



# ReMirrorFugue: Examining the Emotional Experience of Presence and (Illusory) Communications Across Time

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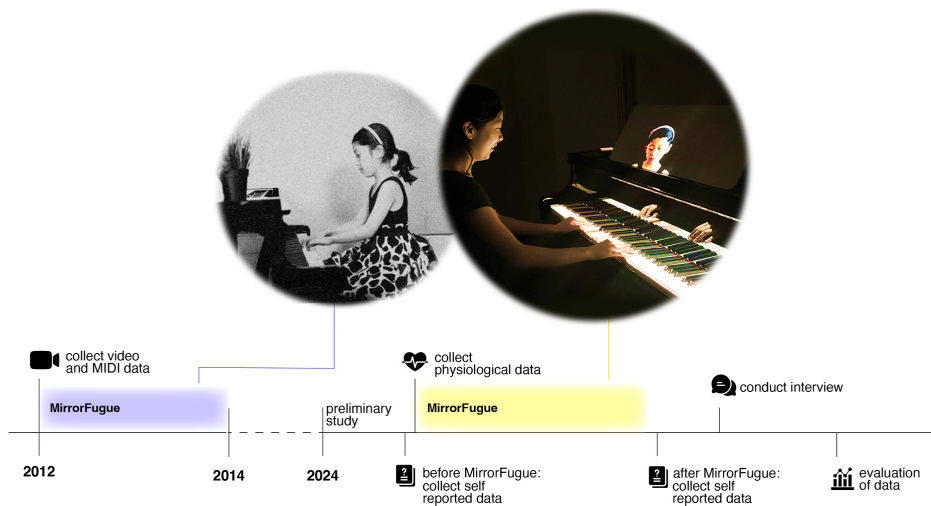


Figure 1: Schematic of our main study’s procedure featuring a participant interacting with her childhood self on MirrorFugue, recorded 12 years ago.

## Abstract

This paper examines how strategies for simulating social presence across distance can evoke a sense of presence and facilitate illusory



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CHI '25, Yokohama, Japan

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ACM ISBN 979-8-4007-1394-1/25/04  
<https://doi.org/10.1145/3706598.3713328>

interactions across time. We conducted a mixed-methods study with 28 participants, exploring their emotional experience of interacting with decade-old recorded piano performances on MirrorFugue—a player piano enhanced with life-sized projections of the pianist’s hands and body, creating the illusion of a virtual reflection playing the instrument. Data were collected via wearable sensors, questionnaires, and interviews.

Results showed that participants felt a strong presence of past pianists, with some experiencing the illusion of two-way communication and an overall increase in connection. The emotional experience was significantly influenced by the participant’s relationship with the recorded pianist and the pianist’s vital status. These findings suggest that telepresence technologies can foster connections with the past, offering spaces for memory recall, self-reflection, and a sense of “time travel.”

## CCS Concepts

• **Human-centered computing** → **Empirical studies in HCI; User studies; HCI theory, concepts and models; Mixed / augmented reality.**

## Keywords

Mixed-methods, telepresence, technology for reflection, social presence, musical experience, piano, affective computing, physiological signals, emotions, interviews, quantitative methods, qualitative methods, augmented reality, ongoingness

### ACM Reference Format:

Xiao Xiao, Hayoun Noh, Adrien Lefevre, Lucy Li, Holly McKee, Alaa Algar-goosh, and Hiroshi Ishii. 2025. ReMirrorFugue: Examining the Emotional Experience of Presence and (Illusory) Communications Across Time. In *CHI Conference on Human Factors in Computing Systems (CHI '25)*, April 26–May 01, 2025, Yokohama, Japan. ACM, New York, NY, USA, 26 pages. <https://doi.org/10.1145/3706598.3713328>

## 1 Introduction

A fundamental goal of telepresence technologies is to experientially bridge distant physical spaces [15]. Originally used to describe the feeling of being present somewhere else for teleoperations applications (e.g. “being there”) [46], telepresence has also been used to describe the degree to which participants in a telemeeting feel the impression of sharing space with a remote site [50].

The second definition of telepresence is the point of departure for our present research. This definition is closely related to the concept of social presence, which describes how well a communications medium transmits verbal and non-verbal cues as well as the apparent “realness” of the communicators [67], in other words, the feeling of a distant person being “there.” According to Nowak, the goal of social presence interfaces is to “provide interactants with a sense that they have shared an experience, had access to another mind, or experienced a face engagement” [52].

Our research begins with the speculation of how telepresence, in the sense of social presence—referred to simply as “presence” moving forward—can be established across time rather than space. We envision interfaces that can evoke the feeling of presence of someone from the past, either a past version of a living person from an earlier stage in life, or a deceased individual. Such interfaces

can help revisit past memories with friends or loved ones, both living and deceased, and enhance the understanding of the evoked individual. They can also enable people to revisit and reflect on past versions of themselves.

In order to establish presence, Mühlbach et al. state that a technology must transmit spatial cues from the remote location as well as communicative signals (verbal and non-verbal) from the remote participants [50]. To establish presence across “remote time,” an interface can similarly establish spatial cues from the temporally remote location and transmit the communicative signals recorded from the past. While reciprocal communication signals cannot be transmitted back in time, we explore how an interface may still provide participants in the present with the sense that they have “shared an experience” or a moment of face-to-face engagement with someone in the past, including a sense of illusory two-way communication.

This paper presents an empirical study on the subjective and emotional experience of presence across remote time. The study was conducted on MirrorFugue (Figures 2 & 5), an augmented piano that simulates the presence of a recorded pianist as a virtual reflection playing the physical instrument by combining life-sized projections of a pianist’s hands and body with the moving keys and acoustic playback of a player piano [79, 80].

MirrorFugue was initially conceived as an interface for remote lessons and concerts, applying social presence strategies to musical interactions over distance [77]. Its creators also described design fiction scenarios for interactions across time, such as engaging with archival recordings of renowned past pianists or playing a duet with a younger version of oneself or one’s relative [78, 80].

During MirrorFugue’s active phase (2012–2014), recordings were made of both amateur and professional pianists. Over a decade later, these recordings provide a unique opportunity to gather empirical data on the envisioned design fiction scenarios across time. Living pianists, now over 10 years older, enable the study of playing a duet with one’s past self or reconnecting with the past version of a relative or close friend. Some recorded pianists have since passed away, offering an opportunity to contribute to recent HCI research on tangible interactions for remembering the deceased, a dimension not originally considered in the MirrorFugue project. Our present study on “reMirrorFugue” focuses on the following research questions:

- **RQ1: How do participants experience MirrorFugue recordings from the past?** — To what extent does MirrorFugue establish a sense of presence across time? How do participants interact with past pianists, and how do they interpret the experience?
- **RQ2: To what extent does an existing connection with a MirrorFugue pianist influence the experience?** — Do interactions and interpretations differ based on a participant’s relationship to the virtual pianist? To what extent does the MirrorFugue experience affect the participant’s feeling of connection with the virtual pianist?
- **RQ3: To what extent does the vital status of a MirrorFugue pianist influence the experience?** — Do interactions and interpretations differ based on whether the pianist is deceased?

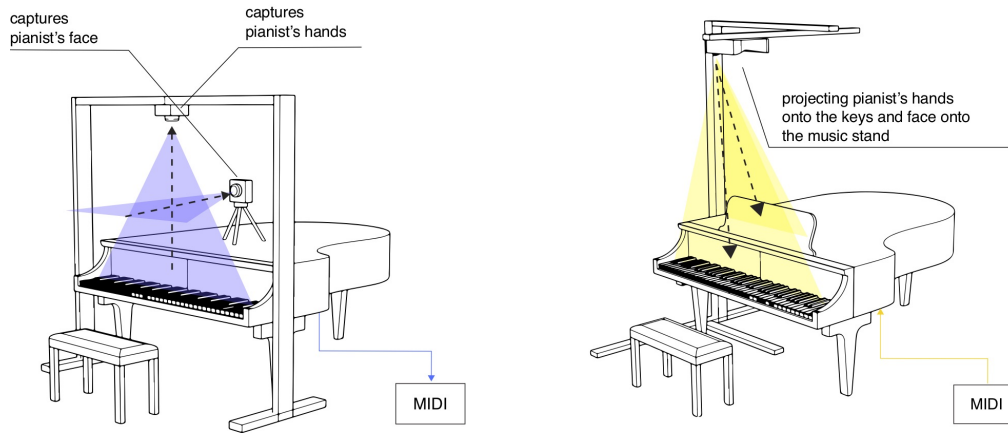


Figure 2: The MirrorFugue recording (left) and playback (right) setups

The study was conducted with 28 participants, who sat at the piano bench to experience 4 archival MirrorFugue recordings. The recordings included pianists with whom participants had varying degrees of existing relationships, as well as deceased pianists. Data on participants' subjective experience was collected via semi-structured interviews and questionnaires. Physiological data on participants' affective state was collected via a bracelet worn during the MirrorFugue experience.

Our main contribution offers empirical data on the experience of interacting with individuals from the past through a “telepresence” interface. On one level, the results supported our initial hypotheses. Participants reported feeling the presence of pianists, even while fully aware of the pianists' absence. Some participants who improvised along with the MirrorFugue recordings even experienced an illusory sense of two-way communication. As an interface mediating interpersonal connection, the MirrorFugue experience generally led to an increased sense of connection with the pianist. Moreover, experiences varied significantly depending on the participant's existing relationship with the pianist and whether the pianist was living or deceased.

We also uncovered unexpected insights into how participants interpreted the experience beyond our initial research questions. Besides serving as a tool to connect with the specific pianists from the past, MirrorFugue also provided a “safe space” for participants to connect with themselves, revisiting past memories and reflecting on the passage of time. Our study demonstrates that remote communication technology can be repurposed to connect with individuals from the past and shows the value of doing so, both in fostering connections and creating meaningful spaces for reflection.

## 2 Background

To provide context for our research questions, we outline strategies for simulating the presence of collaborators across distance, examples of projects that focus on specific types of remote interpersonal relationships, and interfaces for connecting with the deceased. Additionally, we give precedents for our research methodology that combines questionnaires and interviews with physiological sensors.

**2.0.1 Strategies for Presence Across Distance.** A variety of strategies have been explored to simulate the presence of remote collaborators. The visual modality has been extensively employed to transmit spatial and communicative cues, particularly in the field of Computer Supported Collaborative Work (CSCW). For spatial cues, projects have focused on establishing a shared desktop workspace [76], drawing surface [26, 70, 71], or room-scaled space [57]. For communicative cues, projects have explored the transmission of hand-gestures [26, 70, 71], full-body movements [70] and facial expressions including eye contact [26, 53].

The tactile modality has also been explored, with one key question about the sharing of physical objects across distance. Some projects feature physical items that coexist with virtual representations of remote objects [76] while others employ actuated interfaces to mirror the movement of a remote object through a physical counterpart [7]. Another approach involves shape displays that render both remote objects and the hands of collaborators [41].

Another key question is how to transmit touch across distance [74], with projects exploring the use of heat [10, 21], pressure [21], and vibration [10, 17]. Other, more artistic explorations of communicating presence transmit physiological signals such as breathing, mapped to the movement of shape changing interfaces [34, 69].

**2.0.2 Interpersonal Relationships in Distance Communications.** Numerous telecommunications interfaces have been designed to target specific interpersonal relationships. Many of these systems focus on long-distance couples [38, 39, 42] and family members, including parent-child [8, 66], grand-parent-grandchild [37, 60], or siblings [31]. Other featured relationships include close friends [30] and strangers [11].

Designs for specific relationship contexts share some strategies with projects on simulating presence, such as the simulation of touch [38], but also utilize other approaches, like integrating photos and videos to trigger shared memories [37, 39] and incorporating rituals around shared objects or activities [8, 60, 75].

Much recent work on remote presence has centered around social robots, proposed and tested in family settings [65] and in care for the elderly with dementia [49]. These investigations explore sensory and social cues to simulate social presence and co-presence

[3], with recent findings indicating that an existing relationship plays a key role in participants' perception of presence [20].

To communicate the presence of the past pianist, MirrorFugue employs several strategies, which have been previously explored, including the use of visual and tactile modalities to convey gestures of the hands and upper body. Unlike existing projects that focus on a single type of interpersonal connection, our present research examines how technology can facilitate human connection across a broad range of human relationships.

**2.0.3 Connecting with the Deceased.** The term telepresence has been used to describe various strategies for recreating the deceased and enabling illusory interactions with them [43]. These recreations often involve recorded images and sounds, particularly of historic figures for whom extensive data is available, such as a recreation of a Frank Sinatra concert [13]. Physical embodiments, like robotic likenesses, and AI-driven interactivity have also been employed. A particularly emotionally charged example is a South Korean mother interacting with a virtual recreation of her deceased daughter [45]. However, such approaches lack extensive user studies on the experiences they create.

Within HCI communities, the focus has been on technologies for remembrance and maintaining ongoing bonds with the deceased [35, 72, 73]. Such projects relate to larger questions about digital memory and how digital artifacts might be passed down to future generations [22]. Various methods of maintaining ongoing bonds with the deceased have been explored, including posthumous digital messages [29] and tangible objects designed for grieving and remembrance [23, 72, 73], sometimes developed through participatory design with target users [35, 48].

Objects for ongoingness generally avoid recreating the deceased or enabling illusory interactions. Rather, they focus on poetically designed tangible objects for facilitating remembrance, incorporating photos [73], ashes [23], smells and sounds [35], or evoking cultural rituals [72]. Consistent with the concept of thanatosensitivity [44]—a call within HCI to better understand people's relationship with death and their complex, individual grieving processes [40]—these objects are almost always evaluated through user studies, from design probes to longitudinal studies that provide insights into how people incorporate these objects into their grieving.

While MirrorFugue simulates presence and allows real-time interaction, it does not create new images or actions of the deceased. It aligns with HCI research on ongoingness by providing data on how an interface not specifically designed for grieving can be repurposed for meaningful interactions with the deceased.

## 2.1 Methodology for Examining Subjective Experience

Evaluating the subjective experience of interactive systems for remote communication and communication with the deceased have primarily relied on qualitative measures, including self-report questionnaires. To evaluate experiences of social presence and co-presence, the Networked Minds survey is commonly used [5]. Perception of interpersonal closeness is often assessed using the Inclusion of Other in the Self (IOS) Scale [4] and the Perceived Interpersonal Closeness (PICS) Scale [59]. Interviews are also a

standard method for gaining qualitative insights into user experiences, frequently employed in studies of distant communication and ongoingness interfaces [35, 65, 72].

In contrast, the field of affective computing has established quantitative approaches to measuring emotional arousal through physiological signals, based on the premise that emotions are inherently bodily experiences [58]. Since physiological responses are unconscious, they help reduce the bias often associated with self-reported evaluations, providing more objective evidence [24]. This method also allows for real-time data collection, unlike questionnaires that depend on memory recall. Physiological signals have been particularly useful in studying emotional responses to music and acoustics [2, 12, 28].

Our study is unique in combining physiological data analysis with questionnaires and interviews to provide a comprehensive understanding of subjective experiences.

## 3 Pilot Studies

We conducted two pilot studies to confirm the relevance of our research questions on the influence of existing relationships with the pianist and of the pianist's vital status on the MirrorFugue experience, to test the qualitative methodology, and to gather initial insights. These studies used a version of MirrorFugue adapted for a Yamaha Disklavier upright piano.

### 3.1 Pilot 1

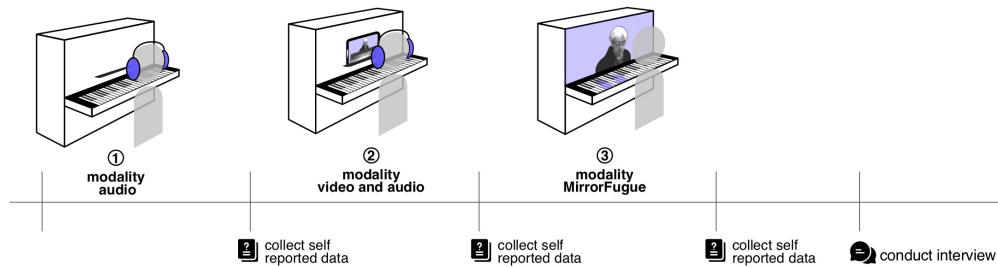
The sense of presence in MirrorFugue was previously established through comparisons of different interface configurations, including projection vs. no projection, moving keys vs. no moving keys, and the location of the projection [80]. However, no data was collected to compare the MirrorFugue experience with traditional formats for recorded music—audio and video. Our first pilot study aimed to address this gap and to probe how the pianist's vital status affected the experience across these three conditions (Figure 3).

10 adult participants (4 female/6 male) were recruited by word of mouth from the first author's university (Table 1). Participants experienced one of two recorded pieces three times, first as audio, then with video, and finally on MirrorFugue. Audio was played through headphones for the first two conditions, and video was shown on an iPad. One piece featured an internationally renowned deceased pianist while the other showcased a living professional pianist. Both recordings were over 10 years old, around 5 minutes long, and had similar tempi and moods.

Participants sat in front of the piano for all three modalities and were told that they were free to touch or play the instrument. After each recording, they reflected on their experience through a questionnaire, followed by a semi-structured interview at the end. Consisting of eight questions, the questionnaire aimed to explore participants' connections to the music and the pianist across the three modalities (see Appendix). It inquired about participants' interactions with the music (e.g., playing along or humming) as well as the emotions and memories evoked during the session for each modality. The questionnaire aimed to facilitate reflection on participants' experiences and guide the semi-structured interviews, where participants were asked to elaborate on their responses.

**Table 1: Participant information for Pilot 1**

ID	Age	Gender	Piano Level	Years playing	Which Pianist?
1_P01	40s	F	Amateur	5	Deceased
1_P02	40s	F	Non-pianist	-	Alive
1_P03	20s	M	Non-pianist	-	Deceased
1_P04	20s	M	Amateur	0.01	Alive
1_P05	30s	M	Non-pianist	-	Deceased
1_P06	20s	F	Non-pianist	-	Alive
1_P07	20s	F	Amateur	10	Deceased
1_P08	20s	M	Amateur	0.01	Alive
1_P09	20s	M	Amateur	0.01	Deceased
1_P10	20s	M	Non-pianist	-	Alive

**Figure 3: Schematic of Pilot 1**

The pilot study revealed diverse experiences across the three modalities, especially in connecting with the music versus the artist. Audio-only was often favored for musical connection, while MirrorFugue facilitated a strong connection with the virtual pianist, transcending personal musical preferences. Some participants struggled to verbalize their MirrorFugue experience, and 8 of the 10 participants reported the desire to play together with the virtual pianist, even when they themselves do not play the piano.

The relationship to the virtual pianist influenced the experience on MirrorFugue more than the other two modalities. Participants felt a deeper connection with pianists they already knew and projected personal connections onto the MirrorFugue pianist, such as memories of family members who played the piano. Additionally, knowing the deceased status of a virtual pianist had little impact on the audio and video experiences but made the MirrorFugue experience feel more precious to participants.

### 3.2 Pilot 2

The second pilot examined how an existing connection with a living pianist influenced the experience of MirrorFugue (Figure 4). 6 adult participants (3 male, 3 female) experienced a three-minute performance of a living amateur pianist on MirrorFugue, recorded over 10 years ago. Participants were recruited by word of mouth based on their varying degrees of connection to the virtual pianist, including the pianist's partner, a close friend, two acquaintances,

one complete stranger, and the recorded pianist herself (Table 2). As in the first pilot, participants were encouraged to touch the piano or play along if they wished.

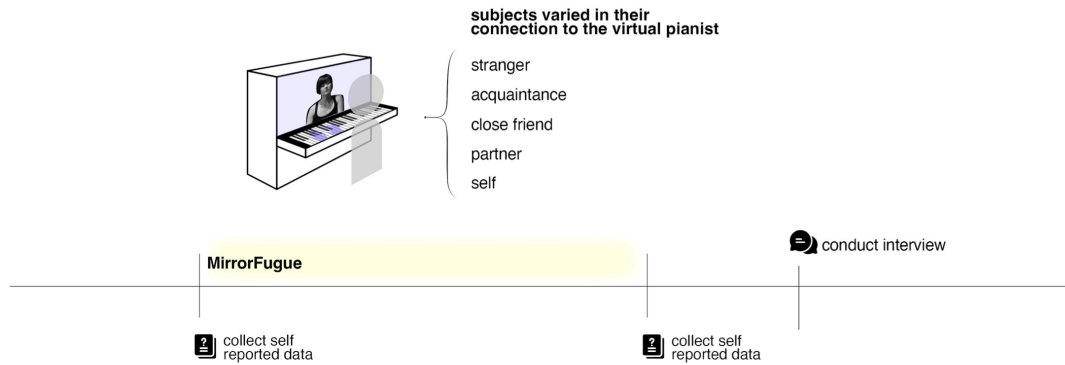
Participants experienced MirrorFugue once while seated at the piano and completed a questionnaire on their relationship and connection with the virtual pianist before and after (see Appendix). The pre-questionnaire comprised five questions and examined participants' relationship with the pianist using the Perceived Interpersonal Closeness (PICS) Scale [59] and the connection they felt using the Inclusion of the Other in Self (IOS) Scale [4]. The post-questionnaire revisited the IOS Scale to assess any changes in participants' feeling of connection and asked about the connection felt during the MirrorFugue experience. These questionnaires were designed to facilitate reflection and guide the semi-structured interview at the end of the study.

The 20–25-minute semi-structured interviews allowed participants to expand on their questionnaire responses, exploring their perceptions of the virtual pianist, emotions and memories evoked, sense of connection and presence, and whether the experience felt rooted in the past or the present. Changes in their connection to the pianist were also assessed.

This pilot confirmed that deeper existing relationships led to a stronger feeling of connection with the MirrorFugue pianist while more shallow or non-existing relationships led participants to project their own thoughts. The close friends recalled shared

**Table 2: Participant information for Pilot 2**

ID	Age	Gender	Piano Level	Years playing	Relationship to Pianist
2_P01	20s	F	Non-Pianist	-	Stranger
2_P02	20s	M	Amateur	0.01	Acquaintance
2_P03	30s	F	Amateur	33	Self
2_P04	20s	F	Non-pianist	-	Acquaintance
2_P05	30s	M	Amateur	26	Family/Partner
2_P06	40s	M	Non-pianist	-	Friend

**Figure 4: Schematic of Pilot 2**

memories, the partner gained new perspectives and was moved to improvise a duet. Interacting with one’s past self triggered more emotions during reflection than during the experience, where the self pianist was distracted by self-critical thoughts about the past recording.

## 4 Main Study

The pilot studies suggested that MirrorFugue facilitates a feeling of emotional connection with the recorded pianist that qualitatively differs from the experience of listening to an audio recording or watching a video on a screen. Context about the pianist, such as an existing relationship with the pianist and knowledge of a pianist being deceased, also seemed to influence the MirrorFugue experience.

Having confirmed the pertinence of our research questions, we proceeded to our main study to dive deeper into participants’ felt experiences while interacting with past recordings on MirrorFugue.

### 4.1 Procedure

The study took place in a quiet, light-controlled room at a research lab. MirrorFugue on a 6’ Yamaha Disklavier grand piano was deployed in the center of the room (Figures 2 & 5). Subjects experienced a MirrorFugue recording from the following pianists in a randomized order while sitting at the piano bench:

- **A)** a living non-professional pianist<sup>1</sup>
- **B)** a deceased non-professional pianist

<sup>1</sup>P07 listened to himself for the pianist A session and is a professional pianist. He was a university student at the time of recording.

- **C)** a living professional pianist<sup>2</sup>
- **D)** a deceased professional pianist.

Multiple recordings were used for the Pianist A slot, specifically for participants who were the pianist themselves or family members of the self-pianists. See Table 3 for details on which Pianist A recording was assigned to each participant. Recordings lasted between 1 minute 20 seconds and 6 minutes 20 seconds. As in the pilots, participants were encouraged to touch the keys of the piano or play along if they wished.

### 4.2 Subjects

28 adult participants (16 female, 12 male) were recruited based on their existing connection to at least one of the recorded pianists (Table 3). 17 participants had some piano experience, with 12 able to improvise and 4 playing professionally. An additional 5 have taken some piano lessons.

Relationships to the recorded pianists ranged from self, family, friend, acquaintance, to stranger. 22 participants listened to a default Pianist A, to whom they are either a stranger, an acquaintance, friend, or family. The remaining 6 participants listened to a family member or themselves as Pianist A. All participants listened to the same recordings for Pianists B, C, and D. Two family members of pianist B participated in the study as well as a family member of pianist C and pianist C himself.

Pianists A, B, and C were recorded between 2012 and 2013, recruited from the researcher’s community, leading to some overlap

<sup>2</sup>P02, who was the pianist C, listened to himself for this session. Pianist C data from P02 and P13, a family member of P02, were included in the familiarity analyses in section 5.2



**Figure 5: (Left) MirrorFugue recreated on an upright piano, with a deceased pianist featured in Pilot 1. (Right) MirrorFugue recreated on a grand piano with the default Pianist A.**

in participant connections. Pianist D was recorded in 2014 for an exhibition in a different city, and none of the participants knew him personally though some have heard of him. All participants received a \$20 Amazon gift card for their participation.

### 4.3 Data Collection, Pre-processing, and Analysis

Qualitative data were collected via questionnaires before and after the MirrorFugue experience and a semi-structured interview at the end of the study, which was audio-recorded for transcription and analysis. Quantitative data on participants’ heart rate (HR), electrodermal activity (EDA) and hand movement (ACC) were continuously collected during the MirrorFugue experiences using an Empatica E4 bracelet on their non-dominant wrist.

**4.3.1 Questionnaire.** The pre- and post-questionnaires examined how familiarity with Pianists A and B—self, family, friend, acquaintance, or stranger—affected the MirrorFugue experience. The goal was to compare participants’ experiences based on the degree of their existing relationship. These questionnaires were omitted for Pianists C and D, as most participants were strangers to them, resulting in unbalanced groups unsuitable for quantitative comparison. However, individual participants’ experiences reflecting their existing relationships with Pianists C and D were still captured during the interviews and are reported in Section 5.2.2.

The pre-questionnaire assessed whether participants were pianists, evaluated their familiarity with the pianist using the Perceived Interpersonal Closeness (PICS) Scale [59], and captured their perceived level of connection through the Inclusion of Other in Self (IOS) Scale [4]. The post-questionnaire had three questions: evaluating the connection felt during the MirrorFugue experience on a scale from 1 (no connection) to 5 (fully connected), noting any changes in perceived level of connection, and asking if the experience would enhance their connection if they met the pianist again. The outline for the questionnaires can be found in Table 4. The exact questionnaires given to participants are found in the Appendix.

**Analysis:** Questionnaire results, such as felt connection before and after a session or participant’s piano level, were used as dependent and independent variables in the quantitative analysis. Following an established mixed-methods approach [9], responses also served to inform the interview and its analysis. For instance, based on questionnaire responses, an interviewer might ask, “Your connection with Pianist A has increased; can you explain why?”

**4.3.2 Physiological Signals.** Our analysis focused on the heart rate (HR) and accelerometer (ACC) data. The EDA data was not included in the analysis because it was unusable for a large number of participants due to below-threshold values [19].

**Preprocessing:** The raw HR data stream provided by the Empatica E4 is computed from the blood volume pressure (BVP) signal, with one measurement per second. In order to standardize the HR for all participants to overcome the limitation of individual differences in HR baseline, we computed the  $\Delta HR$  for each point  $t_x$  in the data, given by the HR value at time  $t_x$  minus the first heart rate at the start of the session,  $t_0$ :

$$\Delta HR(t_x) = HR(t_x) - HR(t_0) \quad (1)$$

The  $\Delta HR$  makes it possible to study the effect of a parameter on emotional arousal. Negative  $\Delta HR$  can be observed when a participant relaxes, with the heart rate decreasing, while positive  $\Delta HR$  is observed when the participant is stimulated.

The raw HR for the entire duration of each session (i.e. a pianist’s performance) was collected, but we focused on the first 60 seconds of each session to standardize the time across varying session lengths. While previous research suggests 30 seconds is enough to capture the emotional impact of an acoustic environment [55], we chose 60 seconds, assuming a more pronounced impact at the start of the session [54]. Inspection of the remaining data confirmed that the first 60 seconds captured the most significant impact in most cases.

The analysis of the accelerometer (ACC) stream from the E4 provided clues to the physical activity of participants’ non-dominant

**Table 3: Participant Information for the main study.**

ID	Age/Gender	Piano Level/Years	Which A	Rel. to A	Rel. A length	Rel. to B	Rel. B length
P01	20s/F	Amateur/3	Default	Stranger	–	Stranger	–
P02*	60s/M	Professional/50	Default,P02	Friend,Self	15/–	Friend	50 years
P03	30s/M	Professional/23	Default	Stranger	–	Stranger	–
P04	30s/M	Amateur/10	Default	Friend	4 years	Stranger	–
P05	20s/F	Amateur/7	P05	Self	–	Stranger	–
P06	60s/F	Non-pianist/–	P05	Family/Partner	19 years	Acquaintance	10 years
P07	30s/M	Professional/20	P07	Self	–	Friend	1.5 years
P08	20s/M	Amateur/16	Default	Stranger	–	Stranger	–
P09	40s/F	Non-pianist/–	Default	Friend	12 years	Stranger	–
P10	20s/M	Amateur/18	Default	Friend	1.5 years	Stranger	–
P11	60s/M	Amateur/50	P11	Self	–	Friend	25 years
P12	60s/F	Non-pianist/–	Default	Family/Partner	36 years	Stranger	–
P13*	40s/M	Amateur/43	Default,P02	Stranger,Family	–/47 years	Stranger	–
P14	30s/F	Non-pianist/–	Default	Friend	6 years	Stranger	–
P15	40s/M	Non-pianist/–	Default	Friend	7 years	Stranger	–
P16	40s/F	Professional/25	Default	Stranger	–	Stranger	–
P17	20s/F	Amateur/17	Default	Stranger	–	Stranger	–
P18	20s/F	Non-pianist/–	Default	Acquaintance	0.14 years	Stranger	–
P19	30s/F	Amateur/5	Default	Acquaintance	0.01 years	Stranger	–
P20	30s/F	Non-pianist/–	Default	Friend	10 years	Acquaintance	10 years
P21	30s/M	Amateur/10	Default	Friend	7 years	Stranger	–
P22	20s/F	Non-pianist/–	Default	Friend	2 years	Stranger	–
P23	60s/F	Non-pianist/–	Default	Friend	15 years	Family/Partner	60 years
P24	20s/F	Non-pianist/–	P11	Family/Partner	19 years	Stranger	–
P25	60s/F	Amateur/40	Default	Friend	8 years	Friend	40 years
P26	40s/F	Non-pianist/–	P11	Family/Partner	13 years	Acquaintance	–
P27	30s/M	Amateur/20	Default	Acquaintance	2.5 years	Stranger	–
P28	90s/F	Amateur/10	Default	Friend	10 years	Family/Partner	96 years

\*Data from the Pianist C session were used for the familiarity analyses for P02 (pianist C himself) and P13 (a family member).

hand. The magnitude of the 3-dimensional acceleration data provided by the E4 ( $ACC_x$ ,  $ACC_y$ ,  $ACC_z$ ) was used to reduce the data to a single dimension.

$$\|ACC\| = \sqrt{ACC_x^2 + ACC_y^2 + ACC_z^2} \quad (2)$$

Each session’s data is then re-centered around its average, enabling comparisons across recordings while preserving the original scale. Because ACC reflects voluntary movements of participants’ hands, which can happen at any point during the sessions, we used data from the entire session period.

**Statistical Analysis:** We first conducted Shapiro-Wilk tests to evaluate the distribution of the results of the  $\Delta HR$ , ACC, and felt connection before/after the experiment, and the results indicated that all the variables follow a non normal distribution with the following p-values respectively (p-value < 0.05, p-value < 0.001, p-value < 0.005).

We then conducted multiple statistical analyses with dependent variables including  $\Delta HR$ , ACC, and self-reported connection. Different independent variables were considered for each research question. For RQ1, the independent variables included session order (1, 2, 3, 4), pianist (A, B, C, D), musical tempo, and participant piano level (Section 5.1.1). For RQ2, the independent variables were

felt connection (before, during, and after the session) and familiarity between the participant and pianist (Section 5.2.1). For RQ3, the independent variable was the pianist’s vital status (alive or deceased) (Section 5.3.1).

**4.3.3 Interviews.** Semi-structured interviews, lasting between 20 and 70 minutes, took place in the same room where participants had experienced MirrorFugue and was audio-recorded with the participant’s permission for transcription purposes.

Interviews began after the MirrorFugue experience, after giving participants time as needed to gather their thoughts. Before starting, participants were reassured of their confidentiality, informed of their right to pause or stop at any time, and debriefed on safety procedures. The interviews began by prompting participants to describe their overall MirrorFugue experience in their own words, followed by specific questions exploring their emotional responses. The outline of core questions can be found in Table 5.

Upon concluding, participants were reminded of their rights to obtain the collected data, to withdraw from the study and access mental health resources if needed.

**Thematic Analysis:** Interviews were first transcribed from recordings and anonymized to ensure privacy. Applying a standard qualitative analysis method [64], the research team carefully

**Table 4: Details of the main study questionnaires.**

<p>Pre-questionnaire</p>	<ul style="list-style-type: none"> <li>• Are you a pianist?</li> <li>• Describe your relationship with the pianist (Stranger, Acquaintance, Friend, Family/partner).</li> <li>• If the pianist is a stranger, have you heard of them before? If not, how long has your relationship been, and how often do you interact with them?</li> <li>• Please leave a check mark that best represents your relationship with the pianist. If you want to provide further comments, please feel free to write.</li> </ul>
<ul style="list-style-type: none"> <li>• In the image below, circle the image that best represents the level of connection you feel with the pianist.</li> </ul>	
<p>Post-questionnaire</p>	<ul style="list-style-type: none"> <li>• Reflecting on the recent experiment, did you experience any connection to the pianist? If so, please select the one most appropriate from 1 (felt no connection) to 6 (felt connected).</li> <li>• Reflecting on the recent experiment, do you feel that your connection to the pianist has changed? Please circle the image that best represents the current level of connection you feel with the pianist, considering only your feelings.</li> <li>• If you were to see the pianist in person now, would you feel more connected to them in any way?</li> </ul>

reviewed the transcripts while simultaneously cleaning the data. We then conducted qualitative analysis using Atlas.ti, following a reflexive thematic strategy [6], incorporating both open and axial coding [32, 33] on our 28 interview transcripts.

An initial line-by-line analysis of the first four interviews with the entire coding team allowed themes and codes to naturally

emerge. Subsequently, each transcript was assigned to a team member to code, with the entire team meeting daily during the first week to further develop emergent patterns into broader themes through axial coding [32, 33]. After the first week, the coding team met weekly to discuss and refine emerging themes and codes throughout the rest of the analysis process. As the researchers maintained

**Table 5: Outline of core questions that guided the semi-structured interviews of the main study.**

Core Questions
<ul style="list-style-type: none"> <li>• How would you describe or define your overall experience with MirrorFugue?</li> <li>• What emotions did you experience during the MirrorFugue, if any? Can you identify specific moments when these emotions were triggered?</li> <li>• How would you describe the sense of presence of the pianists during the MirrorFugue experience?</li> <li>• How did the emotions evoked by the performances of deceased pianists differ, if at all, from those of living pianists?</li> <li>• How did you experience a sense of connection to any of the pianists? If so, with whom did you feel the most connected, and how did this connection vary among the pianists?</li> <li>• If you played a duet, what motivated you to do so and how did it feel? How did it affect your emotions or level of connection, if any?</li> <li>• How do you think this experience influenced your connection to the pianist you have a pre-existing relationship with? Can you share any memories that came to mind, if any?</li> <li>• If you were observing a past version of yourself, how did that experience affect you? Did it bring up any memories? Did you feel more connected to this past version of yourself?</li> </ul>

\*Based on participants' responses, follow up questions were posed to explore the most relevant aspects their experiences.

close collaboration and frequent communication, we omitted inter-rater reliability. Our collaborative approach enabled us to reach a consensus and complete our codebook once no additional codes emerged from the analysis.

The final codebook included 68 sub-codes, such as "Feeling of Sharing," organized into 13 code groups like "Reasons for Evoked Connections." These sub-codes were aligned with specific research questions, for example, "Enhancing Understanding (RQ2)" and "Departure from Reality (RQ3)." These were then arranged under three overarching themes: "Description of MirrorFugue Experience," "Mediated Connections," and "Blurring Past and Present." This systematic structure informed the organization of the Findings sections, where we discuss insights derived from these categorized codes.

#### 4.4 Ethical Considerations

In our research, we implemented strict ethical and safety measures to ensure a secure environment. Anticipating that our work might evoke intense personal reflections, we provided mental well-being support, though no participants reported needing it. To respect privacy, we avoided sensitive questions unless initiated by the participants. Since the interviews were conducted after interactions with MirrorFugue to capture emotional responses, we allowed ample time for participants to compose themselves beforehand. The study received ethical approval from our institution's review board, with whom we worked closely to ensure robust ethical protocols and secure data management. All sensitive data, including personal histories, was stored in encrypted, university-secured files, accessible only to authorized researchers.

#### 4.5 Positionality Statement

The diverse expertise of our research team shaped our approach to data collection and analysis. The lead researcher provided insights into the emotional impact of piano music based on over 30 years of piano experience. An expert in emotional responses to sound guided the quantitative analysis of physiological data, while a researcher experienced with vulnerable populations conducted the

interviews. HCI researchers specializing in tangible technologies for remembrance contributed to data analysis. To reduce bias, we cross-checked transcripts with relevant experts: pianist researchers reviewed data from pianist participants, and grief experts examined data related to deceased loved ones. We acknowledge that our backgrounds may have influenced interpretations of our data.

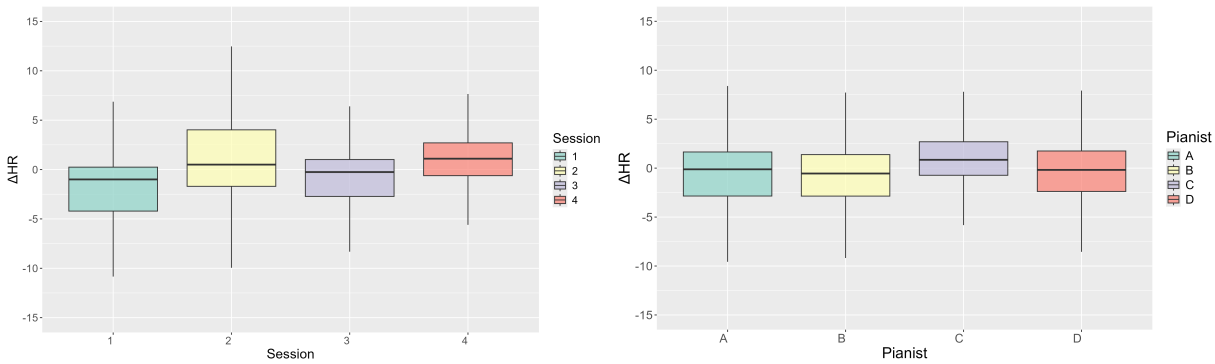
## 5 Findings

The following sections correspond to each of our three research questions, with quantitative and qualitative findings playing complementary roles. Quantitative findings reveal statistically significant patterns across participants' data while qualitative findings provide context, uncovering individual experiences and explaining the reasons behind these patterns.

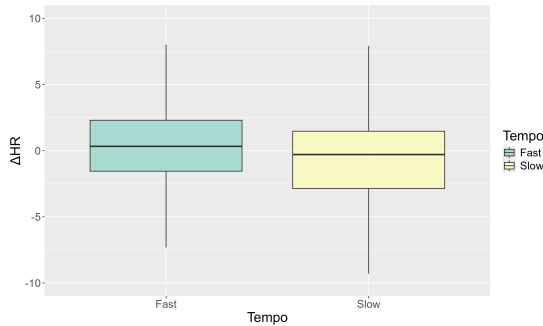
### 5.1 Overall Perceptions and Experiences

We first present general trends in how participants experience MirrorFugue. On the quantitative side, we set the stage for analyzing the effect of existing relationship and pianist vital status by first assessing the influence of other potential influencers of  $\Delta$ HHR. On the qualitative side, we describe participants' overall impressions and interpretations of the MirrorFugue experience.

**5.1.1 Quantitative. Novelty and Habituation:** Building on prior work on the novelty effect of technologies [16, 61], we examined the influence of session order to understand participants' responses to a novel experience and their potential acclimatization over time. A Friedman rank sum test revealed a significant effect of session order on  $\Delta$ HHR ( $p < 0.05$ ). However, the average data across sessions followed a non-monotonic pattern, and Kendall's tau showed a very weak correlation ( $p > 0.05$ ), indicating that the changes did not occur consistently in a single direction. Figure 6 illustrates the absence of habituation given the variability in  $\Delta$ HHR across sessions. Nevertheless, the decrease in standard deviation with each session hints at a possible acclimatization effect.



**Figure 6: (Left) Boxplot of  $\Delta$ HR by session order. (Right) Boxplot of  $\Delta$ HR by pianist. Data from all Pianist A's were considered here.**



**Figure 7: Boxplot of  $\Delta$ HR by musical tempo. Note that tempo corresponds to pianist professional level: both professional pianists played fast pieces, while non-professionals played slow pieces. Only data from the default pianist A is considered here.**

Interestingly, we observed unexpectedly low  $\Delta$ HR values in session 1. This can be attributed to the elevated heart rate before the session, likely caused by movement and conversations with the researchers during the preparation period. This pre-session elevation may have obscured the anticipated heart rate increase during the participants' initial interaction with the system.

**Pianist and  $\Delta$ HR:** Interacting with the pianists through MirrorFugue led to an increase in  $\Delta$ HR values for some participants and a decrease for others, depending on the specific pianist (Figure 6, right). However, the results of the Friedman test showed that these differences were not statistically significant ( $p > 0.05$ ).

**Musical Tempo and  $\Delta$ HR:** The Wilcoxon signed-rank test showed a significant effect of musical tempo on  $\Delta$ HR ( $p < 0.0001$ ), consistent with previous findings [63]. This effect aligns with pianist professional level, as professionals played fast pieces and non-professionals played slow ones. Despite the significance, the wide distribution of  $\Delta$ HR seen in Figure 7 suggests other factors may also be exerting an influence.

**Participant Activity Level:** Observations of acceleration recorded by the E4 bracelet on participants' non-dominant hands showed that 50% of the participants interacted with the keyboard during at least

one session. However, because accelerometer data was recorded only from the non-dominant hand, some participant movements may not have been captured. A Mann-Whitney-Wilcoxon test revealed a statistically significant difference in acceleration rates between pianists and non-pianists ( $p < 0.001$ ). The act of playing the piano during the experience suggests that participants were stimulated by the interaction. The standard deviation of acceleration was notably high for three participants who watched their own performances (P2, P7, P11), suggesting that experiencing their own past playing strongly prompted them to play along.

**5.1.2 Qualitative. Initial Reactions:** Subjects generally appreciated the MirrorFugue experience, describing it as “beautiful” (P5), “fascinating” (P8), “mesmerizing” (P24), “surprising” (P19) and “special” (P21). Different participants paid attention to different aspects of MirrorFugue. Subjects with some piano experience often focused on the hands, such as P07, a professional pianist, who reported “looking at the hands the whole time.” P11, an amateur pianist, appreciated “being able to have some idea of what the pianist will play” by “seeing the hands move.” Those with less piano experience expressed more appreciation for seeing the face of the pianist, such as P4, whose “choice to watch the person” made her “feel more connected” than watching “the hands and the piano itself.”

Many participants reported feeling the presence of the virtual pianists. For example, P17 described feeling that Pianist A “was performing the piece” and not “just watching a recording.” The acoustic playback with the moving keys played an important role in establishing the feeling of presence. P25, observed that the “experience of hearing an actual acoustic piano live is very different from hearing the recording of a piano.” P09 remarked that “what really helped was feeling the keys when they moved and moving with them to feel the touches.” For P13, it was the combination of “life-sized visuals along with the control of the piano” with the “reflection” on the surface of the piano that made the experience “feel very real.”

**Feeling and Interpretation of Presence:** The sense of presence was felt by participants despite the conscious knowledge that nobody was there. P05 describes being entranced by the paradox of “feeling someone's presence” but “also knowing that I am the only one in the room.” P10 expressed a similar experience, that is

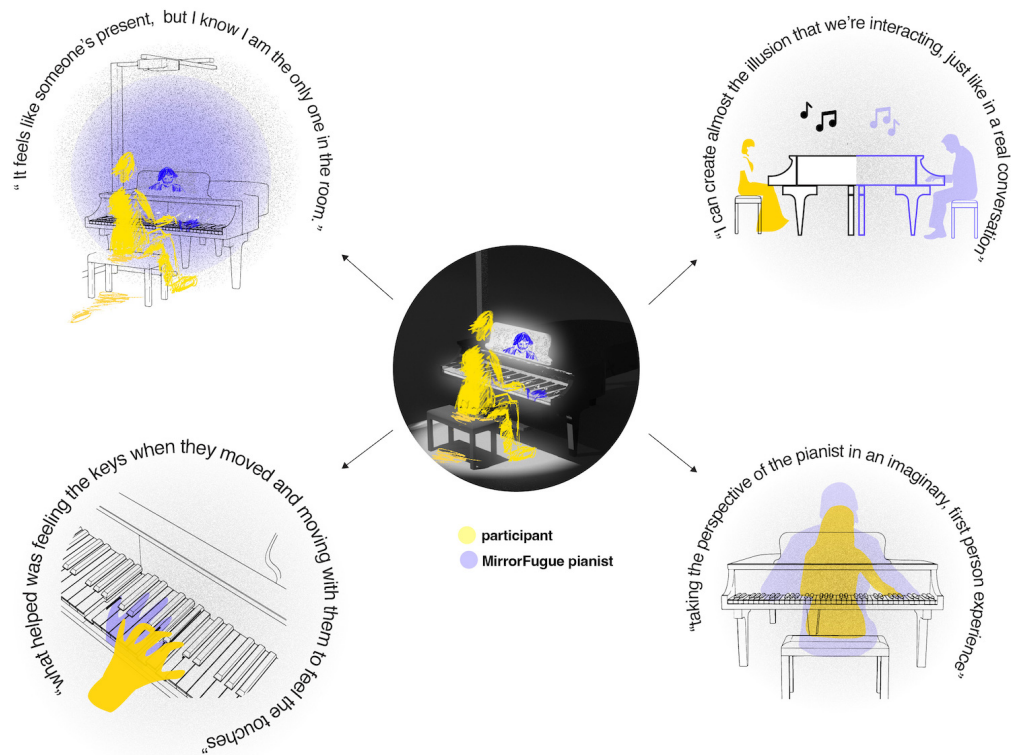


Figure 8: Visual summary of RQ1 interview findings: How participants experience MirrorFugue

“tough to explain” where “it felt like they were in the room with me but at the same time not.” Several participants remarked on the close spatial relationship with the pianist, which created a feeling of “intimacy” (P22).

In interpreting the presence of the virtual pianists, participants used the language of “traveling” in time. Some felt like the “past came to the present” (P05) While others described MirrorFugue as “a window into the past” (P25) or simply that they traveled to the space of a pianist (P28). A few participants described how MirrorFugue enabled “taking the perspective” of the pianist (P05) “in an imaginary, first person experience” (P23) or being “inside their presence” (P14).

**Illusory Communications:** For participants who are able to improvise, MirrorFugue became a medium of illusory communication with the virtual pianists. Even while knowing a MirrorFugue performance is “something that is fixed in the past,” P02 described his interactions as “a conversation in the present.” P08 reported a similar feeling of being able to “interact with them in my own perception, I can create almost the illusion that we’re interacting, just like in a real conversation.”

At the same time, the knowledge that nobody is there in the room gave some amateur pianist participants a feeling of “freedom to interact.” As P13 expressed,

“If I wanted to watch something, I could watch it. If I wanted to just listen, I could listen. If I wanted to play with it, I could play with it, and there’s no judgment.

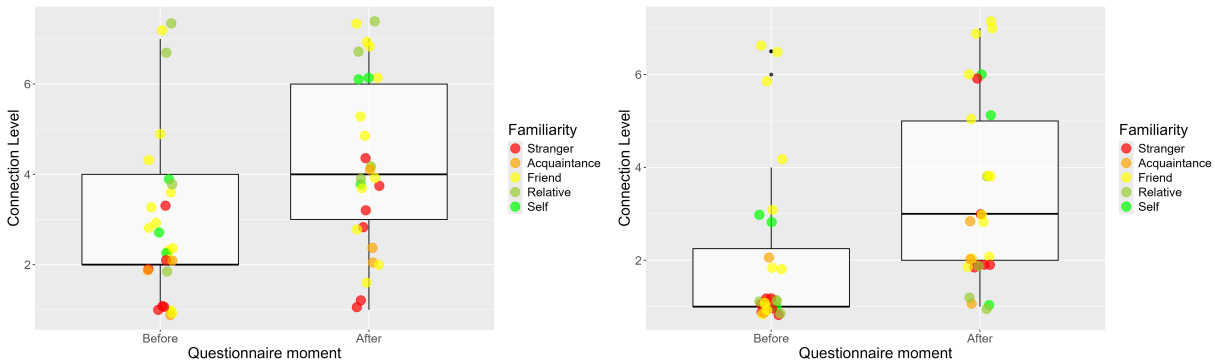
So I could play complimentary. I could trip all over what they were playing. I could mimic.”

## 5.2 Mediating Connection and Influence of Existing Relationships

Here we focus on MirrorFugue as an interface for mediating connection with recorded pianists across time. Quantitative analysis, which requires balanced groups, focused on pianists A and B, because participants were recruited with varying levels of existing connection with these pianists. While the participants’ relationships with pianists C and D did not have the balanced groups necessary for quantitative analysis, they were still discussed qualitatively in the interviews. In this section, pianist A includes both the default pianist A, whose recording was experienced by friends, acquaintances, and one family member, and 4 other pianists, whose recordings were experienced by the pianists themselves and/or their family members (see Table 3 for which pianist A was assigned for each participant).

Section 5.2.1 first reports on general trends from the survey and  $\Delta$ HR analysis. Section 5.2.2 then highlights findings from the interview that serve to explain the overall trends.

**5.2.1 Quantitative. MirrorFugue and Connection:** Analysis of the questionnaire data revealed that 77% of participants who interacted with pianists A and B experienced an increase in their sense of connection after the MirrorFugue experience (Figure 9). Moreover, a Wilcoxon signed-rank test demonstrated a significant



**Figure 9: Box plots of participants’ self-reported felt connection before and after the MirrorFugue experience for the default pianist A (left) and pianist B (right). The overlaid points show the values for each participant, color coded by their familiarity with the pianist.**

difference in connection levels before and after the interaction ( $p < 0.001$ ), supporting the finding that MirrorFugue enhances the connection between participants and the pianist.

**Familiarity and Connection:** The impact of participants’ existing familiarity with pianists A and B on their reported sense of connection during the MirrorFugue experience was analyzed using a Kruskal-Wallis chi-squared test. The results showed that familiarity did not have a significant effect on the participants’ reported connection ( $p > 0.05$ ).

**Familiarity and  $\Delta$ HR:** The level of existing familiarity had a significant impact on participants’  $\Delta$ HR during the MirrorFugue experience. A first analysis focused on sessions with pianist A and a second on pianist B, selected for their best distribution of familiarity levels based on self-reported data (Figure 10). Kruskal-Wallis chi-squared tests revealed significant effects of familiarity on  $\Delta$ HR ( $p < 0.001$ ). Further pairwise comparisons using Dunn’s test confirmed these differences were significant across groups, with adjusted  $p$ -values showing significance between “acquaintance/heard of” and “family/friend” ( $p < 0.001$ ), “acquaintance/heard of” and “stranger” ( $p < 0.05$ ), and “family/friend” and “stranger” ( $p < 0.05$ ).

**Self-Reported Connection and  $\Delta$ HR:** The relationship between self-reported perceived connection during the MirrorFugue experience and  $\Delta$ HR was evaluated using Spearman’s rank correlation ( $p < 0.001$ ) and Kendall’s Tau ( $-0.2496$ ), revealing a significant negative correlation. In other words, a higher reported sense of connection was generally associated with lower  $\Delta$ HR. This aligns with previous research on increased parasympathetic activity (e.g., relaxation) in the presence of close friends [51]. However, although the correlation is significant, its strength is only moderate. This may be due to the high standard deviation of  $\Delta$ HR for friends ( $SD = 10.0$ ), which was substantially higher than for acquaintances ( $SD = 4.48$ ) and strangers ( $SD = 2.48$ ). While several participants experienced a decrease in heart rate when seeing their close friend on MirrorFugue, indicating a sense of comfort, others appeared to become more excited. Such a response has also been found in prior work, which suggests that increased familiarity with a stimulus increases arousal [47].

The highly significant difference in physiological responses across familiarity levels despite relatively small sample sizes reinforces

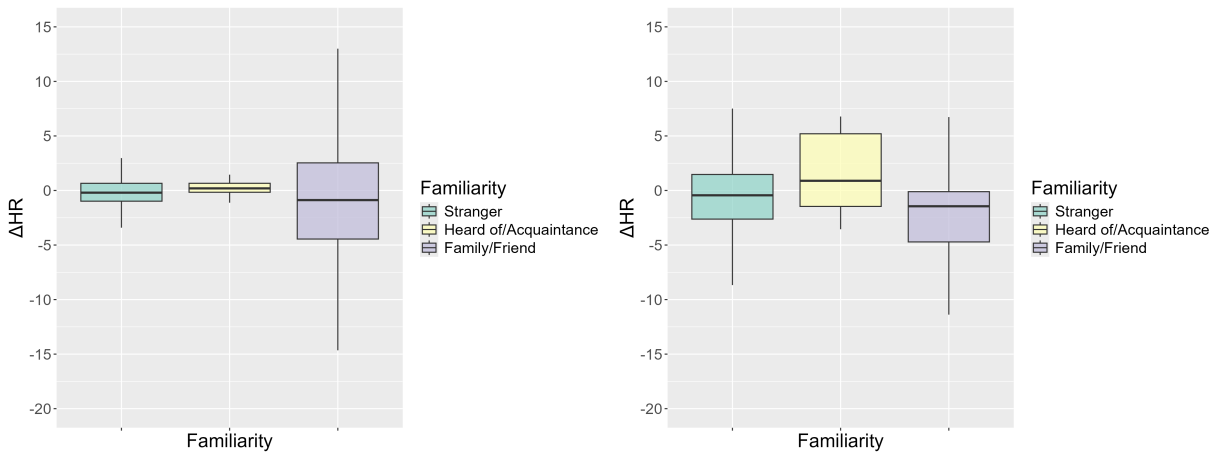
our earlier finding that MirrorFugue effectively simulates the social presence of recorded pianists. Positioning MirrorFugue as an interface for mediating connection across time, we show measurable differences in how participants connect with individuals based on their existing relationship. Participants’ personal and nuanced reasons for feeling connection are elaborated in the following section.

**5.2.2 Qualitative. Reasons for Connection:** During the interview, participants elaborated on their reasons for feeling more connected to the MirrorFugue pianists. P01 described an “emotional exchange” with the pianist “from the music, the pianists’ expressions and the tactile feeling.” Similarly, P10 spoke about “feeling emotional” from the music itself as well as the “empathy” of seeing someone “face to face also feeling emotional.”

For several participants, mostly non-pianists, the imperfections in a virtual pianist’s playing also increased the feeling of connection. P15 stated that “the imperfections are what makes the experience the strongest” because they “made it more human.” P06 also described feeling especially close with pianist B “because he didn’t play the piano smoothly” and that “he kind of messed up.” Conversely, the one participant who reported feeling less connection after a MirrorFugue session recounted “being very cognitive rather than emotional” as he identified what he considered to be technical defects in the virtual pianist’s playing (P03).

**Experiences of Strangers:** Reinforcing the quantitative analysis, existing relationships played a big role in participants’ self-described feelings of connection. When the MirrorFugue pianist was a stranger, less connection was felt in general. P07, who had an existing connection with pianists A, B and C, felt much less emotional connection with pianist D, whom he did not know, describing the experience as “not stimulating at all.” A pianist himself, P07 described pianist D’s playing as “really interesting” and “educational” but “it just didn’t do anything for me.” P17, who knew none of the virtual pianists, described a distinction between connection with the music versus the pianist. She “felt a connection to the piece” of pianist A “but not necessarily a connection with her.”

**Experiences of Acquaintances:** Subjects for whom a MirrorFugue pianist was an acquaintance reported gaining a new understanding of the individual. P22, an acquaintance of pianist A,



**Figure 10: Box plots of  $\Delta HR$  for pianist A (left) and pianist B (right) by participants' existing familiarity level with the pianist**

spoke of “the privilege” to “experience a past part of [pianist A’s] life” that she “didn’t see before.” Several other acquaintances of pianist A described the “really wanting to talk to her” (P10) about their MirrorFugue experience, which gives “more material for two way interaction” (P04) in the future. Similarly, P27 indicated it would be “fun to talk about this experience [with pianist A], as I am sure we will.”

**Experiences of Friends:** When MirrorFugue pianist was a close friend, such as P02 with Pianist A, the experience was a “reminder of that period,” when the recording was made, which brought up memories of “pianist A evolved and what her struggles were.” Another friend of Pianist A who knew her at the time of recording was reminded of “how she moved then,” and remarked that “now when I met her she seems more fluid than she was in the past.” A close friend who did not know the virtual pianist at the time of recording nevertheless felt a familiarity with Pianist A of the past, commenting that the MirrorFugue experience “pretty much matched” with “how he knew [pianist A],” and that “it felt like the present” (P21). Another friend, P14, who did not know pianist A at the time of recording, reflected on the major life events that happened to Pianist A after the recording that she couldn’t have known.

**Experiences of Family:** For family members of virtual pianists, as with friends, the experience also “brought back fresh memories” (P06). The mother of a MirrorFugue pianist who was recorded as a child, P06 remarked on being positively surprised by the perspective.

“like you totally forgot how she looked like. You can see the photos, but how she played, her tiny hands, and how she’s so focused, her mouth half open. That is actually what you want to see. When you usually look at the camera, you make a pose, even as a kid they know how to make the best smile. But on the piano is different, even if we have tons of videos of [our daughter], this is very different.”

P24, the daughter of a MirrorFugue pianist, who “never really paid attention before to his playing because [she] grew up with it,” gained

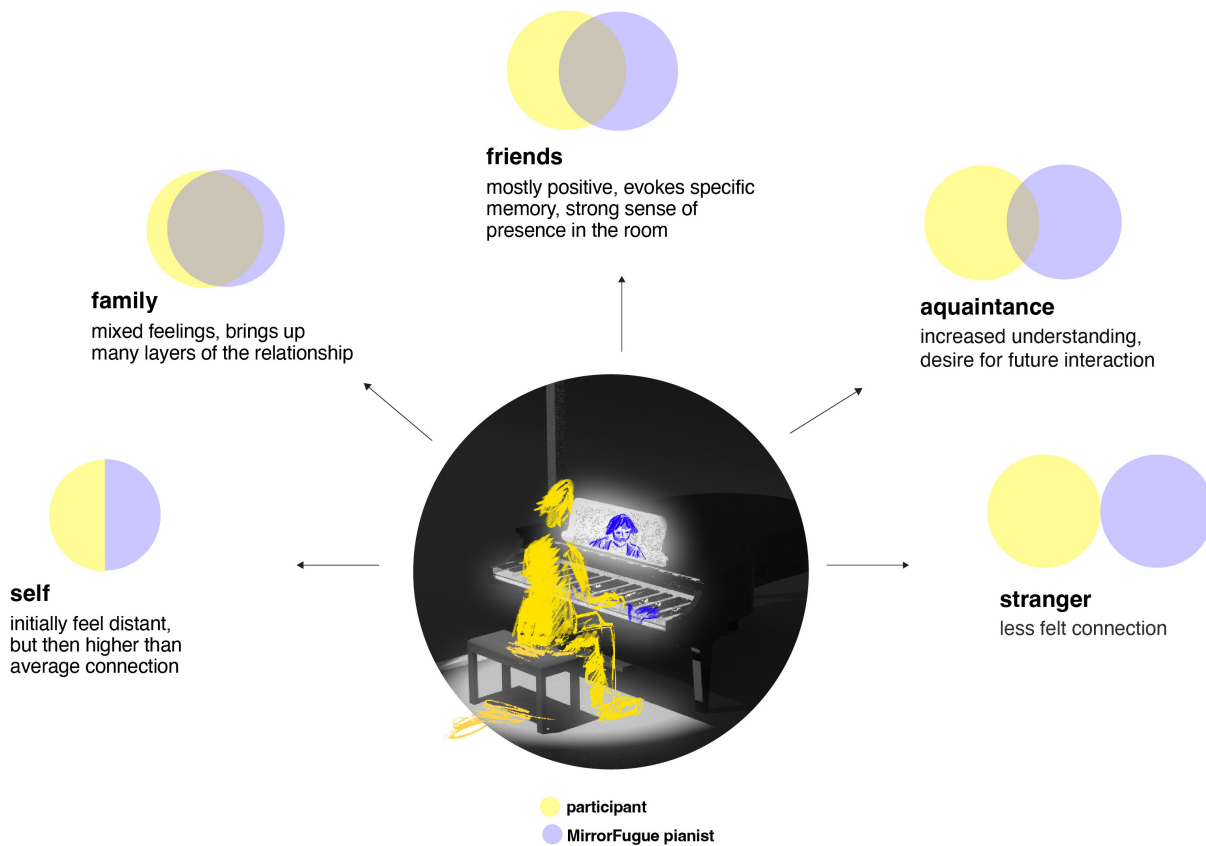
a new appreciation of her father as a musician through the experience, realizing “wait, this is actually pretty cool to actually see him doing it.”

While the friends of MirrorFugue pianists’ tended to recount positive emotions and memories as a result of the experience, what came up for family members was not always positive. As P13, a sibling of a virtual pianist remarked, “As you get older, you recognize people in your family are great, but they also have flaws. In the process of playing with him, little bits of those things are coming up, both positive and negative.” P12, a mother of a virtual pianist, also recounted memories of conflicts with her daughter.

**Experiences of Self-Pianists:** When pianists watched themselves on MirrorFugue, many initially “felt a distance” (P07), which matched the preliminary results of the Paris study. Elaborating on his experience, P07 reported feeling “closer to myself than I thought I would, like I understood what’s going on” but “it felt like an exhibit.” P05, who was recorded as a child, described the experience as “jarring,” stating “I didn’t really recognize my past self,” because she was “a completely different person to who I am now.” When watching his own past improvisation, P02 described feeling “detached and connected at the same time.” Despite knowing “it is obviously me,” P02 did not instantly remember the moment and felt like “it was another musician playing.”

As the recordings progressed, they became a way for the self-pianists to access and reflect on a “snapshot” (P05 and P07) of a past that they do not often think about. P07 retraced his stream of consciousness while watching his own past recording “that’s a long time ago, so I just sort of remembered what was going on at the time. I’m like, Oh wow, I seem distracted. And then I’m like, oh, that was because this thing was happening” which resulted in “a lot of empathy for myself.” As his past recording progressed, P02 described “learning my own piece, and smiling at the things I was doing at that time, because you keep changing as a musician.” For P11, the experience of watching his past self play brought back other, even more distant memories of playing the piano, which he recounted at length during his interview.

**Influence of Familiarity on Interpretation:** Interpretation of the MirrorFugue experience depended at times on the participant’s



**Figure 11: Visual summary of RQ2 interview findings: influence of existing relationship with the pianist on the MirrorFugue experience**

relationship to the virtual pianist, as seen in the descriptions from participants who had different types of relationships with multiple virtual pianists. P22 summarized the differences as “the more I knew them, the more it felt like the past. The less I knew them, it felt like the present.” P15 reported some similar experiences, feeling like “he traveled to the past” when watching pianist A, a friend that he did not know at the time of recording, while for pianist B, with whom he had a second degree personal connection, “it felt like [he] traveled” to the present.

However, the pattern did not hold for all participants. P07 described the experience as “different for each one.” He “traveled to the past” for himself, but for pianist C, with whom P07 has played together in the past, “it felt like he was there with me and like we were interacting” in a way that “the past and present were co-existing.” In contrast, for Pianist B, whom P07 knows personally but have had less experience playing piano together, it felt like “travel to the past.”

### 5.3 Interactions with the Deceased

Here we examine whether experiences with deceased MirrorFugue pianists quantitatively and qualitatively differ from experiences with pianists currently living. Two deceased pianists, B and D, are

respectively compared living pianists with matching skill levels A and C.

Though some significant quantitative differences were found in participants’ physiological responses, these results should be interpreted with caution due to the small number of pianists and the presence of confounding factors.

Qualitative findings show that participants’ relationship with the deceased and participants’ own life events substantially shape their experience. Here, “relationship” includes not only a past face-to-face relationship but also more tenuous links, like having heard of the deceased or the deceased reminding the participant of someone. Interview quotes suggest that the degree of existing connection may likely be a confounding factor in the quantitative analysis. At the same time, they attest to striking differences in participants’ qualitative experience of deceased versus living pianists.

**5.3.1 Quantitative. Vital status and  $\Delta$ HR:** Participants who interacted with living pianists had a mean  $\Delta$ HR of -1.81, with a median of -0.425 and a standard deviation of 3.12 (Figure 12, left). In contrast, those who interacted with deceased pianists showed a more negative mean  $\Delta$ HR of -3.97 and a median of -1.46, accompanied by a higher standard deviation of 3.98. These findings suggest that deceased pianists elicit a stronger physiological response, resulting

in greater variability in participants' heart rates. Additionally, the Wilcoxon signed-rank test revealed significant differences in  $\Delta$ HR between participants who interacted with living versus deceased pianists ( $p < 0.05$ ).

After controlling for familiarity by comparing the  $\Delta$ HR values of participants interacting with living versus deceased pianists C and D (Figure 12, right), and focusing exclusively on the “stranger” category to maintain consistency in participant numbers, the Wilcoxon rank-sum test revealed a significant difference in  $\Delta$ HR between those interacting with living versus deceased pianists ( $p < 0.0001$ ).

**5.3.2 Qualitative. Overall Influences:** Knowledge of the deceased status of virtual pianists made a difference for some but not all participants. For some participants, such as P19, the strong sense of presence of MirrorFugue “really felt like I was at a concert” and made “things feel very much alive.” Similarly, P27 observed that even though “the thought crossed my mind” of the pianist being deceased, “I don't know if I was dwelling on that as much because it certainly felt like they were there in that moment.” Some participants, like P18, vaguely mentioned being “more emotional” but could not clearly explain why. When participants could articulate their reasons, they seem largely related to the relationship the participant had with the deceased pianist.

**Influence of Past Relationships with Deceased:** Several participants had an existing relationship with pianist B. For all of these participants, the MirrorFugue experience brought back memories. For P07, who had attended gatherings at pianist B's home, seeing pianist B was a “nostalgic” yet “joyful experience,” which brought back “good memories” of past moments together around the piano. Other participants with prolonged close relationships with pianist B, recalled many memories with the pianist from different periods, including ones far preceding the time of the recording. P25, a close friend of pianist B, describes memories from across decades that “flooded” back,

“it was a sudden moment of experiencing all of my life from when I met him to this moment, like this comfortable person who had been a part of my world all this time.”

Similarly, P23, a daughter of pianist B, said the experience of her father “took me to different periods 30 years apart from each other, but it brought them all up.”

The two participants who were family members of pianist B both employed the language of physical presence to recount their experience. P28 spoke of “a little visit” that she “enjoyed” because it is “always nice to see” her brother. P23, a daughter of pianist B, described the experience as “extremely present” and “very immediate, like I did not think of it as a recording. I thought of it as being made now.” However, her emotional experience was more complex:

“I want more, like a longer time, that's too short. So that makes the presence in a way... fragmented. It can be both strong and weak at the same time.”

**Influence of More Distant Relationships:** Even a distant relationship to the deceased seemed to influence the felt connection. P06 described feeling the most connection when experiencing pianist B, a colleague of her husband, whom she has only met in passing. She recounted “attending his memorial, where there were

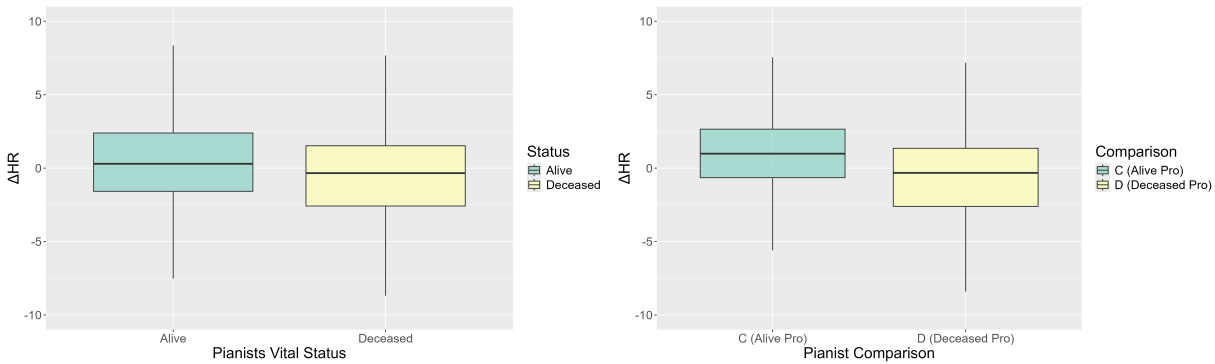
a lot of presentations about him from his friends,” which allowed her to “know him more than I actually knew him.” She clearly stated that her experience would be very “different” had she not “attended the memorial,” had she not “known his background,” or “if he were alive.”

Participants with a second degree connection also experienced memories related to pianist B. P04 did not personally know pianist B, but said that “some people who were really close to him are also very close to me.” For him, the experience of pianist B was highly emotional because “I've heard other people's memories. It's like I had a second hand account, but now I know the memories better than just having heard them. And I got to see, it's like, I actually got to be in the memory.” In contrast, P14 thought more about pianist B's wife, whom P14 does know, and about her present-day struggles that pianist B is “not here” to witness.

**Influence of Music:** In the absence of first or second degree personal connections, Participants' appreciation of deceased MirrorFugue pianists reflected more of their personal interests and life experiences. Resonance with the musical style itself played a big role, such as for P03, a jazz pianist, who said that the experience “made me appreciate his legacy.” P13 described pianist D as someone that he was “really excited to see... as a spectator or a fan” because “he produced a lot of records for some famous artists that I'm very big fans of.” P13 appreciated “the privilege” not only to “witness him playing” but also “seeing his facial expressions, how he's dressed, how he's moving.” P15, “connected most strongly with pianist D,” whom he did not know personally, but acknowledged “a really big bias because of the music.” P15 grew up listening to pianist D's music, and said the MirrorFugue experience “threw me to my past.” He evoked memories of traveling with his mother and her musician partner while listening to the blues and feeling transported to “the time and space, that place that doesn't exist anymore.”

**Projecting on the Deceased:** Deceased MirrorFugue pianists also brought back memories of people close to the participants that they miss. Sometimes the memories were triggered by some aspect of the pianist's physical appearance or movement. For P22, the experience with pianist B triggered “very emotional” memories of her uncle “because he was an older white man.” The uncle was a pianist and composer, and P22 spoke of her desire to interact with him on MirrorFugue. For P17, pianist B reminded of her grandfather “because he was more elderly and more uncertain on the piece.”

Subjects who recently experienced a loss of someone close to them were especially touched by the performances of deceased pianists on MirrorFugue. P16 had recently attended a memorial of a mentor and felt the interactions with the deceased pianists to be a “precious moment,” saying that “I never met them but I already missed them” about her interactions with all of the deceased pianists. Like P22 and P17, pianist B physically reminded P16 of her mentor, which made her feel the most connected with him out of all the MirrorFugue sessions. P21 recently experienced a loss of a close family member. Though neither pianist B nor D resembled the family member in physical appearance, P21 perceived elements in the emotional comportment of both pianists that still reminded him of his loved one. P21 focused on how pianist D looked like he “got to have fun in his life” in contrast to his loved one who “didn't get to do that kind of thing close to the end.” Watching pianist B, P21 perceived a “stoniness,” and wondered if pianist B “was not doing



**Figure 12: Box plots of  $\Delta$ HR by vital status including all data (left) and only including participants who are strangers to pianists C and pianist D (right)**

great” but “holding a shield,” which reminded him of his family member at the end of life.

**Loss Beyond Death:** Beyond connecting to the deceased, the simultaneous sense of presence and absence in the MirrorFugue experience made participants reflective of “loss” in a broader sense. P09 expressed the desire to see her first boyfriend playing the piano on MirrorFugue, to “spatially” experience what she has in her memories, “like he played for me when we were just the two of us.” However, she knows that it would “probably be sad” with her current knowledge that “his life didn’t turn out so well.” P27 also mentioned the role of MirrorFugue in the context of past relationships, speculating on how “it would be interesting” to have recordings of himself going through “a difficult thing” such as a “breakup” to be a way “to directly share the raw experience of that feeling.”

Finally, for participants going through major life transitions, MirrorFugue became a safe space that facilitated reflection on the passage of time. For example P05, who had just finished her first year of university studies was “self-reflective” not while interacting with her past self but also while watching the other pianists, thinking not only about the past but also about “aging” and “what my future will look like.” P14 had “just graduated” from her studies and described feeling “wistful” and “melancholy” about the passage of time, reflecting on the fact that “none of the pianists exist anymore, like the growing pains, they’re all different people or gone,” which made her “more introspective about the present.”

## 6 Discussion

This paper began with the speculation of whether it is possible to establish “telepresence” across “remote time,” specifically, whether an interactive system can simulate social presence and facilitate a feeling of illusory communication with someone from the past.

Our main contribution is empirical findings on the emotional experience of such an interface. Statistically significant quantitative data uncovered general trends while interviews shed light on individual experiences. We found that MirrorFugue successfully evokes the presence of past pianists and, for some, created a sense of illusory communication with the pianist. The experience led almost all participants to feel increased connection with the pianist.

Existing personal connections influenced not only experiences with currently living pianists but also the deceased.

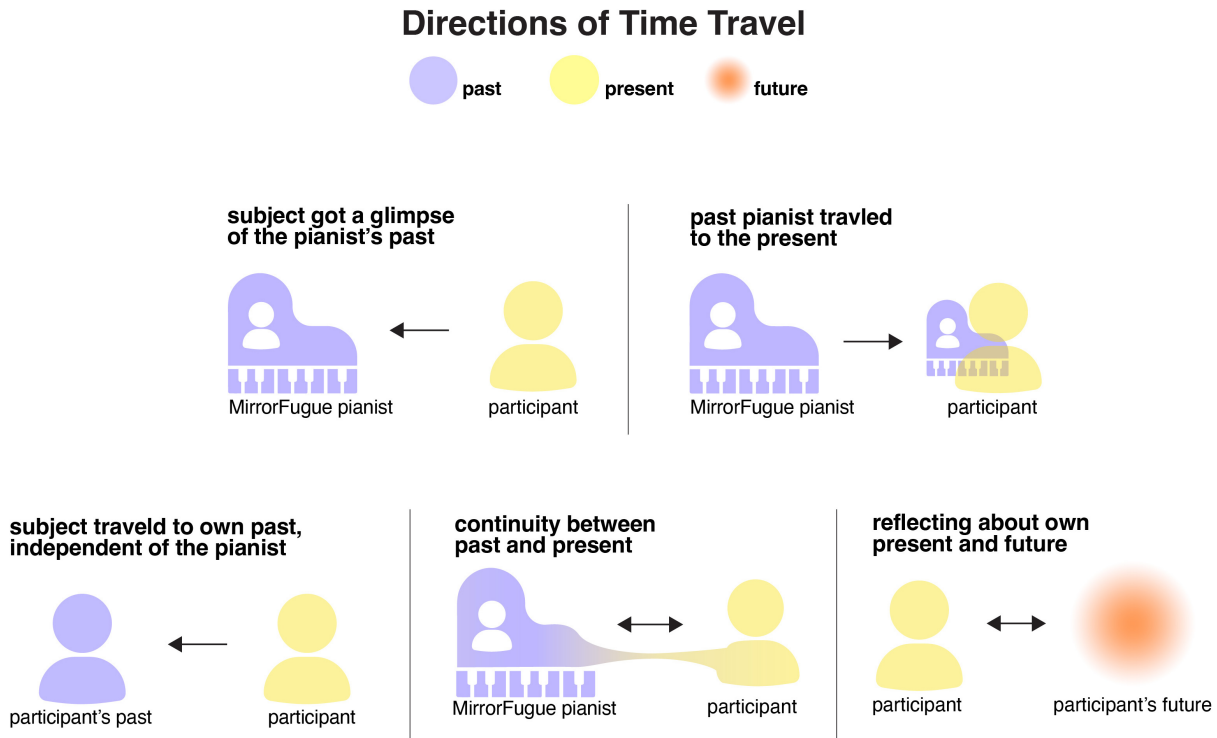
The illusion of two-way communication and resulting connection is reminiscent of Horton and Wohl’s concept of parasocial relationships, where spectators feel they “know” media personas as if they were real-life friends [14, 25]. Such connections arise from parasocial interactions, or the “simulacrum of a conversational give and take,” where media personas acknowledge and engage with their audience in their performance, adapt their conversational style, or directly address audiences verbally or gesturally.

Interestingly, the MirrorFugue experience increased participants’ sense of connection without the pianist directly addressing or acknowledging them, differing from traditional parasocial interaction theory. Moreover, the connection deepened more for participants with an existing relationship with the pianist than for strangers. These findings demonstrate the power of interactive technology design in fostering connections with those not physically present, even in brief interactions, while emphasizing the need to carefully consider the emotional complexities involved.

### 6.1 Perspectives for HCI Literature

Our findings offer new perspectives with respect to prior interactive systems for maintaining ongoing bonds with the deceased and for mediating interpersonal relationships among the living. HCI research in ongoingness draws from Klass et al.’s theory of continuing bonds [36], which frames the maintenance of dynamic, ongoing connections with the deceased as a natural and adaptive part of grieving. Interactive systems for ongoingness facilitate reflection and reminiscence in daily life, with the aim of creating a “future-focused” dialogue between the deceased and the living [35, 72, 73]. While these systems have avoided immersive representations of the departed for fear of the uncanny valley, our work demonstrates that realistic and immersive encounter such as enabled by MirrorFugue, need not fall into the uncanny.

MirrorFugue’s use of life-sized video recordings synchronized with the actuated keys and acoustic playback of the player piano creates a heightened sense of realism, and participants described improvising with MirrorFugue pianists as a “conversation” between past and present, suggesting that more immersive and interactive



**Figure 13: Types of “time travel” mentioned by participants in the interviews.**

encounters with the deceased are possible while preserving the essence of ongoingness.

One limitation of this paper, compared to prior work on ongoingness [35, 72, 73], is the lack of longitudinal evaluation; our study focused on a single, staged encounter. While the piano, as an everyday object, allows us to envision MirrorFugue’s integration into daily life, questions remain about how past performances might be triggered and whether habituation to the recordings could occur. Our quantitative data revealed some novelty effects upon first encountering MirrorFugue (Section 5.1.1), but the significant influence of the pianist’s relationship and vital status, along with qualitative insights, suggest that the sense of presence is not purely novelty-driven and would likely persist over time—akin to repeatedly listening to beloved music or rewatching a favorite film. Additionally, the improvisational element allows for the creation of something new in each interaction. We may also imagine the possibility of integrating novel generative AI models to introduce variations in the virtual pianist’s playing, consistent with their playing style, opening new research questions about the artful use of generative AI in interfaces for ongoingness.

While ongoingness in HCI typically focuses on maintaining bonds with the deceased, recent work by Rubin et al. has extended the continuing bonds framework to relationships between the living, comparing spousal relationships among the living, divorced, and deceased [62]. Indeed, all significant relationships share a history, memories, and past versions of selves, with accessibility to the partner in the present as a key difference.

Technologies that support interpersonal connections among the living often focus on curating memories or mediating interactions over distance [37, 39]. Our study suggests an alternative approach—encounters with a past version of a loved-one—as a way to mediate connection in present-day relationships. This is exemplified by numerous participants, particularly existing friends of the default Pianist A, who reported feeling an enhanced closeness to the pianist after experiencing her presence on MirrorFugue.

Furthermore, the type of encounter enabled by MirrorFugue can address loss in a broader sense. When asked what they wanted to see or hear on MirrorFugue, many participants expressed a desire to reconnect with lost moments or relationships. While this often involved deceased loved ones, it also encompassed other forms of separation or simply the inevitable passage of time that renders certain people or circumstances unreachable—for instance P27 wishing for recordings of himself playing the piano during a breakup or P09 longing to see her first boyfriend play the piano for her again. These findings demonstrate the potential of ongoingness interfaces to mediate connections not only with those who have passed but also with past selves and inaccessible parts of people’s lives.

Interactive technology that evoke presence and allow for illusory communications between the present and the past aligns with Ishii’s concept of TeleAbsence, which seeks to extend the notion of Telepresence to the afterlife [18, 27]. The original MirrorFugue was cited as an example of TeleAbsence, but the concept of TeleAbsence has never been experimentally studied. Our study offers empirical insights for the TeleAbsence concept, showing that it is indeed possible to simulate the presence and evoke a feeling of communication

with deceased pianists. It sheds light on the actual “user experience” and outcome of a TeleAbsence encounter, both for interactions with the deceased and for interactions with past versions of living people, including oneself from the past.

## 6.2 Reflections on Unexpected Findings

Our study also generated some unexpected findings, such as a departure from reality in participants’ experience of time (Figure 13). Often, participants used the language of “time travel” in describing their experience. Some participants (e.g. P04) felt like they traveled to the pianist’s past, for a glimpse into a past memory. Others (e.g. P05) felt like the pianist from the past traveled to be in the present. Yet others reported a feeling of timelessness, of continuity between the pianist from the past and the person they know in the present (e.g. P21). Another type of “traveling” facilitated by MirrorFugue centered on the participants themselves, independent of the pianist. Some participants traveled to their own past memories, either in moments shared with the pianists (e.g. P23, P25) or moments evoked by the music itself (e.g. P15). For other participants, MirrorFugue became a reflective space to think about their own present and future (e.g. P05, P14).

Finally, we were struck by the extent to which participants shared their personal memories and stories in their interviews. While our original research questions focused on communication and connection with someone from the past, the extent that the interviews focused on participants’ own personal stories suggests an alternative narrative. The MirrorFugue experience may be as much, if not more, about the participants themselves than about the absent person. In this sense, MirrorFugue creates a meaningful space for nostalgia. Such spaces hold intrinsic value, as nostalgia has been shown to benefit emotional well-being [1].

## 7 Conclusions

This paper empirically explored the subjective and emotional experiences of a telepresence interaction across time through the recreation of MirrorFugue. By having virtual reflections of past pianists, including some who have passed away, appear to physically play the piano, we examined how 28 participants with varying relationships to the pianists—family, friends, acquaintances, strangers, and the pianists themselves—experienced these past recordings.

Our findings revealed statistically significant patterns showing MirrorFugue’s ability to mediate connection with past pianists, influenced by the existing relationship and vital status of the pianist. Interviews shed light on the diverse experiences of participants in feeling the presence of pianists across time, engaging in different forms of “time travel,” experiencing the feeling of real-time music-making with the pianists, and finding spaces for reflection.

Beyond answering our research questions, our approach was novel in its combination of physiological data, questionnaires, and in-depth interviews to study subjective and emotional experiences in HCI. It is also unique in examining the varied experiences among different types of participants, suggesting that in designing technologies that mediate human relationships, the nature of the relationship plays a key role in the experience of the technology. This research also stands out in its consideration of the passage of time, by revisiting an interface from over a decade ago—a rare practice in

HCI. We hope that our rich results can encourage other researchers to revisit and re-contextualize the value of legacy interfaces.

In pursuit of our original research questions, a host of new questions emerged. Some can be explored experimentally, such as how user experience might change if generative AI allowed MirrorFugue pianists to respond. A more challenging question is how to generalize MirrorFugue’s qualities to other interactive systems, especially for designers interested in creating similar experiences. Relatedly, we may ask to what extent music is essential for facilitating illusory communication across time.

We can identify key properties of MirrorFugue that could inform “design principles,” such as its integration of visual, auditory, and tactile elements to recreate the pianist’s gestures, the evocative nature of the music, and the tension between the presence and absence of the pianist. However, we believe design principles alone are insufficient to create poetic and poignant experiences across time. What’s more important is attuning to the emotional space of the desired user experience. In the context of TeleAbsence, this emotional space resonates with the Portuguese concept of *saudade*, a deep emotional state of longing for something or someone absent [18, 68]. Our work is also inspired by the Japanese concept of *mono no aware*, a bittersweet awareness of impermanence [56]. We hope our findings help designers connect with these universal yet ineffable aspects of the human experience.

## Acknowledgments

We sincerely thank the pianists for permitting the use of their past recordings and for their openness in meeting their past selves on MirrorFugue. We are grateful to our participants for sharing their time and experiences. Special thanks to Quincy Kuang and Xinyi Zhou for their contributions in setup and data analysis, Roger’s Piano for the Yamaha Disklavier, and the Institute for Future Technologies in Paris and the Tangible Media Group at MIT for their support.

In memory of Ryuichi Sakamoto and Allen Toussaint—the timeless beauty of your performances continue to move and inspire us.

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## Appendix 1. Questionnaires for Pilot 1, Pilot 2, and Main Study

### Questionnaire for Pilot 1

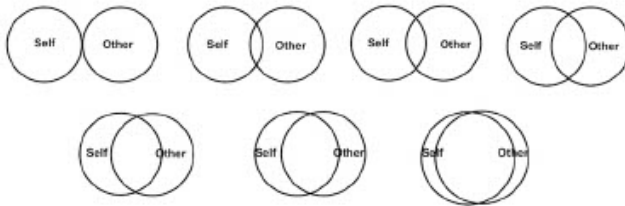
Post-questionnaire
<ul style="list-style-type: none"> <li>• Did you experience any sort of connection with the piece? If so, please circle the one most appropriate from 1 being felt no connection to 6 being felt connected.</li> </ul> <ul style="list-style-type: none"> <li><input type="checkbox"/> 1 out of 5: I felt no connection during the whole time.</li> <li><input type="checkbox"/> 2 out of 5: I felt little connection during some parts.</li> <li><input type="checkbox"/> 3 out of 5: I felt the connection during many parts.</li> <li><input type="checkbox"/> 4 out of 5: I felt a connection in most parts.</li> <li><input type="checkbox"/> 5 out of 5: I felt a connection during the whole time.</li> </ul> <ul style="list-style-type: none"> <li>• If you felt a connection, please describe the connection you felt. What kind of connection was it?</li> <li>• Did you interact with the piece in any way? For example, I played along or hummed along. If you did, please tell us how you interacted and what made you do so.</li> <li>• What emotions, if any, did you feel during the recording?</li> <li>• What memories or thoughts, if any, came to mind during the recording?</li> <li>• Did you feel any difference before and after the recording? And what do you think it's due to? For example, I felt calmer before/afterward.</li> <li>• Are there any other thoughts you'd like to log in addition to what you've shared above?</li> <li>• Are there anything you are curious about or wondered about? For example, it can be about the piece, pianist, or something personal.</li> </ul> <p><i>*Participants were asked to respond for all three modalities: Audio, Video, and MirrorFugue.</i></p>

### Questionnaire for Pilot 2

Pre-questionnaire
<ul style="list-style-type: none"> <li>• How long has your relationship with the pianist been?</li> <li>• How often do you meet the pianist?</li> <li>• Describe your relationship with the pianist (Stranger, Acquaintance, Friend, Family/partner)</li> <li>• Please leave a check mark that best represents your relationship with the pianist. If you want to provide further comments, please feel free to write.</li> </ul>

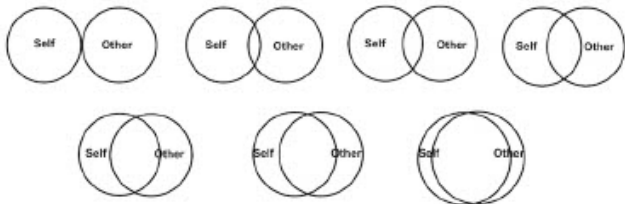


- In the image below, circle the image that best represents the level of connection you feel with the pianist.


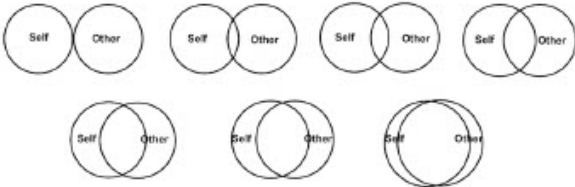


Post-questionnaire

- Reflecting on the recent experiment, did you experience any connection to the pianist? If so, please select the one most appropriate from 1 being felt no connection to 6 being felt connected.
  - 1 out of 5: I felt no connection during the whole time.
  - 2 out of 5: I felt little connection during some parts.
  - 3 out of 5: I felt the connection during many parts.
  - 4 out of 5: I felt a connection in most parts.
  - 5 out of 5: I felt a connection during the whole time.
- Reflecting on the recent experiment, do you feel that your connection to the pianist has changed? Please circle the image that best represents the current level of connection you feel with the pianist, considering only your feelings.



## Questionnaire for Main Study

Pre-questionnaire
<ul style="list-style-type: none"> <li>• Are you a pianist?</li> <li>• Describe your relationship with the pianist (Stranger, Acquaintance, Friend, Family/partner)</li> <li>• If the pianist is a stranger, have you heard of them before? If not, how long has your relationship been, and how often do you interact with them?</li> <li>• Please leave a check mark that best represents your relationship with the pianist. If you want to provide further comments, please feel free to write.</li> </ul>

<ul style="list-style-type: none"> <li>• In the image below, circle the image that best represents the level of connection <u>you feel</u> with the pianist.</li> </ul>

Post-questionnaire
<ul style="list-style-type: none"> <li>• Reflecting on the recent experiment, did you experience any connection to the pianist? If so, please select the one most appropriate from 1 being felt no connection to 6 being felt connected. <ul style="list-style-type: none"> <li><input type="checkbox"/> 1 out of 5: I felt no connection during the whole time.</li> <li><input type="checkbox"/> 2 out of 5: I felt little connection during some parts.</li> <li><input type="checkbox"/> 3 out of 5: I felt the connection during many parts.</li> <li><input type="checkbox"/> 4 out of 5: I felt a connection in most parts.</li> <li><input type="checkbox"/> 5 out of 5: I felt a connection during the whole time.</li> </ul> </li> <li>• Reflecting on the recent experiment, do you feel that your connection to the pianist has changed?</li> </ul>

Please circle the image that best represents the current level of connection you feel with the pianist, considering only your feelings.

- If you were to see the pianist in person now, would you feel more connected to them in any way?

Questionnaire for Main Study (for participants experiencing MirrorFugue with their past self)

**Pre-questionnaire**

- Are you a pianist?
- If you can recall the times when you were performing for MirrorFugue, can you briefly describe your emotional experience?
- In the image below, circle the image that best represents the level of connection you felt with your past self when you were performing on MirrorFugue.

\* Self: you now; Other: Past self

**Post-questionnaire**

- Reflecting on the recent experiment, did you experience any connection to the pianist (your past self)? If so, please select the one most appropriate from 1 being felt no connection to 6 being felt connected.

1 out of 5: I felt no connection during the whole time.

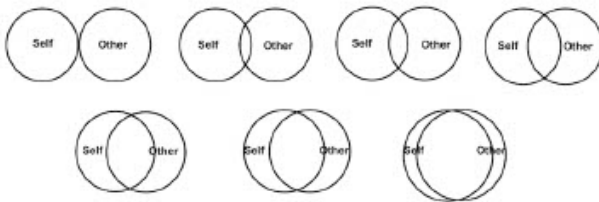
2 out of 5: I felt little connection during some parts.

3 out of 5: I felt the connection during many parts.

- 4 out of 5: I felt a connection in most parts.
- 5 out of 5: I felt a connection during the whole time.

- Reflecting on the recent experiment, do you feel your connection to the pianist (your past self) has changed? Please circle the image that best represents the current level of connection you feel with the pianist (your past self).

\* Self: you now; Other: Past self



- How would you describe your emotional experience? Please select all that apply.
1. It felt like I was traveling back to that exact moment.
  2. It felt like I was traveling back to that period (e.g., around the time it was filmed).
  3. It felt like I was co-existing with my past self.
  4. It felt like my past self had traveled to this moment.
  5. I felt the emotions I had experienced back then.
  6. I did not remember the emotions I had when this was filmed.
  7. It brought up new emotions.
  8. I felt distanced from my past self.
  9. My past self in MirrorFugue did not feel like me.
  10. I did not feel emotional.
  11. Other: \_\_\_\_\_