest not only in hardware/software, but also in narrative writing, in creating coherence between object, space, and digital layer, and in designing an experiential arc that accompanies the visitor towards a form of active engagement.

This study also revealed that the quantity and distribution of digital content can have an impact on visitors. Environments with too many closely spaced AR stimuli can reduce immersive engagement, while more diluted and sensorially consistent experiences can restore higher levels of immersion. Therefore, it would be advisable for the implementation of AR/VR not to lead to an excess of simultaneous informational content and for there to be a balance between it and experiential value (Buchner et al. 2022; Miao et al., 2024).

In methodological terms, this study also highlights an important point: in field contexts, neurophysiological measurement offers significant opportunities but requires a balance between data richness and ecological validity. The reduction in the tools used in the Italian study compared to the US study can be interpreted as a progressive refinement aimed at preserving the ecological value of the experience and reducing operational interference, without sacrificing informative indicators.

In conclusion, future studies should therefore evaluate the economic sustainability and effectiveness of AR/VR, considering not only the direct and immediate economic return, but also broader indicators related to the quality of the experience, engagement, loyalty, and the propensity to provide support over time. From this perspective, museums can develop a culture of controlled experimentation in ecological contexts, comparing different narrative or informational design solutions, content density, and calls to action, to evaluate more comprehensively the effects of AR/VR technologies.

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