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Heart and Soul: The Ethics of Biometric Capture in Immersive Artistic Performance

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ABSTRACT

Biometric data plays a multifaceted role in innovative artistic endeavours. As artists continue to break new ground by integrating performers' biometric data into live performances, others collect biometric data from audiences to measure engagement. Given the sensitive and personal nature of biometric data, particularly in relation to immersive technology, it is imperative to ethically consider how this data should be handled in performative contexts. To clarify these ethical considerations, we conducted a scoping review of sources related to immersive biometric performance in HCI, Performing Arts, and Social Sciences published over the past 30+ years. We detail how and why biometric data is being used in immersive artistic performance, identify associated ethical questions and concerns, and develop a framework of ethical considerations for artists and researchers in this space. In doing so, we emphasise an 'ethics by design' approach that considers values such as privacy and autonomy alongside artistic merit.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); HCI theory, concepts and models.

KEYWORDS

Biometrics, Ethics, Immersive Technology, Artistic Performance

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1 INTRODUCTION

Artistic performance has long used technology to engage, provoke, and delight audiences [137]. Many artists readily engage with digital technologies as "tools of enhancement and experimentation" [27]. Indeed, the rapid development of such technologies has presented fertile ground for innovative and transgressive performances involving drones [34], artificial intelligence [168], and virtual reality (VR) [84, 190].

Technologies that measure biological data—encapsulating physiological, biological, and behavioural data about the human body—have a particularly notable history of use in boundary-pushing artistic performance. From early explorations of translating brain signals into music in the 1960s [134, 161] to contemporary performances that integrate artists' physiology [7, 29, 72, 177], biometric data is being used in a variety of ways to shape artistic outputs. The HCI community has played a pivotal role in driving this body of work, with explorations of how biometrics can enhance the experience of music [88, 118], dance [48], interactive art installations [175], and theatre [184]. Studies have explored the collection of biometrics from different groups, including artists, performers, and audience members [78, 174]. There have also been efforts to enhance artistic performance by combining biometrics with other technologies, particularly immersive systems like VR [75, 98, 127]. This latter development dovetails with the increasing use of biometric data in head-mounted displays (HMDs) (e.g. [157]), which often depend on biometric data to function. As these advances continue, there is enormous potential for the use of biometrics in performances to progress at a similar pace.

However, biometric data is among the most sensitive data that one can collect about a person and thus brings important ethical considerations regarding its collection, storage, and use. Concerns surrounding the privacy, security and fairness of using biometric data in contexts such as identification and surveillance are well known [87, 122]. These concerns become even more pressing given the proliferation of immersive technologies and HMDs, which utilise an array of biometric measurements through eye, face and motion tracking. This data can enhance VR's functioning and personalisation features [81], but it can also be recorded, used to reidentify people, and shared with third parties (including advertisers) without the user's knowledge or consent [52, 53].

Despite the steadily growing interest in the use of biometric data in artistic performances, there are few comprehensive accounts of these uses, and little guidance on the ethical considerations involved. Artistic endeavours are unique in their ability to push boundaries, challenge audience perceptions, and critique issues using technologies in meaningful ways. In this sense, the ethical expectations we might have for artistic performances in their use of biometrics may not be the same as those we have in other contexts such as research. Yet upholding the welfare of artists and audience members is essential even within the performance-as-critique, especially where the collection, storage and use of this data may be opaque even to the artists themselves. What could biometric data inadvertently reveal about a performer or an audience member? How can performers and audience members give their informed consent to share their biometrics in a performative context? And how is this data to be stored and managed?

In responding to such questions, this paper first aims to identify how and why biometric data has been utilised in artistic performances, including those making use of immersive technologies. Further, it aims to examine the ethical discussions occurring in these contexts, and to present an ethical framework to guide the use of biometrics in immersive artistic performance. To address these aims, we conducted a scoping review of sources in HCI, Performing Arts, and Social Sciences published over the past 30+ years. We found that biometric data has been used in a wide range of performances. While we found limited engagement with the potential ethical concerns that may arise when capturing biometrics during performances, some sources raised concerns around values such as privacy, autonomy, trust, authorship, artistic integrity, and artistic merit.

This paper offers two key contributions. First, we contribute a detailed review of the use of biometric data in immersive artistic performance. Second, we contribute an ethical framework (the 'BEAP framework') for researchers and artists using biometric data in artistic performances. Our framework can support the design, execution and evaluation of artistic performances that remain responsible and ethical in their collection and use of biometric data.

2 RELATED WORK

To lay the groundwork for our scoping review, this section offers a brief overview of biometric data and its relationship to immersive technologies and discuss some of the ethical issues surrounding biometric data. We then turn to the relationship between ethics and technology in performative contexts and offer a brief overview of approaches to ethics in HCI.

2.1 Biometric data and immersive technologies

Biometric data can be defined as measurements collected from a person that can be used to infer personal characteristics [17]. Some biometrics are immutable, such as a person's DNA, while others vary depending on bodily function and environmental factors. These include, but are not limited to, bone structure, skin reflectance, dental characteristics, fingerprints, hand geometry, blood pressure, pulse, heart rate variability (HRV), and brain activity. Other biometrics are based on behavioural data, including eye movements, body movements, gait, and voice and speech utterances. The collection of much biometric data relies on medically non-invasive sensors and devices [83], including electroencephalogram (EEG) machines to measure brain activity, electrocardiogram (ECG/EKG) machines to measure electrical activity in the heart, and galvanic skin response (GSR) electrodes to measure sweat gland activity.

Biometric data is often highly individualised and thus can be used to identify people based on unique markers [61]. Some biometrics are also revealing of internal states and processes that can be difficult to detect or that can only be assessed through subjective measures. This has led to biometrics being used in scenarios including security and authentication [66, 68], emotion recognition [31], estimation of cognitive load [196], and detection of complex physiological responses such as stress [143].

Immersive technologies have an increasingly close relationship to biometric data capture and are increasingly used in performances. Commercial VR headsets such as the Oculus Quest 2 use data from eye-tracking, body movement and head position to enable user interaction with virtual objects and environments [53]. Biometric data has also been employed to enable new kinds of interactions within immersive technologies, such as the measurement and visualisation of users' blood flow and vital signs [95]. Other work explores the use of biometrics for improving accessibility [158] and building mindfulness [123] in VR environments.

2.2 Ethical issues with biometric capture

Biometric data has numerous useful applications, and the integration of biometrics into immersive technology has the potential to enhance user experience, particularly when used to support artistic performances or enable people to enjoy the arts remotely (such by watching a concert in VR). However, concerns have been raised about the collection and use of biometric data, including issues such as privacy, security, data-reuse and misuse, validity, interpretation and bias, and social exclusion [65, 111, 124, 189]. Writing from a consumer law perspective, Heller warns of the potential for immersive technology companies to link users' identities to their 'biometric psychography', creating consumer profiles with details like health or sexual orientation for intrusive marketing practices [52, 53]. Other studies have highlighted the potential for the unwanted identification of individuals in immersive environments based on biometric data that was not collected for the purpose of identification, including facial dynamics [146] and movement data [100].

The importance of privacy regarding personal data has been recognised by various institutions and legal systems worldwide. For example, the European Union adopted the General Data Protection Regulation (GDPR)[1] in 2016 to formalise the protection of personal data [181]. The GDPR introduced biometric data as a special category of protected data that can identify and authenticate unique individuals and is thus subject to a higher level of protection. According to the GDPR, biometric data can only be processed subject to specific guidelines, such as only after obtaining explicit consent from the data subject (Chapter 2, Article 9). Despite protections such as these, many ethical questions about the processing of different forms of biometric data remain unclear. For example, scholars have raised questions about whether biometric

[1] https://gdpr-info.eu/

data that is not used for identification (such as for measuring emotional reactions) [14], images of biometric characteristics [163] and unprocessed biometric data [45] are actually afforded special protections under the GDPR, and point out that "broad exceptions and overall vagueness of the law leaves the door open for specifically risky uses of biometric data" ([45], see also [71]). Furthermore, as the GDPR is an EU regulation, it may not apply to biometric data collection that occurs outside of Europe.

These issues are particularly pressing given the growing ubiquity of biometric data [111]. Biometric data is becoming easier to collect using off-the-shelf hardware, including smartphones [63]. Immersive technologies containing non-invasive sensors such as Emotiv headsets and Myo Armbands are increasingly available at relatively low cost, prompting their use in a variety of research contexts [1, 62, 125]. The range of inferences that can be made about people based on biometric data is also expanding. Röddiger et al. reported that sensors worn in or around the ear can reliably detect 47 different phenomena about a person, including health conditions such as bruxism (teeth grinding) and sleep apnoea [132]. These examples illustrate the need to think carefully about the implications of collecting biometric data alongside existing laws and regulations, especially as biometric capture becomes more advanced and adopted at scale through immersive technologies.

2.3 Ethics and technology in artistic performance

Artistic performance has a complex ethical relationship with technology. Many artists have embraced technology to pursue artistic goals and explore novel creative spaces. In recent years, several performances have been held in virtual spaces [187], while researchers have begun exploring audience experiences of VR concerts [10, 113, 180] and the potential for VR to play a role in musical training [114].

At the same time, technologies can create ethical tensions in relation to performance: take, for instance, the potential use of musicians' and actors' biometric data to create an AI-generated likeness without their consent [40, 79]. Certainly, the performing arts are no stranger to critiquing technology. Many artistic performances are exploratory 'liminal spaces' that interrogate taken-for-granted technological practices such as facial recognition for surveillance [107], and present provocations by utilising the very objects and processes being critiqued (see, for example, the *Classification Cube* [99]). In this sense, artistic performance can simultaneously participate in and ethically critique certain practices in relation to technology, purposefully designing "transgressive" and "uncomfortable" interactions that can produce powerful, entertaining, and even enlightening experiences [11, 13].

Furthermore, performances—much like virtual environments—can lie "between the 'real' and the 'not real"' [145], setting them apart from the usual ethical demands and norms of the world beyond the performance. The use of biometrics and biological material in performance has brought to the fore existing ethical tensions involved in the navigation of these hazy boundaries, raising questions of agency and responsibility in works where audience members may contribute parts of themselves—including biometric data—to the performance [11].

When it comes to discussing the ethics of biometric capture in immersive artistic performance, then, we cannot speak of ethical issues without recognising that these same issues may be integrated and shaped in a performance in diverse, meaningful, and intentional ways. This is perhaps one reason why there have been limited efforts to create ethical codes of conduct for creating 'ethical art' in relation to technology. As we will explore in the next section, such codes and frameworks—including those used within HCI—are often prescriptive and normative in nature, and are not always appropriate for diverse contexts, including performative ones [11, 90].

2.4 Ethics and values in human-computer interaction

As HCI has shifted and developed as a discipline, so too have the ethical paradigms by which HCI researchers understand and frame their work. What was once a field that drew on science and engineering knowledge to enhance usability and optimise interfaces now encompasses myriad ethical, sociological, and humanistic interests [142]. The kinds of institutional and professional ethics that are associated with academic research across disciplines—further reflected in the codes of ethics associated with large computing bodies such as the ACM[2] and the IEEE[3]—have long had a foothold in HCI research, highlighting the importance of protecting users and upholding best practices [11]. But ethical concerns in HCI go further still. By the 2000s, HCI had seen an increasing interest in the incorporation of ethical and moral values into HCI research and design [142]: for example, Friedman's value-sensitive design approach [43, 44] advocated for the design of computing technology to involve identifying, articulating and implementing values with moral importance such as privacy, fairness, and accountability alongside "traditional criteria of usability, reliability, and correctness".

This concern with ethical and moral values continues today, with a number of works supporting proactive practices that make values explicit in HCI design practice [57, 147], including an 'ethics by design' approach that advocates the integration of ethical principles in design alongside an ongoing and active participation in monitoring the risks and impacts of a project [2, 26, 93, 108]. HCI research has also expanded its purview beyond traditional human subjects research in such a way that has prompted a rethinking of how HCI research should engage with participants [112], including paying attention to the ethical considerations involved in working with vulnerable or marginalised people and an emphasis on "reflective and empathetic" approaches in sensitive settings [186].

At the same time, some HCI researchers have drawn from existing philosophical and ethical theories in both research and design, including deontology and utilitarianism [198]. Deontology emphasises moral behaviours as those that adhere to certain rules regardless of the outcome, such as the Kantian categorical imperative to "act only according to that maxim whereby you can at the same time will that it should become a universal law" [64]. Consequentialism, on the other hand, emphasises moral behaviours as those that consider the outcomes or consequences of that behaviour, such

[2] https://www.acm.org/code-of-ethics
[3] https://www.ieee.org/about/corporate/governance/p7-8.html

as the classic utilitarian goal to maximise "the greatest happiness for the greatest number" [149]. These popular moral theories have dominated certain areas of HCI, such as in the design of artificial moral agents (AMAs) [198]. Nevertheless, other theories such as pragmatist and dialogical philosophies have been used in HCI work to develop ethical sensibilities "through experience and deliberative practice" while being "'answerable' to others" [30], emphasising instead an ethically responsive approach to working with research partners and stakeholders.

When it comes to ethical guidance in relation to the performing arts in HCI, the literature starts to thin. HCI has developed a close relationship with the performing arts, with HCI researchers and artists working together to stage, support, and explore interactions in performative spaces [11, 12]. However, the core ethical goals and values of these two disciplines often diverge, leaving a situation in which HCI often does not—or cannot—address ethical research and design in performative contexts with many of its existing frameworks. In response to this gap, Benford et al. [11] propose the adoption of Responsible Research Innovation (RRI) [160, 182] to address the ethical tensions involved in HCI's "turn to the cultural". The RRI framework, which stems from work in policy development but has seen some interest in HCI [9, 49], advocates for a mutually responsive and responsible strategy to research and innovation under an ethical lens [182]. This can involve a) *anticipating* the impacts of the research; b) being *reflexive* about the research process and existing norms; c) *engaging* with stakeholders inclusively; and d) *responding* to these processes by taking meaningful action [160]. In performance, this may involve engaging the participants and audiences in ethical debate; constantly negotiating boundaries (even within a performance); establishing expertise for decision-making regarding consent, withdrawal and data management; and open, collective debriefing after a performance [11].

In conducting our review, we wanted to consider the implications of the inclusion of biometrics in artistic performance in ways that are cognisant of the complexity brought about by the conflicting ethical frames of HCI and the arts. In turn, we build on ethics by design and Benford et al.'s [11] adaption of the RRI framework for HCI and performance more generally to create an ethical framework for artists and researchers to reflect on when navigating ethical questions around biometric capture within their unique performative contexts. This is a practical framework that leaves open any commitments to particular moral theories. Our framework extends previous work by focusing on the specific case of biometric capture within immersive artistic performance, which reflects a compelling setting in which biometric data can be used in simultaneously novel, engaging, and ethically challenging ways.

3 METHOD

To meet our aims, we conducted a scoping review—a rigorous yet flexible approach to literature review that gives an overview of a topic, concept or field by mapping out and clarifying relevant key characteristics or factors [109, 110, 119–121, 172]. Scoping reviews are well-suited to topics that are emerging [109] or possess a "complex or heterogeneous nature" [69]. This makes it an ideal method for the present study, which sets out to examine the interrelations and boundaries between biometrics, immersive environments, artistic performance, and ethics. Our goal is not to provide a definitive survey of all literature in this space, but is rather to obtain enough sources to understand the scope of what has been reported to date.

Our review follows the approach outlined by Levac et al. [80], which builds on Arksey & O'Malley's [3] foundational scoping process consisting of five steps: 1) identifying the research question; 2) identifying relevant studies; 3) study selection; 4) charting the data; and 5) collating, summarising and reporting the results. Levac et al.'s [80] approach emphasises reporting on an iterative, team approach and describing associated challenges to bring transparency to the scoping review process. With this in mind, we detail our process in the following sections.

3.1 Identifying the research questions

To develop our research questions, we engaged in an iterative, team-based pre-screening process that involved searching Google Scholar using combinations of topically relevant keywords ("biometrics", "immersive technology", "artistic performance", and "ethics"). This allowed us to clarify the four concepts and iteratively refine our search terms. We also consulted with two liaison librarians at our university, one specialising in Science, Engineering and IT and the other in Arts, who assisted in refining our search terms.

Through this pre-screening process, we arrived at relatively inclusive definitions for the key concepts covered by our review. We defined 'biometrics' as any measurements pertaining to the human body, including measures of physiology (e.g. heart rate) and behaviour (e.g. gestures). 'Immersive environments' included experiences brought about by immersive technology such as VR and mixed reality (XR), but also included artistically immersive environments that aim to absorb the audience in a performance through lights, sounds, and other effects. 'Artistic performance' came to encompass performances of music, dance, and theatre, along with multimedia art projects and installations. We initially focused on music as a starting point, but quickly discovered the use of biometrics spanned the performing arts, so broadened our scope. Finally, we adopted a wide definition of ethics that encompassed the principles and values, both moral and aesthetic, that shape our understandings of a given issue or technology; this includes issues such as privacy, informed consent, and artistic merit. With these concepts in mind, we defined three research questions:

RQ1: How is biometric data being used in immersive artistic performance?

RQ2: For what purpose is biometric data being used in immersive artistic performances?

RQ3: What ethical considerations are being discussed in relation to immersive artistic performance?

3.2 Identifying relevant articles

We performed an extensive literature search across six academic databases: ACM Digital Library, Scopus, Frontiers, Performing Arts Periodicals Database, RILM Abstracts of Music Literature, and Music Periodicals Database (see Appendix A.1 for an example Boolean search phrase). These databases were chosen to reflect the interdisciplinary nature of the subject matter. We did not set a time limit for article publication and searched for all articles published up until July 2023.

We also engaged in Google searches using different combinations of our key search terms. We found that relevant work in this area was not solely described in academic publications but was also presented in media articles, white papers, and websites. We therefore expanded our search beyond academic databases to include these sources given their potential to enhance the scope of our review and illustrate how biometrics are being used in practice.

We used Covidence,[4] a web-based tool for conducting literature reviews that is suited to supporting scoping review workflows among teams, to manage the scoping process. In total, we imported 819 sources from our searches into Covidence. We also imported 46 additional sources that we acquired through citation chaining, whereby references that appeared relevant at the full text screening stage (Section 3.3.2) were sought out, imported into Covidence, and subjected to the screening process described in the following sections. After removing 31 duplicates, 834 sources remained for manual screening.

3.3 Selecting articles

We selected sources for analysis by drawing from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) screening process [176], which presents a checklist for researchers to ensure "transparent and clear reporting of systematic reviews" [115]. The PRISMA process for systematic reviews involves screening articles for inclusion based on their abstracts and full texts, and this process helped us to ensure articles were selected and managed in a consistent and rigorous way (see Appendix A.2 for the full PRISMA chart for this review). While the PRISMA approach is often presented as a linear process, scoping reviews are typically iterative [80], and this was true of our review. For example, articles were sometimes added or removed after team discussions about the scope of our review, which evolved iteratively based on the articles we were finding.

3.3.1 Abstract screening. At the abstract screening stage, we determined that our inclusion and exclusion criteria should address the many overlaps between biometrics, immersive environments, artistic performance, and ethics (see Appendix A.3 for the full list of exclusion criteria). We decided to send articles to full text screening if their abstract mentioned at least two of these key elements, and where one of those key elements was artistic performance, because this is the overarching context of our review.

With these criteria in place, the first and last author independently read each abstract to determine inclusion or exclusion. Any disagreements were discussed and resolved. In total, 473 out of 834 sources were excluded at this stage, leaving 361 studies to be further screened for eligibility.

3.3.2 Full text screening. In the full text screening stage, both the first and last authors read through each full paper in Covidence. We decided to include papers in our review if they discussed or explored the use of biometrics in artistic performance. We considered ethics and immersive environments to be optional inclusion criteria because there were many cases in which sources explored the use of biometrics in performances without discussing ethics or characterizing the work as 'immersive'. Such sources were retained because ethical issues can be subtly evident even if they are not explicitly discussed in a performance, and the absence of ethical considerations is of interest to our third research question. Similarly, artistic performances may not use immersive technologies such as VR but can be characterised as 'immersive' in an artistic sense, e.g. through the use of lights or dark rooms that are intended to immerse people in the setting. We wanted to include such performances to understand how biometrics were being used within them, in turn providing a more complete picture of the literature.

We inevitably encountered edge cases: for example, some sources described the use of biometrics in contexts such as online video game streaming [130, 131] and interactive art pieces (e.g. [96, 151, 195]). These arguably fall outside the realm of traditional performing arts like music and dance but nevertheless involve performative and artistic elements. We decided to include these cases when they offered information that appeared useful for answering our research questions. Any inclusion/exclusion conflicts were resolved in research meetings. A total of 255 out of 361 sources were excluded at this stage, leaving 106 studies for analysis.[5]

3.4 Charting the data

This stage of the scoping process involved reading the included sources in full and extracting information to address the research aims (known as 'charting' the data). We extracted relevant data from the 106 sources via a data extraction form template (see Supplementary Material), which presented prompts for the research team to fill in for each source. The authors collectively discussed and designed this template to capture basic data such as each source's title, authors, and study details where relevant (including aim, method, and findings). The template also collected information related to each of the four considerations of interest in this study, such as what the performance involved, how biometrics were used within it, and any relevant ethical considerations raised by the source's authors.

The template underwent a piloting process whereby five of the authors read and extracted data from 10 eligible texts (two per author) using an initial template designed in Microsoft Word. The template was then refined and entered into Covidence, and each author re-reviewed their pilot papers. The remaining papers were distributed evenly among the authors for review. The first and last authors acted as secondary reviewers, checking each review and making additional notes in the process.

3.5 Collating, summarising and reporting the results

Analysis of the extracted data involved both quantitative and qualitative components. First, the full data set was exported from Covidence into an Excel spreadsheet. We gathered basic numerical data about the sources, including counts of publications in each year, types of biometric data collected, and how many sources stated receiving ethics approval. Second, we coded segments of the qualitative data to generate themes that respond to our research questions. This qualitative data included information about the purpose of biometric data collection and any ethical considerations brought

[4]https://www.covidence.org/

[5]All 106 sources included in the analysis have been marked with an asterisk (*) in the reference list.

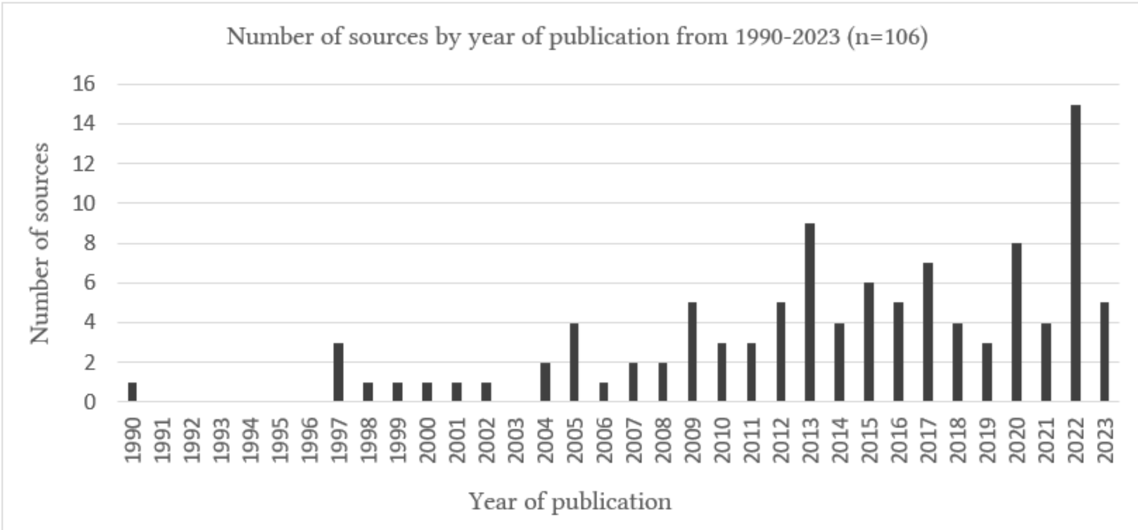

Figure 1: Bar chart demonstrating the number of final scoping review sources (out of 106) that were published each year from 1990 to 2023.

up in the sources themselves or by the reviewers. These themes were generated through inductive coding of the literature, drawing from both explicit statements in the sources themselves (semantic coding) as well as purposes or ethical considerations underlying the texts based on our own interpretations of the data (latent coding) [171]. This was again an iterative process that involved the first author entering the relevant data into qualitative data management software NVivo, inductively coding the data, and arranging the codes into themes. The themes were discussed and refined among the authors in subsequent meetings.

The numerical data and associated descriptions address RQ1, demonstrating the ways that biometric data is integrated into immersive artistic performance. The qualitative analysis answers the question of 'why' biometric data is being collected in artistic performances (RQ2) and outlines the ethical considerations raised in the sources (RQ3). These results are presented in the next section. In our Discussion, we reflect upon our findings and present a guiding ethical framework for artistic practice and research that involves the collection of biometric data in immersive performative contexts.

4 FINDINGS

In this section, we first characterise the 106 sources in our review, covering information including year of publication, affiliation country, publication type, and the types of immersive environment featured. We then present our core findings in line with our three research questions.

4.1 Characteristics of the literature

The years of publication of the final set of sources ranged from 1990 to 2023, with publication numbers growing over time and peaking notably in 2022 (see Figure 1). The affiliation countries of the first authors or performers spanned across 19 countries, with the UK (27) and USA (29) representing the majority. Most sources were academic papers (89); other publication types included 4 media articles, 3 website descriptions, 2 white papers, 2 performance videos, 2 university articles, 1 workshop description, 1 discussion paper, 1 book chapter, and 1 book.

4.1.1 Performances. Of the 106 sources, 88 explicitly featured (rather than discussed in more general terms) an artistic performance of some kind. Musical performances represented the highest number (42), followed by dance (25), art installations (23), theatre (9), film (3), and online video game streaming (2). Some performances encompassed more than one modality, such as those that combined both music and dance [51, 72, 75, 133, 162, 188]. For example, the choreomusical performances *Venus Sunrise* and *Biotic-Abiotic Interactions* featured a performer dancing upon the electronic textile carpet *Tapis Magique*, which allowed the dancer to compose music based on their body postures and gestures [188]. Some art installations (defined loosely here as interactive exhibitions or crafted artistic devices) also featured music and/or dance [56, 116, 117, 155, 165]. For example, the *Brain Opera* [116–118], described as a "large, touring multimedia production" [116] that was born in the MIT Media Laboratory in 1995-96, enabled participants to interact with a variety of biometric art installations and instruments such as the *Digital Baton* [91] then experience them in live music and dance performances.

4.1.2 Immersive environments. There were 98 sources that described or utilised an immersive environment. The majority were categorised as artistically immersive (77), followed by virtual reality (7), augmented reality (5), mixed reality (3), a physically immersive ride (2), a video game (1), interactive fiction (1), extended reality (1), and an adaptive virtual environment (1).[6] The tools used to

[6]Note that not all sources featured an immersive environment, and some featured more than one type of immersive environment and/or type of technology used to facilitate that immersive environment.

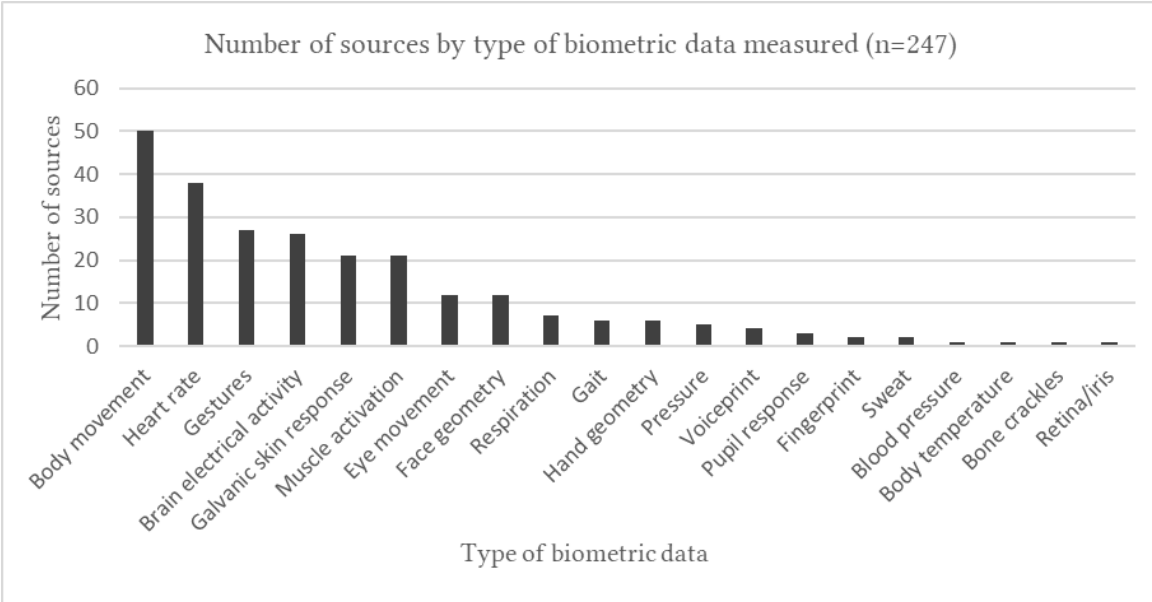

Figure 2: Bar chart illustrating the number of sources that collected different types of biometric data.

facilitate these immersive environments included video (34) and audio (24) projection, screen displays (13), lighting effects (9), 3D motion capture (8), VR headsets (7), smartphones (2), physical rides (2), and augmented reality glasses (2).

4.2 RQ1: How is biometric data being used in immersive artistic performance?

4.2.1 Type and collection of biometric data. Immersive artistic performances made use of a wide range of biometric data taken from performers, audience members, and/or visitors, either integrating this data directly in the performance itself, making use of it retrospectively for evaluative purposes, or for research and analysis. This includes movement-based data such as body movement and gestures; physiological measurements such as heart rate and GSR; eye-tracking data including pupillary response and eye movement; brain electrical activity; identification data such as face and hand geometry; and more uncommon data such as bone crackles [29]. Body movement (50), heart rate (38), gestures (27), and brain electrical activity (26) reflected the four most common types of data collected (see Figure 2).[7]

Biometric data was collected through a variety of sensors appropriate to the type of data being collected: for example, accelerometers and cameras were used to track body movement and gestures, while electroencephalograph machines (EEGs) were used to record brain electrical activity. Commercially available devices with built-in sensors were used in numerous performances to collect biometric data. Examples included the use of Myo armbands to measure arm movement and muscle activation [23, 37, 94, 126–128, 166], Microsoft Kinect devices to measure body position and motion [50, 60, 104, 133], Emotiv headsets to measure brain electrical activity [106, 154, 193, 194], and smartphones to measure heart rate, brain electrical activity, and body movement [36, 48, 74, 92]. Many performances involved bespoke devices that integrated sensors relevant to the performance. For instance, Hurban [58] created a portable custom device called the *Sound Drop* that contained a gyroscope/accelerometer and other sensors, designed to react to dancers' movements and allow them to generate sounds during their performance.

4.2.2 Display and integration of biometric data. In many performances, biometric data was collected from performers, audience members and/or visitors and subsequently displayed or integrated into the performance itself. In such cases, biometric data was processed and translated into a variety of formats, including sound (42), music (34), video projections (28), lighting (16), displayed stats (13), performance outcomes (6) (where the biometric data shaped what was presented to the audience), computer-generated models (6), and physical artifacts (3).

In some performances, biometric data was integrated in only one form. For instance, Robinson et al. [131] created and evaluated a tool called *All the Feels* to display the heart rate, skin conductance and facial emotion of a Twitch streamer to their online audience. In other cases, biometric data was integrated in multiple ways. In the installation *E.E.G. Kiss* [76], pairs of visitors were invited to kiss each other while their brain activity was recorded via EEG headsets; this data was then translated into video and light projections and a musical score.

However, the type of biometric data collected did not limit the way that data was displayed or integrated into the performance. Heart rate had a particularly wide variety of applications: this data was used to produce video projections [25, 36, 56, 98, 162], lighting

[7]Note that not all sources collected biometric data (some only discussed it), and among those that did collect such data, the majority collected more than one type (hence the higher n in Figure 2, which reflects 247 cases of biometric tracking spread across the 106 sources).

Table 1: The uses of biometric data in exploring and shaping the relationships and connections between performers, audience members and performances.

	Performer	Audience	Performance
Performer-to-	Connecting performers with each other; improving collaboration in group performance e.g. *LuminUs* [105]	Sharing performer biometrics with the audience to explore connection; creating mutual artworks; exploring interpersonal synchrony e.g. *Phantom Undulations* [59]	Understanding performers' experiences of performance e.g. the experience of flow in piano playing [89]
Audience-to-	Sharing audience biometrics with the performer(s) to explore connection; reviewing audience engagement e.g. *GROUPTHINK* [56]	Connecting audience members with each other e.g. w*hisper* [139]	Connecting audiences with a performance; prompting reflection; changing performance outcome based on audience response; understanding audience response e.g. *Pulse Topology* [15]

effects [4, 15, 25, 51, 72, 104, 151, 162, 177], sound effects [5, 6, 25, 36, 37, 51, 59, 72, 73, 130, 139, 162], music [5, 6, 72, 76, 97], numerical statistics or charts depicting heart rate [25, 130, 131, 140, 162, 170, 183], physical artifacts [148, 195], and to influence performance outcomes [47, 51, 72, 130, 162]. Nevertheless, certain types of biometric data were commonly used to generate particular outputs—for example, both brain electrical activity [54, 86, 102, 134, 191] and body movements/gestures [18, 20, 58, 60, 88, 91, 103, 116, 117, 126, 127, 167] were used to produce sound and music as part of ongoing movements in experimental sonic performance. This includes brain-computer music interfaces such as the *BCMI-Piano* and *Interharmonium* that generate music from brainwaves [102]. Further examples include performances that leverage movement to generate sound, as in Sarah Nicolls' 2017 performance of *Suspensions* by Atau Tanaka, a piece in which piano playing is augmented by muscle-sensing via Myo armbands [166].

4.3 RQ2: For what purpose is biometric data being used in immersive artistic performances?

Our analysis suggests that artists and researchers are using biometrics for three purposes: 1) Engagement; 2) Interaction; and 3) Evaluation.

4.3.1 Engagement: Using biometric data to explore and shape the connections between performers, audience members, and the performance itself. Some forms of biometric data can be taken as proxies for different emotional states—an elevated heart rate, for example, can indicate excitement or fear. Tracking and sharing these 'hidden' emotional states was an important motivation in many sources, especially to explore more intimate and personal engagements between performers, audience members, and the performance itself. We detail these various relationships and connections below and summarise them in Table 1.

Performer-to-Performer. First, collecting and displaying performers' biometrics during a performance presented opportunities to connect performers with each other. This allowed them to adjust their performance based on mutually displayed biometric data. In the performance *Resonant Frequencies* by Kinetech Arts, dancers' heart rates were translated into music and lights; the artists stated that this allowed performers to "calibrate and negotiate their kinetic energy with one another and the audience" [72]. A group of studies further examined how performers' biometric data could be recorded and shared with other performers to enhance collaboration [48, 97, 105]. The *LuminUs*, for example, explored how translating musicians' body motion and gaze into shared light displays could provide "feedback on aspects of their collaborative interactions" [105].

Performer-to-Audience. The second type of use involved collecting the performer's biometric data and using it to explore the connection [25] or "nexus" [29] between performers and their audience. By sharing a performer's biometric data with the audience, performers' "sensations and experiences 'underneath the skin"' could be shared with and responded to by the audience [37]. In some cases, biometric data was collected from both the performer(s) and the audience to create a mutual artwork or performance, or to explore synchrony between performers and the audience [73, 77, 164]. For example, the mixed-media work *Phantom Undulations* collected physiological data (including electrodermal activity and heart rate variability) from the artist and the audience to create a "contrapuntally fluid and responsive musical experience" reflected in the lights and sounds of an artifact in a gallery [59].

Performer-to-Performance. Third, a handful of studies collected and analysed performers' biometric data to better understand their experience of their own performance. This included collecting physiological indicators from pianists to understand their experience of flow during a piano performance [89], movement qualities from dancers that give insight into performance [38], and a study of how features such as technical difficulty and experienced effort impacted a pianist's heart rate variability [141].

Audience-to-Performer. A fourth set of cases involved collecting the audience's biometric data and sharing it with performers to explore the "invisible link" between them [162]. Live audience data was thought to impact the performers' emotional states [73] and presented opportunities for performers to adjust their performance depending on audience biometrics. For example, the participatory artwork *GROUPTHINK* created an "entangled network" that allowed performers to respond to their audience's heart rate data by adjusting the tempo and mood of the musical performance [56]. Audience biometric data could also allow performers (as well as directors and choreographers) to retrospectively analyse audience engagement in response to different parts of a performance [77, 78].

Audience-to-Audience. Fifth, biometric data was used to connect audience members to one another through shared biometric data displays. Rafael Lozano-Hemmer's works are particularly notable in this regard, encouraging visitors to interact with technology while displaying biometric data such as heart rate and facial expression to other observers through lights and video projections [4, 85]. This practice aims to "connect the public to each other" and encourage reflection on their shared lives and vulnerabilities [85]. Similarly, in the public installation *whisper* [139], participants' breath and heart rate data were collected, visualised and translated into sound (known as 'sonification') so that participants could "interact, interconnect, and interpret their own and other participants' internal data in playful and responsive ways". In a unique study, audience members' physiological responses were captured during a live concert and translated into visualisations in a VR environment so that later viewers could share in "the audience's aesthetic feelings and emotions" during the live event [98].

Audience-to-Performance. Finally, biometric data presented opportunities for artists to explore their audience's connection with the performance or artwork itself. By displaying audience members' biometric data as part of a performance or artwork [151, 175], artists connected audiences to the "liveliness, intensity, and multi-temporality of the artworks" [41]. For example, in a collaboration with luxury vehicle manufacturer BMW, Rafael Lozano-Hemmer designed *Pulse Topology,* an installation that collected the heart rate data of visitors, and used this data to control lights, sound and graphics inside a vehicle to "create a meaningful connection with its driver and passengers" [15]. The 'entertainment value' of biometric data was further explored in papers looking at how such data could enhance the audience's dramatic experience of watching television [170] or even turn amusement rides into theatrical events that engage riders and spectators [140, 183].

Biometric data was also used to prompt reflection among audience members regarding the underlying messages and implications of a performance or artwork. Several sources aimed to provoke audience reflection on "the human relationship to technology" [67], including broader socially relevant concepts such as "our obsessive techno-culture" [76] and "the way we are seen through the lens" of machine learning classification systems [99]. In other cases, biometric data was used to influence elements of a performance, such as the outcome of a film [47], the progression of an interactive story [42], the content of an interactive drama performance [24], or the difficulty of a live-streamed video game [130]. A subset of studies in neuroscience also aimed to understand how audience members' aesthetic and emotional responses to performance were reflected in the brain [32], including studies on real-time brain responses to dance [19] and music [82] via magnetic resonance imaging (MRI).

4.3.2 Interaction: Using biometric data to expand the interactions between a performer and their artistic tools and to create new forms of expressive and artistic control. Moving beyond engagement, a second way that biometrics have been used in performance is to enable new kinds of interactions. This is reflected most starkly in the development of biometric instruments, which enable the artist to produce sounds based on biometric inputs. The early performances of experimental group *Sensorband* in the 1990s are notable for their use of sensor-based instruments to produce electronic music [18]. These include Atau Tanaka's performances with the *BioMuse* controller system, which translated signals from the performer's brain, muscles and eyes into music and sound [73, 88]. Tanaka and colleagues later reflected and built on these works extensively [165–167] alongside other artists keen to explore new ways of controlling musical output. Examples include Arslan et al.'s biologically-driven musical instruments that formed part of a "bio-orchestra" [5, 6], the instruments making up the *Brain Opera* project at MIT [116] such as the *Digital Baton* [91], Laetitia Sonami's *lady's glove* [155], and Cavdir & Dahl's *Bodyharp* [20]. Each of these examples feature assemblages of sensors, software and hardware that transform the performer's biometric data into sound. Meanwhile, questions of how biometric data can or should be sonified—for instance, by letting the data determine the sound in an 'organic' way or mapping data to certain stylistic parameters—have been discussed among scholars in music theory [39].

There has been a concentrated interest in certain kinds of biometric inputs for musical control. The possibility of 'composing music with our minds' has sparked explorations into the sonification of brainwaves by transforming brain signals into sound and music [54, 86, 102, 134, 191]. The "mental state" of participants (ascertained via EEG sensors) was also transmitted into drawn patterns on fabricated physical objects in the artwork *NeuroMaker 1.0* [96]. Other innovative interactions allow performers to create electronic music via eye movement for an "alternative kind of expressive control" [70], such as via the musical interfaces *Oculog* [70], *EyeHarp* [179], and *EyeMusic* [55], which also open up possibilities for musical interactions among people with mobility impairments. Some sources explored the potentials of e-textiles [118, 188] and wearable sensors [58, 150] that enable foot position, pressure, body movement, and gestures to manipulate music and sound. Performance artist Marco Donnarumma's work further explores not only the potential for the body to *control* musical output, but to *generate* it directly through what he terms "biophysical music" in which the performer's muscle contractions create sonic material [28, 29].

In exploring these novel interactions via biometric data, several sources were focused on technically outlining, refining and expanding existing techniques [8, 22, 136] and devices [94, 117] for biometric capture, translation, and output in performative contexts. This includes creating and refining classifications of gestural control mechanisms for generating music [103, 126, 127, 133]. Gasques Rodrigues et al.'s *MotionDraw* tool, for example, allows dancers without technical backgrounds to create visual effects using gestures during live performances [133].

4.3.3 Evaluation: Using biometric data to evaluate performances and create training tools to improve performance. Biometric data has been used to measure audience reactions to a performance; this

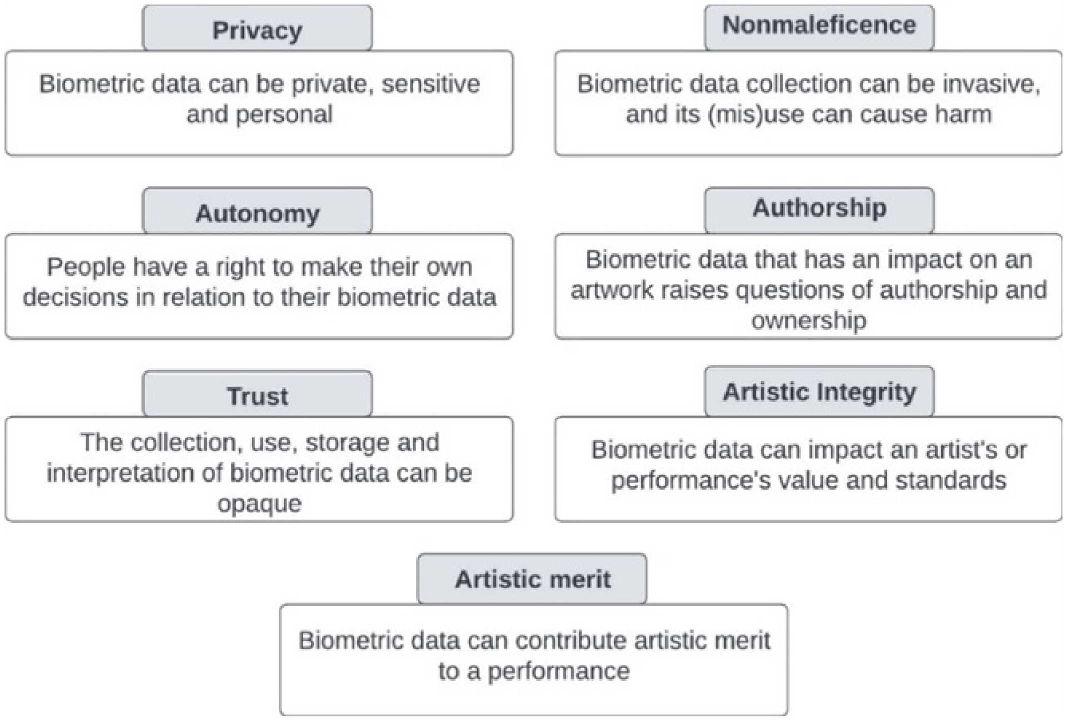

Figure 3: Seven values that capture the ethical concerns raised in the surveyed literature in relation to biometric capture in immersive artistic performance.

is then used to evaluate engagement and enjoyment. Here, biometrics are sometimes used with the aim of maximising audience engagement and 'improving' entertainment products, particularly in the film industry where selecting trailers and pitching movies with the most generated intrigue is important for commercial success [152, 174]. Studies of theatre [75, 184], music [138] and dance performances [78, 92, 159, 173] have also examined the feasibility of biometric indicators and devices for measuring audience engagement and reactions. For example, Martella et al.'s study suggests that smartphones can be used to predict whether audience members enjoy a performance via accelerometer measurements of body movements [92].

Extending these works, there has been interest in exploring ways to detect audience reactions via biometrics during live performances in order to evaluate or even alter the performance in real-time [51, 185]. For example, Yan et al.'s work explored how real-time EEG data from the audience could trigger certain performance cues (such as special effects) via a 'brain-adaptive digital performance' system to help raise engagement in audiences whose attention is waning [193, 194].

Biometric data has also been collected from performers themselves to help evaluate the success of artistic works. Some studies have tracked indicators such as the eye gaze and head movements of musicians to assess cohesion, synchrony, and collaboration, which are important elements of successful group performance [46, 50, 106]. In other work, biometric data has been collected from performers to develop training and educational tools that aim to assist performers in honing their practice. This includes recording dancers' gestures and body movement to develop interactive visuals or computer-generated models for dance training [37, 178], and measuring musicians' muscle activation, hand geometry, and gestures to explore the potentials of digital music assistants [23, 128].

4.4 RQ3: What ethical considerations are being discussed in relation to immersive artistic performance?

Early in the process of reading our sampled papers, it became clear that ethical considerations around biometric data were not often explicitly addressed in the literature. Despite managing data that has the potential to be both personal and revealing, only 15 of the 106 sources (14%) stated that they had received ethics approval for data collection.[8] However, a selection of sources in the dataset did touch upon ethical considerations in relation to biometric capture, offering useful reflections on how to handle such data. In this section, we detail these considerations (summarised in Figure 3), which are organised into seven ethical values relevant to the collection, storage, and dissemination of biometric data in immersive artistic performance.

4.4.1 Privacy. While only a minority of papers discussed privacy issues associated with biometric data, out of the seven values we

[8]In stating this percentage, we acknowledge that not all sources required ethics approval as they did not involve any human participants. We also note that norms for reporting ethics approval vary across disciplines and publication type, and that expectations have changed over time, meaning that some authors may not have felt it necessary to discuss ethical issues.

identified in the dataset, privacy was among the most addressed. Heller's work on biometric psychography highlighted these concerns, arguing that biometric information is sensitive data not only because it can identify an individual, but because it can divulge a person's desires, thoughts, and emotions over time [52, 53]. Such information can purportedly indicate whether a person is lying, how they feel towards an object or person, and may unintentionally reveal serious ailments such as schizophrenia and Parkinson's. EEG, for example, is considered "one of the most useful tools in the diagnosis of epilepsy and other neurological disorders" [102], while the sonification of echocardiogram data can reveal irregular heartbeats [54].

In a small number of sources, an awareness of the sensitive and private nature of biometric data raised practical questions about how this data should be handled. In keeping with the value of research transparency, some sources noted that they made their raw biometric data publicly available; however, the authors of *E.E.G. Kiss* questioned whether such data should be placed in a "transparent database to be used by others" [76]. Another group of authors commented on the importance of aggregating biometric data to maintain individuals' privacy and ensure that they cannot be identified [130]. Commenting on his artwork *Pulse Topology*, Rafael Lozano-Hemmer noted that electrocardiogram data is "very private information. But when you put it together with the heartbeats of all the other participants, you get a chorus" [15], suggesting not only ethical but also aesthetic merit to data aggregation. On the other hand, some performance experts in a study on audience responses to performing arts preferred viewing individual audience response data over aggregated data because this acknowledged audience diversity [78].

4.4.2 Autonomy. Upholding autonomy—that is, respecting people's ability to make their own decisions—is an important principle in research ethics that has given rise to the practice of informed consent. Ten sources described soliciting informed consent from audience members and/or performers, though these were mostly within a research context [20, 22, 32, 51, 82, 89, 98, 141, 159, 162]. In one study that collected heart and electrodermal activity from the audience of a stage performance to influence staging elements, audience members were informed about the sensor data and potential risks through flyers and brochures, an introduction at the beginning of the performance, and consent forms placed on their seats for them to sign. This technique, which allowed participants to choose whether to participate, resulted in 41 out of 139 audience members (29.5%) not signing their consent forms [51].

Other sources did not state that informed consent was acquired, but took the approach of posting a sign outside the performance informing audiences of data collection, with entry considered as consent to the collection of biometric data [173]. In the art installation *Classification Cube* [99], in which viewers' faces and bodies were subjected to classification by a machine learning system via video recording and face detection, viewers were informed before entering "that the system does *not* collect or share any information". The authors state that this approach is unlike other art projects that "explicitly share personal data".

Some sources also expressed concern over how biometric data could influence people's behaviours and agency in sometimes disempowering ways [37, 107]. Concerns were raised over systems that could "covertly manipulate a person's state", as might occur in performances and films that adjust what is displayed based on audience biometrics (such as by introducing 'scare tactics' to achieve a desired level of fear among the audience) [42]. Even without purposeful influence from a system, performers and audience members alike may try to impact their internal state in order to influence or even disguise their internal physiology [5, 148].

This potential lack of control in relation to the use of biometric data in performance took shape in further ways that had practical implications. In *Fairground: Thrill Laboratory*, a series of live events in which amusement park riders' biometrics were displayed to spectators, riders often experienced a "loss of control during intense moments". These moments were publicly displayed to spectators via a live video feed [140]. This prompted the authors to wonder if riders and ride operators should be able to switch off the public broadcast, or if riders should be able to approve their videos before public release.

4.4.3 Trust. Several studies expressed a lack of trust in companies and governing bodies to keep biometric data safe or private. For example, it was noted that it is not always clear how data is stored or used in commercially available immersive headsets, and there is a risk of this data being sold or monetised; furthermore, there are few legal protections regarding biometric data collected on these devices [52, 53, 192]. Reflecting on the art installation *E.E.G. Kiss*, the authors imagined how EEG 'kiss data' could be used in other ways to our disadvantage: "What if our kisses are stored in databases against our will and analyzed by algorithms owned by banks that decide on home loan applications? An all-too-passionate kiss can indicate that the wild romance will end up in a dramatic divorce. A flat and boring kiss will transmit the same message" [76].

Some sources further questioned whether we can trust our own biometric data [76] and our interpretations of it. One paper acknowledged that biometric responses captured in real-time from audience members can be interpreted in many ways and "cannot capture reflective responses to art that happen after the fact" [78]. Another urged caution in inferring causal paths between biometric data and self-reported measures: for instance, there may be a variety of reasons behind any links between physiological markers (e.g. glance time) and associated self-reported emotion (e.g. self-reported boredom) [106].

4.4.4 Nonmaleficence. Nonmaleficence—the moral imperative to 'do no harm', particularly in medical and research contexts—was occasionally evoked in some studies expressing concern that displaying biometric data could harm participants. There were concerns that publicly sharing such private data in a performative context could potentially be embarrassing [88] and uncomfortable for those whose biometric data is displayed, making for a vulnerable experience [84]. While some sources stated that there are no known risks associated with biometric data collection and HMD usage [174, 194], others showed awareness of the invasiveness of some biometric collection devices and their potential impact on users' comfort levels [5, 78, 140, 162].

4.4.5 *Authorship.* Four sources [135, 148, 153, 192] raised the following question: Who is the author or owner of a performance/artwork in situations where biometric data from an audience or participant has an impact on the performance/artwork itself? According to the authors of the *NeuroMaker 1.0*, in which participants' EEG data was transformed into decorative patterns and etched onto objects, participants were the authors of their own creations; however, participants often identified the designers as the authors of their created objects [96].

4.4.6 *Artistic integrity.* There was a concern in some sources that biometric data, particularly when used for evaluative purposes, could ultimately undermine the artistic integrity of a performer or performance. An artist may be considered to lack integrity if "they place some other—competing, distracting, or corrupting—value over the value of the artwork itself, in a way that violates their own artistic standards" [101]. In one study [78], performance experts expressed concern that using biometric data from an audience to evaluate a performance could lead to the erasure of the "ups and downs" of performance, and that post-hoc analyses based on biometrics could encourage the misguided perception that "optimal dance contains nothing but leaps". They also expressed a concern that producers may "eradicate certain artists" who do not generate the desired emotion in the audience, and that biometric data could encourage artists to engage in the unhelpful "guilty pleasure" of reviewing valence graphs in response to their performances.

Biometric data was seen to potentially minimise performances or artworks in other ways too. The author of a study involving an interactive dance performance integrating performer biometrics questioned "how much . . . the technology serve[d] or subjugate[d] the dance" [37], while another questioned whether biometric data can "reduce the individual dancer's performance, essence, to merely a collection of angles and data points" [153]. Similarly, the authors of a paper describing the development of a gesture-based AI assistant for giving guitar students real-time feedback considered whether such a system "could lead to specific styles of playing the guitar, potentially limiting instrumental creativity" [128].

4.4.7 *Artistic merit.* Despite the concerns detailed in the previous sections, many sources commented on the benefits of integrating biometric data in immersive artistic performance, suggesting a key tension: the need to balance the ethical risks with potential artistic merit. For instance, measuring an audience's physiological responses to a performance could inform performers of their most engaging moments [92, 185] and provide organisers with quantitative proof of the benefit of their performances [92]. Allowing audience members' biometric data to influence an artwork or performance was also claimed to "empower users" and "help put back some magic in the world" [42].

Several sources pointed out the role of artistic works in exploring ethical questions around technology. Considered to be "safe spaces" [56, 99], performative contexts were noted as being well-placed to critique biometric data and associated technologies [67, 107, 155] by co-opting them for artistic purposes. For instance, capturing participants' body and face data can raise awareness of the ethical implications of surveillance technologies, including their failure to capture "gender complexities" and "emotional diversity" [99] as well as their tendency to inaccurately and inappropriately "classify and control marginalized, vulnerable populations" [107]. Indeed, making users vulnerable during a performance through the collection of biometric data could be precisely what allows for the creation of "deeply meaningful experiences" [135].

On the other hand, one source reflecting on a gallery-based art project (which included installations that collected biometric data from young people) acknowledged the "fascinating insights, artefacts, and data" they collected, but also asked "what were the young people taking away?" [41]. This consideration, unique among the data set, raises the question of whether the benefits of collecting biometric data in a performance also extend to benefit those whose data is collected.

5 DISCUSSION

This review coalesces the myriad ways in which biometrics have been used, motivated, and discussed in artistic works. Biometric data, from common signals such as EEG and heart rate to more esoteric indicators like bone crackles, have been used to explore engagement between performers and audience members, to pursue novel artistic interactions, and to evaluate and refine performances. Biometrics have been transformed into sensory outputs such as music, sound, and lights as part of performances, and have been analysed retrospectively to improve later performances. In more unique cases, biometric data has even been used to actively influence the flow of a performance, creating an organic "liveness" [188].

In surveying these innovations, however, we also note a comparative lack of attention to the ethics of using biometric data in immersive performative contexts. Despite well-known concerns over issues such as privacy, security and fairness in relation to biometric data [87, 122], most sources did not acknowledge ethical issues associated with biometric capture. Many important ethical issues relevant to performance and biometric capture were almost entirely unaddressed in the corpus. This includes the ethical questions and challenges identified by Benford et al. [11] in their discussion of HCI and performance, such as how to navigate personal boundaries (particularly when "unwitting bystanders" are involved), how to (re)establish consent throughout a performance, when to permit participants to withdraw from the performance, and how to deal with unexpected insights from data display. The potential for social exclusion among groups of people who are unable or uninclined to engage with biometric technology was also not discussed [189].

Instead, there was often a focus on data acquisition over ethics, with papers exploring how biometric data could be collected more easily, more accurately, and integrated more seamlessly (e.g. [92, 133]). As we saw in Section 4.4, some sources did raise concerns and questions that overlap with existing issues related to biometrics, with additional concerns surrounding artistic integrity and artistic merit. However, these concerns were often secondary, and the questions were almost always left unanswered. This is perhaps not surprising given the goals that artists sometimes have when using technology in performance. In an interview with *Sensorband*, artist Atau Tanaka commented that, "as artists, our first instinct is not to make technical improvements to the system, but rather, to manipulate the technology in a creative manner" [18]. Artists' goals are understandably tied to creative engagement, while technical—and ethical—concerns can, in some cases, take a secondary position.

Nevertheless, the broad array of ethical concerns and questions that the sources left open suggests there is room for a comprehensive and actionable set of ethical considerations to assist artists and researchers in meaningfully navigating ethical issues alongside aesthetic and technical aims. Many institutions and jurisdictions are already subject to regulations and legislations that govern the use of biometric data, including the GDPR. However, there are global discrepancies in these standards and requirements, and even in locations with stronger biometric data regulations, there are limitations and loopholes in these regulations that necessitate further ethical oversight [14, 45, 163]. As discussed in Section 2.4, performative and artistic contexts also often have motivations and methods that complicate the ethical space around biometric data, prompting the need for more tailored guidance. Identifying and clarifying where ethical concerns can arise—particularly in ways that are not conducive to meaningful aesthetic engagement—is an important next step to take in artistic projects engaging in biometric capture.

5.1 The Biometrics and Ethics in Artistic Performance (BEAP) Framework

In this section we offer a practical framework to support the ethical collection, storage and use of biometric data in immersive performances. Our framework coalesces information from three key sources: the values we identified as part of our findings in this study, our own reflections on the scoping review as an interdisciplinary team, and existing literature on ethics in HCI and performance. In particular, our framework is rooted in an 'ethics by design' approach that emphasises the consideration of ethical values throughout a project's lifecycle [26, 108]. Our framework also follows in the footsteps of Benford et al.'s adapted RRI approach [11], which promotes the transparent and open involvement of stakeholders before, during and after a performance with an ethical lens.

Recommended in the BEAP framework, therefore, are practices that derive from these approaches (see [160]). This includes *anticipatory* practices such as the development of action plans to mitigate potential harms from biometric capture; *reflexive* practices such as building a thorough understanding of biometric data collection and its implications; *inclusive* practices such as engaging in ongoing consultations and consent negotiations with those whose data is collected (referred to as 'participants' in the following sections); and *responsive* practices that involve active adjustments and decisions taken in response to the previous practices throughout a performance [11].

In this spirit, our reflexive framework offers a set of seven guiding prompts, related ethical considerations and potential actions for artists and researchers working with biometric data in immersive artistic performance. The BEAP framework is detailed below and summarised in Table 2.

5.1.1 Who is biometric data being collected from? In immersive artistic performance, biometric data might be collected from performers, audience members, research participants, general users, visitors to an installation, or members of the public. The boundaries between these groups can often be blurred—for instance, a single person might be at once an audience member and research participant [98, 162].

Delineating who is involved in biometric data collection is of ethical importance because it provides a foundation for identifying harms that may arise in relation to their biometric data. For instance, audience members new to biometrics may be less willing to have their data displayed to others when compared to seasoned biometric performers who are keen to explore the artistic potential of technology. As we saw in Section 4.4.7, performers may express concern over how their data could be used against them if it is being collected for evaluative purposes [78]. Some performers may even find the introduction of biometrically driven technology to be disruptive to traditional performing arts [58]. Furthermore, children (see [41, 192]) and other more vulnerable groups may be involved in a performance, prompting extra consideration.

By the same token, it is important to consider who may be excluded from biometric data collection. Here, the environment in which collection takes place in may exclude certain individuals. Mainstream museums, for instance, have been criticised as exclusionary spaces that reinforce "racialized, gendered, and classed assumptions" [129, 169]. Furthermore, the technology being used can also dissuade or even directly exclude individuals. For example, certain EEG machines are not designed to accommodate people with natural African hair [35], while facial recognition systems may fail to work correctly for people who do not "fall within the range defined as 'normal' by the individual system's commissioners, designers and administrators" [189], such as those with facial differences.

How, then, might those whose biometric data is (not) being collected be uniquely disadvantaged or even harmed? Such harms may be mitigated by working closely with relevant participants where possible, discussing any potential concerns with them, clarifying potential risks, focusing on inclusive design, and drafting an action plan to identify and address any potential harms.

5.1.2 What biometric data is being collected? The type of biometric data being collected has different ethical implications. *Emotiv*, the producer of mobile *Emotiv* headsets, claims that EEG can be used to detect and identify brain disorders such as epilepsy and dementia, seizure activity, sleep disorders, and cognitive functions (including attention, distraction, stress, and cognitive load); this same data can be used for market research that makes judgments about consumer preferences [33]. Heart rate can indicate a person's risk of cardiovascular disease [16] and emotional responses [197], while facial recognition and gait can be used to identify individuals [144]. On the other hand, an indicator such as foot pressure may reveal comparatively less sensitive information, particularly if it is only being used to generate a transformed output (e.g. sound) under the control of the performer [188].

Taking time to research and understand the type of biometric data being collected is a key step in recognising potential infringements on a person's privacy [192]. What could a person's biometric data reveal about them, both to others and to themselves? This question is poignant when a person's biometric data is being displayed publicly without being transformed into more unrecognisable forms such as sound, as might be the case in a performance that directly displays numerical statistics of a performer's heart rate (e.g. [25]).

Table 2: The BEAP Framework for navigating ethical concerns surrounding the use of biometric capture in immersive artistic performance.

Key prompt	Ethical Considerations	Potential actions
1. Who is biometric data (not) being collected from? (Section 5.1.1)	• What kinds of harm might come to individuals and groups as a result of data collection? • What are the preferences and concerns of those whose data is being collected? • Are children or other vulnerable groups involved in data collection? • Who is being excluded from data collection?	• Plan with inclusivity in mind • Create an action plan for identifying and addressing potential harms • Work closely with participants in the artistic and technical development process • Discuss and respond to concerns with participants
2. What biometric data is being collected? (Section 5.1.2)	• Could an individual be identified from the biometric data being collected and/or displayed? • What can this data reveal about them, both to others and to themselves? • Is this the sort of thing that a participant might prefer to keep private? • How are unusual biometric readings or emergencies (such as heart or brain events) going to be handled?	• Research the type of biometric data being collected and its medical applications • Carefully consider how the data is to be shared in the performance and what it can reveal about participants • Create an action plan for dealing with sensitive situations connected to biometric data
3. What is the biometric data taken to indicate? (Section 5.1.3)	• How might interpretations of biometric data influence how participants are understood and treated? • How might this data mischaracterise a participant?	• Research how the biometric data being collected can be interpreted • Ensure any inferences being made are discussed with participants • Create an action plan for dealing with instances where self-reports and biometric indicators do not align • Give participants a platform to discuss their own insights into their experiences
4. How is biometric data being collected? (Section 5.1.4)	• How might the design of the biometric data collection device cause discomfort or mislead participants about data collection? • Are bespoke data collection devices or commercially available devices being used? • Are participants informed of the processes of biometric data collection? • Have participants consented to have their biometric data collected?	• Consider participant comfort and potential to mislead in the design of biometric capture devices • Review the privacy policies of commercially available devices before using them • Consider how best to inform participants and establish consent, including how to build trust with participants • Consider 'opt-out' to be the default option for participants
5. How is biometric data being used in relation to the performance or artwork? (Section 5.1.5)	• How much control do participants have over their biometric inputs and outputs? • Is any displayed data individual or aggregated? • Is the data transformed into outputs that render it unrecognizable as biometric data? • Who is the data displayed to? • How might participants try to manipulate their biometric data in potentially harmful ways?	• Carefully consider the potential for harm when biometric data is being shared or displayed • When publicly displaying biometric data, seek out ways to aggregate and render this data unrecognizable • Consider offering participants control over their data, such as giving an option to 'disconnect' from data collection, and to choose how and who it is shared with
6. How is biometric data being managed? (Section 5.1.6)	• Does any biometric data need to be stored? • How, where and for how long is this data going to be kept? • Who has access to the data? • What security measures are in place to protect this data?	• Only store data when it is necessary • Create a data management plan for all stored data • Take appropriate security measures such as encryption to ensure data security • Research and avoid platforms that are known to misuse data
7. Why is biometric data being collected? (Section 5.1.7)	• Do the potential merits of this project outweigh its potential risks? • Could the project's goals be achieved in other ways that do not involve biometric data collection? • Does the project potentially overlook or exclude certain perspectives?	• Weigh artistic merit with ethical risks carefully • Determine what forms of data collection are necessary • Collect the minimum amount of data needed to fulfil the goals of a project • Regularly consult with participants to discover if the goals of a project align with their interests

There are also questions about the responsibility one has if anything unusual is noticed in a participant's biometric data. Should the participant be informed, and under what circumstances? If there was a potential or actual emergency (such as a heart or brain event) that was indicated by a person's biometric data, how would this be handled (see [11, 140])? Would the performance be paused? Preparing a plan for such events when dealing with biometric data is a way to ensure any users and their data are handled sensitively and respectfully.

5.1.3 What is the biometric data taken to indicate? Biometric data can be interpreted as representing an array of internal states. An audience member whose GSR amplitude increases may be taken to be experiencing arousal, which can in turn be interpreted as engagement. Likewise, facial coding analysis may suggest a person is experiencing an emotion with positive valence such as happiness or excitement.

Ethically-speaking, these kinds of inferences are not benign. How might such interpretations influence how these different figures are understood and treated, both within the performance and beyond it? Inferences related to engagement and preferences can be sold or misused by third parties, particularly when this data is collected through commercially available VR headsets [52, 53]. At the same time, while such data can be personal and revealing, it may not always be complete or accurate. Going back to our examples in the previous paragraph, GSR alone does not provide information on positive or negative valence, and facial coding is only based on *probabilities* that a captured facial expression represents an identified emotion [174]. Furthermore, biometric data can be incorrectly recorded or measured, and correlations between self-reported emotions and biometric data can still be difficult to decipher [106].

The fact that biometric data can be used to make probing and sometimes mischaracterising inferences about a person, or group of people, points to issues of trust that are interwoven with biometric capture. To nurture trust in this space, any claims or inferences made about a person or group of people based on their biometric data should be justified with adequate research and discussed with participants when gaining informed consent. Clarifying these inferences also helps to guide decisions about what actions will be taken in instances where, for example, a person's self-reported emotion diverges from the inferences associated with their biometric indicators (see e.g. [140]). Here, drawing from Benford et al.'s RRI approach, offering participants an opportunity to debrief, and to share their own experiences and understandings of their biometric data, could encourage meaningful and respectful engagement [11].

5.1.4 How is biometric data being collected? Devices used for biometric collection can be perceived as more or less invasive. While many forms of biometric data can be collected from non-invasive wearable devices, introducing a new device designed to monitor a person's body can still be an uncomfortable experience. A VR headset that obscures vision, or a wearable garment that hinders movement, may feel more invasive than a small handheld device. At the same time, devices that are unintrusive (for instance, a participant's own smartphone—see [92]) may also mislead participants about how much data is being collected, or become so unnoticeable that participants forget their function.

Bespoke data collection devices bring about different ethical considerations to commercially available ones. While it may be clear how a bespoke device created by a performer for their own work collects and stores data, it is not always evident how commercially available devices such as VR headsets do so [52, 53].

These issues point to the importance of considering participant comfort, and the potential to mislead, in the design of biometric capture devices. Any use of commercial devices in this regard should be carefully considered. At the same time, informing participants of how biometric data is to take place (and acquiring their consent) is an important step for setting appropriate expectations and respecting participants' autonomy, especially given that "data ethics are not well understood by participants" despite a recurring theme of "concern" among them [153, 154].

There are therefore opportunities to explore appropriate ways of informing people—particularly public visitors or audience members who may not be connected to the project—about the processes of biometric data collection. In a public performance that collects biometric data from audience members, informed consent might involve providing each visitor with a pamphlet or guide that informs them of how biometric data is being collected and used, outlines a privacy policy [192], and invites consent (see e.g. [51, 162]). Where appropriate, such as in the performance-as-critique, this information may also be integrated into the performance itself [99]. With an eye toward building trust, consent might even be negotiated throughout and after a performance, especially where the participant may wish to review and 'curate' the captured data [11]. When immersive technology such as VR is being used for biometric capture, Heller recommends that 'true informed consent' should be sought: "Users should be informed in clear and simple language about the trade-offs they are making in choosing to use immersive technology" [53]. She further recommends that users should be able to opt-in, with opt-out as the default option [52].

5.1.5 How is biometric data being used in relation to the performance/artwork? Biometric data can be collected in a vast number of ways. If it is integrated into the performance, a key consideration is how it will be shown to performers, audience members, and/or the public. A streetside artwork that publicly displays the biometric data of passersby (e.g. [151]) will have different privacy implications than a performance that uses one performer's data to create a novel soundscape (e.g. [188]).

There is a risk of jeopardising participants' autonomy: How much control does a participant have over their biometric inputs and outputs? While audience members and visitors can be at risk of embarrassment or discomfort at having their data shared, performers are at risk of feeling disempowered in the process of biometric data collection, particularly if it challenges artistic integrity. These concerns may arise in cases where biometric data is being used to evaluate a performers' craft, or when performers are asked to "produce credible and useful biodata on demand" [110]. At the same time, even where autonomy is seemingly upheld, biometric data is 'seductive': People enjoy trying to work out how technology works [77] and will actively manipulate their biometric data in order to explore its effects, such as by raising their heart rate to see how it impacts an output (see [130, 148]). This can heighten health and safety risks.

There are several possible ways to address these concerns. Biometric data that is individual, recognisable, and displayed publicly requires much more careful consideration than aggregated, unrecognisable, and privately conveyed data, so opportunities to anonymise biometric data may be sought. Furthermore, offering participants a level of control over their data aids in respecting their autonomy. Where appropriate, a project may offer participants the option to 'switch off' or 'disconnect' from biometric data collection, and to choose how and who it is shared with (e.g. publicly or just with family and friends—see [11, 140]).

5.1.6 How is biometric data being managed? In some performative contexts, biometric data may be 'ephemeral' in the sense that it is used in a particular performance and then discarded. In other cases, the data may be stored in a database accessible to the researchers, or even in third-party databases. A first consideration in the management of biometric data, then, is whether the biometric data needs to be stored. While it may not be necessary in a time-limited performance that uses a performer's biometric data to create music (e.g. [166]), it may be necessary in projects that involve the creation of gesture databases to inform dance practice (e.g. [178]) or that aim to recreate a live experience in VR (e.g. [98]).

If data does need to be stored, it is recommended that those involved "make every reasonable effort" to maintain privacy and security and partake in best practices, including protecting and encrypting all data [192] and making plans for how long the data will be retained. When commercially available biometric collection devices are used, it is beneficial to avoid platforms that are known to misuse data, establish an understanding of who owns the biometric that is collected through these devices, and ensure that sensitive biometric data is not sent, stored or retained on external servers but is rather contained within the collection device itself (such as a HMD) [52]. This is especially the case for individual biometric data (in contrast to aggregated data), which is more personal and has stronger privacy implications. Taking steps to create a data management plan can help to uphold users' privacy, but it can also help to address any prospective issues surrounding authorship and prepare for potential misuse of data that may result in harms to a participant, such as unwanted advertising or identification.

5.1.7 Why is biometric data being collected? In Section 4.4.7, we saw that the use of biometrics in immersive artistic performance can contribute to artistic merit, both expanding and refining performances. Biometrics can offer a powerful basis for transgressive expression and critique, while artistic contexts offer spaces for "experimenting with technology, facing its resistances, pushing its limits" [37]. Biometrics can also lend themselves to exciting and novel interactions: while systems such as the *PIF (Physiological Interactive Fiction)* allow for biometrically-controlled storytelling tailored to a reader [42], other systems such as *EyeMusic* present opportunities for people with severe disabilities to make music with eye movements [55]. These aesthetic, experimental, and accessibility motivations for collecting biometric data must be taken into account when balancing ethical risks with the potential merit of an artistic project.

Addressing these issues would involve questions such as: Do the potential merits of this project outweigh its potential risks? In situations where a project does have notable artistic merit, could the project's goals be achieved in other ways that do not involve biometric data collection, such as through a 'Wizard of Oz' approach [37]? While it may be tempting in an exploratory space to "collect first and ask questions later" [39], it is nevertheless important to determine which data is necessary to collect to achieve the proposed merit (see [53]), and to "collect the least amount of data you need to achieve your goal" [192]. Consider, further, whether the motivation for biometric collection excludes or overlooks certain perspectives. Do the performers involved want their data collected to be used for the evaluation of performance? Do audience members want to attend performances that simply seek to maximise (a dubious form of) marketing-driven engagement?

Building an unbiased view of the project is likely to require regular consultations with involved participants and artists. But finding a balance between artistic merit and ethical risks also starts early in the design process, as answers to the above questions have implications for the ways performances and technologies that mediate performances (such as VR systems) are designed.

5.2 Limitations and future work

The BEAP framework is an indicative first step towards assisting artists and researchers in navigating the complex ethical issues that arise in relation to biometric data capture in immersive artistic performances. It is not to be taken as a complete guide; rather, it is intended to be used as a framework of provocations that can be referred to throughout the design and implementation of an artistic performance and its associated technologies. The guiding prompts are discrete but are also interrelated; answers to one question might also inform answers to another, and there may be many more questions and answers that are not accounted for. Relevant laws surrounding biometric capture are subject to change as biometric data collection and its uses continue to evolve, so keeping up to date with any changes in regulation is advisable [52]. We intend for this framework to act as a reference to be used alongside existing institutional and legal requirements such as the GDPR, particularly where such requirements fall short.

The BEAP framework aims to be specific enough to provide actionable guidance (see [147]), and in particular to mitigate ethical risks to those whose biometric data is being collected. But it also aims be broad enough to allow for the consideration of a wide range of ethical values identified in our findings. This more encompassing approach contrasts with approaches driven by specific values, such as privacy-by-design [2, 21], though a future exploration of specific values in relation to biometric capture in immersive performance could produce meaningful discussion.

Furthermore, we acknowledge the inherent complexity of this space: different performances have their own unique, shifting aesthetic and creative requirements, and immersive performances using biometrics are "based on technology that flips and changes every year" [18]. In such changeable and diverse environments, ethical considerations similarly need a certain flexibility or agility [11, 156], inviting "ethically legitimate judgment calls" as opposed to "one size fits all" requirements" [90]. We welcome the further development and adaptation of this framework to better suit performative contexts as they evolve.

6 CONCLUSION

This paper has presented a scoping review of interdisciplinary sources over the past 30+ years on biometric data capture in immersive artistic performance. We found a multitude of innovative uses of biometric data spanning the arts. These uses have aimed to enhance engagement between performers, audience members and performances; to explore new forms of interaction and control; and to evaluate and hone performance. Despite the interest in using biometric capture in immersive artistic performance, however, we found relatively little ethical engagement with this particularly sensitive form of data. Nevertheless, some questions and concerns have been raised in the literature, centring around the values of privacy, autonomy, trust, nonmaleficence, authorship, artistic integrity, and artistic merit.

To assist artists and researchers in navigating ethical issues associated with biometric capture in immersive artistic performance, we contribute the BEAP framework. This set of seven provocations draws from ethics by design and RRI approaches to invite a proactive, ongoing and collaborative consideration of relevant ethical issues that is mindful of the creative and often exploratory nature of performance. Our findings highlight the immense creativity driving the ongoing creation of performances that capture our hearts in novel ways, and we hope the BEAP framework can lend some clarity and direction in responding to the ethical dilemmas arising in these ever-evolving spaces.

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APPENDICES

A.1 SEARCH PHRASE EXAMPLE

An example of a Boolean search phrase used to search for articles was as follows:

[[All: ethic*] OR [All: principle*] OR [All: moral*]] AND [All: biometric*] AND [[All: "virtual reality"] OR [All: vr] OR [All: "immersive"]] AND [[All: art*] OR [All: music*] OR [All: dance*] OR [All: perform*]]

A.2 PRISMA CHART

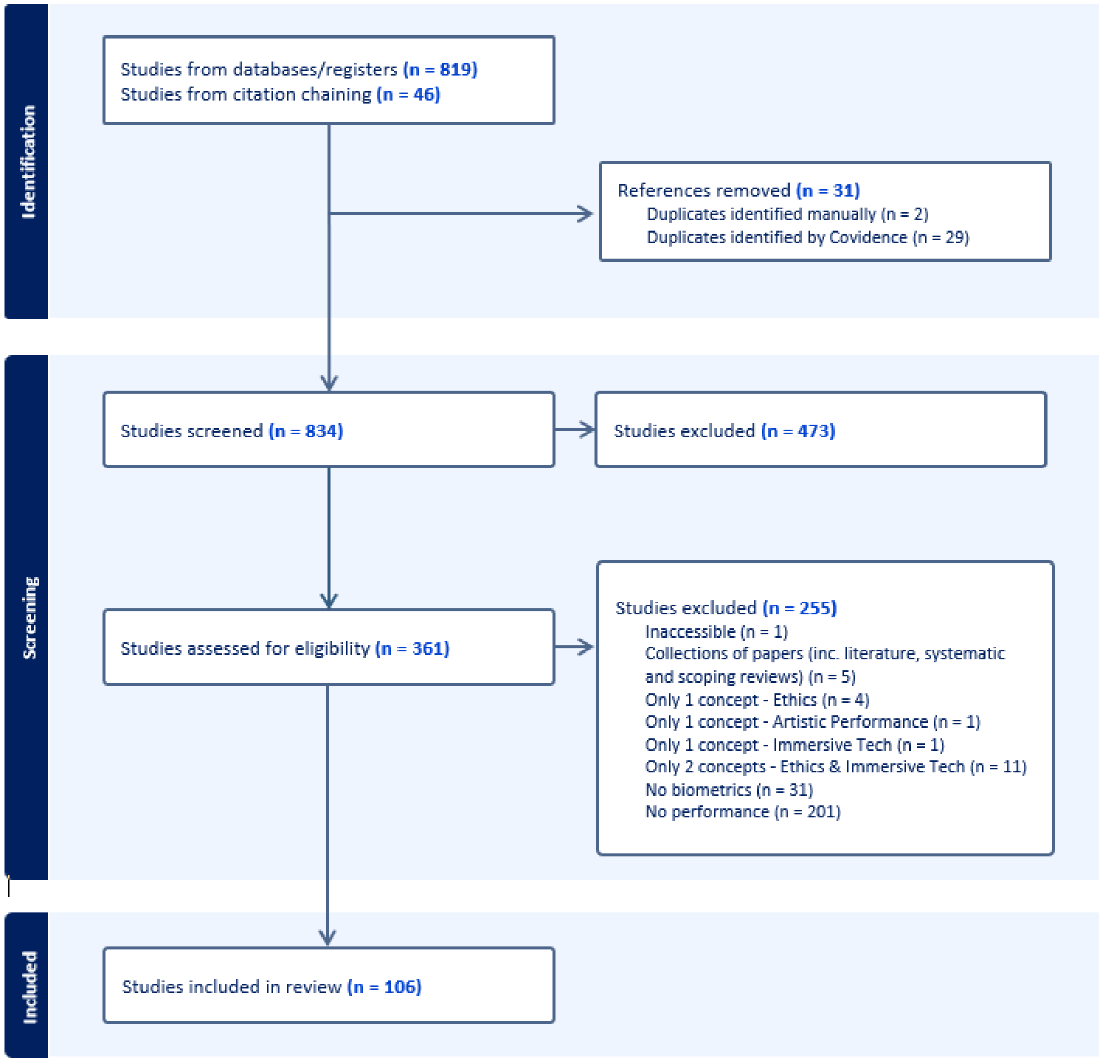

Figure 4: PRISMA summary of the identification and screening process, including numbers and reasons for studies excluded at each stage.

A.3 EXCLUSION CRITERIA

These exclusion criteria were implemented to arrive at a set of texts that contained sufficient and interpretable information and detail for analysis:

- Does not include discussion of artistic performance (abstract)
- Does not include discussion of artistic performance or biometrics (full text)
- Written in a language other than English
- Panel or symposium description (with no detailed information)
- Course notes and slides
- Student work (below PhD level)
- Book reviews
- Collections of abstracts or papers (rather than a single source), including literature, systematic and scoping reviews