EMPATHISING AND SYNCHRONISING IN MUSICAL INTERACTIONS: A BIDIRECTIONAL PROCESS

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A thesis by publication submitted in
partial fulfilment of the requirements for the degree of
Doctor of Philosophy

The University of Sheffield
Faculty of Arts and Humanity
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March 2024

Abstract

Empathising with others and synchronising with their movements are essential aspects of human behaviour in social interactions, both entailing alignment with others' actions and feelings. However, how do these processes affect one another, and what is their relationship during musical interactions, a microcosm of social experiences? This thesis addresses these questions, contributing theoretically and empirically via three journal papers investigating a hypothesised bidirectional relationship between empathy and interpersonal synchrony. Paper 1 critically reviews the existing literature and develops a theoretical framework proposing a positive feedback loop between empathising and synchronising with others in musical interactions. Subsequently, Papers 2 and 3 focus on musical interactions of adult and child musical novices, testing central predictions of the framework. The studies utilise mixed-methods approaches and examine a variety of populations to address critical knowledge gaps and provide empirical evidence for crucial unidirectional aspects of the feedback loop model. Their results suggest that empathy enhances the social bonding experience stemming from synchronous interactions in adults and facilitates interpersonal synchrony in children. Additionally, findings show that synchrony facilitates empathising between children following brief musical encounters, implying that synchronising provides social cues directing attention to partners' movements and feelings. Overall, the thesis deepens our understanding of the complex relationship between synchrony and empathy, laying the groundwork for future empirical investigations focusing directly on the bidirectional nature of those two processes. This work also promotes new perspectives on the intertwined dynamics of social and musical behaviour, advocating for a shift from a unilateral to a bidirectional research focus and highlighting significant implications for music education.

Keywords: empathy, interpersonal synchrony, musical interactions, individual differences, bidirectional relationship, positive feedback loop, social bonding

Acknowledgements

I would like to thank my supervisors, Prof Renee Timmers, Prof Nicola Dibben, and Dr Jennifer MacRitchie, for their expert advice and guidance throughout my doctoral journey. I owe particular thanks to Renee for encouraging me to explore opportunities beyond my PhD research and publish from an early stage. Her dedication to supporting my research and providing thorough assistance with my methodologies, data analyses and manuscripts has greatly influenced my work. I am also deeply grateful to Nikki for her insightful guidance, which encouraged me to delve deeper into crucial aspects of my project. Her compassionate mentorship and pastoral support during moments of uncertainty have also been a constant source of strength. I am also deeply appreciative of Jenni's invaluable contribution to my research and the development of my problem-solving skills. Her expert advice during data analysis was crucial in navigating obstacles encountered during this doctoral journey.

I extend my appreciation to the participants of my empirical studies. I am deeply grateful to those who joined me from various parts of the world for the online study and engaged with me in stimulating discussions about music. I would also like to thank the pupils, teachers, headteachers and parents/carers of the Greek School in Sheffield and the 1st, 5th, 18th, 19th, and 23rd Primary Schools of Heraklion in Greece for their fantastic cooperation during my second study. They indeed made data collection both smooth and enjoyable.

My sincere thanks go to my father, Petros Tzanakis, for his inspiration and support as a research assistant during my second study. I am deeply thankful for his assistance in ensuring a successful data collection and for sparking my enthusiasm for a topic that fascinates both of us. I am also very grateful for Justin Christensen's patient guidance and assistance with regression models, as well as my cousin, Giannis Tzagarakis, whose invaluable support was instrumental in helping me organise my thoughts before proceeding to complex data analysis. I also extend my gratitude to Mark Doffman for his insightful contributions during my confirmation review, which shaped the ideas underpinning my research. Finally, to my dear parents, family, and friends from the UK and Greece, who have stood by me throughout this journey, offering emotional support and enduring countless conversations about empathy and synchrony – your encouragement has been my rock over the past 3.5 years, and I am deeply grateful for that.

Funding Statement

The completion of this doctoral research and thesis was supported by a Faculty of Arts and Humanities, University of Sheffield Research Scholarship.

List of Publications by Candidate

Published journal paper

For the Theoretical Paper (Paper 1) in Chapter 2, please see:

Tzanaki, P. (2022). The positive feedback loop of empathy and interpersonal synchronisation: Discussing a theoretical model and its implications for musical and social development. *Music & Science*, 5. https://doi.org/10.1177/20592043221142715

Forthcoming publications

For Paper 2 detailing Study 1 in Chapter 3, please see:

Tzanaki, P., MacRitchie, J., Timmers, R. & Dibben, N. *Unravelling the effects of empathy on social bonding following interpersonal synchrony through music: a mixed-methods approach.* [Manuscript submitted for publication]. Department of Music, The University of Sheffield.

A preprint is also available here:

Tzanaki, P., MacRitchie, J., Timmers, R. & Dibben, N. (2024a). *Unravelling the effects of empathy on social bonding following interpersonal synchrony through music: a mixed-methods approach.* PsyArXiv. https://doi.org/10.31234/osf.io/zxc8v

For Paper 3 detailing Study 2 in Chapter 4, please see:

Tzanaki, P., Eerola, T. & Timmers, R. *Actions and feelings in sync: Exploring the reciprocal relationship between synchrony and empathy in children's dyadic musical interactions.* [Manuscript in preparation]. Department of Music, The University of Sheffield.

For the CASES report (Paper 4) in Chapter 5, please see:

Tzanaki, P. *The Greek CASES: Translation and validation of the Cognitive, Affective, and Somatic Empathy Scales for children.* [Manuscript in preparation]. Department of Music, The University of Sheffield.

Underlying, openly accessible datasets, analysis code and stimuli

For the datasets, analysis code and stimuli of Study 1 (Paper 2), please see:

Tzanaki, P., MacRitchie, J., Timmers, R., & Dibben, N. (2024b). *Unravelling the effects of empathy on social bonding following interpersonal synchrony through music: a mixed-methods approach: Dataset, interview transcripts and stimuli* (Version 1). [Dataset]. The University of Sheffield. https://doi.org/10.15131/shef.data.24954150.v1

For the datasets, analysis code and stimuli of Study 2 (Paper 3), please see:

Tzanaki, P., Eerola, T. & Timmers, R. (2024). *Actions and feelings in sync: Exploring the reciprocal relationship between synchrony and empathy in children's dyadic musical interactions: Datasets and stimuli* (Version 2). [Dataset]. The University of Sheffield. https://doi.org/10.15131/shef.data.25382701.v2

CONTENTS

List of Tables & Figures

CHAPTER 1 - Thesis overview and summary of main contributions

CHAPTER 2 - Theoretical Paper (Paper 1)

CHAPTER 3 - Study 1 (Paper 2)

CHAPTER 4 - Study 2 (Paper 3)

CHAPTER 5 - CASES Report (Paper 4)

PREFACE

The idea of exploring the relationship between empathy and synchrony was first conceived in January 2016 when I was searching for a topic for my master's dissertation. I had always been interested in the concept of synchrony in music as my father, a music teacher, had ingrained in me the idea that *"everything around us has a rhythm and requires synchrony to function"*. As a music teacher myself, I found the effects of rhythmic and mirroring musical games on children's attentiveness and interest fascinating, sparking a desire to investigate a topic related to synchrony. After reading two influential articles - one highlighting that synchronised musical interactions can enhance children's empathy (Rabinowitch et al., 2013) and the other proposing that social skills can function as both consequences and influences of interpersonal coordination (Keller et al., 2014) - I found myself wondering: Could empathy also shape how children experience synchrony? And if it does, *could this, along with previous findings, imply a bidirectional relationship between empathy and synchrony?*

In this doctoral research, I sought to explore whether empathy - the ability to share the emotional and mental states of others - and interpersonal synchrony - the coordination of movements among individuals - could reinforce one another in musical interactions. The exploration commenced with reviewing existing literature and constructing a theoretical model proposing a bidirectional relationship binding the two processes in musical contexts. The framework synthesised existing evidence and conceptual perspectives, offering a theoretical basis for future empirical work on the topic. Following this, I conducted two empirical studies investigating important unidirectional aspects of the synchrony-empathy relationship. Although not directly addressing the question about their reciprocal relationship, this approach aimed to elucidate crucial unexplored aspects of the proposed interplay, providing insights for a future longitudinal study delving into bidirectional facets. The research process presented challenges due to the COVID-19 pandemic and the restrictions on conducting in-person experiments. Nonetheless, certain adaptations were made to incorporate an online study instead, still enabling the investigation of important knowledge gaps without requiring participants' physical presence.

This thesis follows a publication format, incorporating three papers: a theoretical article comprising the aforementioned review and proposed framework and two further papers detailing the

empirical studies of the thesis. Prior to this, an independent chapter (Chapter 1) presents an overview, explaining the linkage between papers. Specifically, the chapter first establishes the background and main research questions before introducing the papers and discussing their theoretical and empirical contributions. In its final section, the chapter synthesises study outcomes and theoretical perspectives, highlighting important implications and proposing essential steps for future research. I adopted this format following my research visit at RITMO, the Centre for Interdisciplinary Studies in Rhythm, Time and Motion, in Norway at the beginning of 2023, where such a practice is more common. I hope that this approach will enable readers to gain an understanding of the main contributions through a standalone chapter before delving into each paper to read about the studies in greater detail.

Following Chapter 1, the three thesis papers are consolidated in Chapters 2, 3 and 4, including details about my contribution to each study. The theoretical article in Chapter 2 has already been published and is openly accessible in the Music & Science journal. The second paper detailing the first empirical study (Chapter 3) was recently submitted to the Guest Edited collection on “Empathy” in Scientific Reports, and a preprint is available in PsyArXiv. The third paper of the thesis (Study 2 in Chapter 4) is intended to be submitted to the collection "Music and Pro-sociality" of Frontiers in Cognition in the following months. Lastly, a supplementary research report (Chapter 5) is incorporated after the papers, outlining the process I followed to translate into Greek and validate an English empathy questionnaire for children. Although not directly linked to the research aims, the questionnaire played an important role in the second study, and it will soon be available as an openly accessible resource.

In addition to this thesis, my PhD journey has encompassed a wide range of learning and development experiences that greatly enhanced my skills as a doctoral researcher and bolstered my present work. These experiences involve acquiring skills in conducting multilevel analysis in R, actively participating in the MusicMindMachine lab and the broader research community at the Department of Music, completing a two-month research visit at a Norwegian Centre of Excellence, collaborating with esteemed external partners, such as Professors Tuomas Eerola and Jonna Vuoskoski, and chairing SysMus23, the 16th International Conference of Students of Systematic Musicology. These rich and diverse experiences enhanced my project management, problem-solving and leadership skills, thereby enriching both my doctoral research and future career. I am deeply thankful for the support of my

supervisors, who encouraged me to embrace such opportunities and develop my research profile across diverse domains.

I would like to conclude this preface by emphasising the open-access principles underlying my doctoral research. While this publication format is more established in music PhD theses of Scandinavian countries, it is still emerging in the UK, particularly in arts and humanities research. Nonetheless, opting for this type of thesis intended to align with the evolving trends in academic publishing, facilitating accessibility and engagement. Indeed, the format enabled writing individual papers and publishing them in open-access journals or uploading their manuscripts to preprint platforms. These practices ensured not only the transparency of my research but also broader access to scholarly work on the topic. Moreover, the empirical studies entailed collecting tapping data from 144 children and conducting 80 interviews with adult participants. Given the difficulties in gathering a substantial volume of data, especially from groups that are often challenging to recruit, making these datasets openly accessible is crucial. Therefore, uploading all data, code and stimuli of the studies to ORDA, the University of Sheffield's data repository, will enable future research on the topic without the need for additional data collection. I hope my work will inspire future postgraduate researchers to adopt a similar thesis format and embrace open-access-related principles. Practising such approaches from an early-career stage can significantly elevate research quality, promote the early dissemination of research, and create more opportunities for collaboration.

References in this preface

Keller, P. E., Novembre, G., & Hove, M. J. (2014). Rhythm in joint action: Psychological and neurophysiological mechanisms for real-time interpersonal coordination. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1658). https://doi.org/10.1098/rstb.2013.0394

Rabinowitch, T. C., Cross, I., & Burnard, P. (2013). Long-term musical group interaction has a positive influence on empathy in children. *Psychology of Music*, *41*(4), 484–498. https://doi.org/10.1177/0305735612440609

CHAPTER 1

Thesis overview and summary of main contributions

Background, aims and main research questions

At first glance, empathy and synchrony might appear to be two unrelated concepts. Empathy is often associated with compassion or sympathy for a person in pain or need, whereas synchrony is commonly related to oscillators in nature aligning in time. Nonetheless, a closer look at human behaviour within social interactions unveils that the processes of empathising and synchronising with another individual share some intriguing parallels. Indeed, both processes play a pivotal role in social interactions, encompassing deliberate and subconscious aspects that enable individuals to understand one another and attain shared objectives, e.g. having a conversation or dancing together (Singer, 2009; Molnar-Szakacs & Overy, 2006). Empathy also involves paying attention and sharing the emotional state of another person while acknowledging your own feelings to avoid emotional distress (Decety & Lamm, 2006). Similarly, interpersonal synchrony requires monitoring and anticipating another person's movements to adapt and align with them while maintaining awareness of one's own actions (Keller et al., 2014; Fairhurst et al., 2023). Considering these similarities, the following questions emerge:

1) Could the processes of empathising and synchronising with others influence one another reciprocally, i.e. practising one encourages the development of the other, and vice versa?
2) If so, what personal, inter-individual or contextual factors might enhance or hinder these processes and, subsequently, their bidirectional relationship?
3) And finally, what are the implications of this process? Why is it important to investigate this relationship and its bidirectionality?

The present doctoral research synthesises theoretical perspectives and empirical evidence in three academic papers to address these key research questions and examine the relationship between empathy and interpersonal synchrony in musical contexts. Following a review of the existing literature, Paper 1 (Chapter 2) responds to these questions on a theoretical basis, proposing a bidirectional synchrony-empathy relationship and discussing the factors affecting it, as well as its implications. Subsequently, two empirical studies address important sub-questions deriving from the aforementioned

review (Paper 1), which concern unidirectional aspects of the synchrony-empathy interplay. In particular, the sub-questions stem from Research Questions 1 and 2 above, addressing knowledge gaps in the effects of synchrony and empathy on one another and potential factors enhancing or diminishing these unidirectional effects. Regarding the first research question, Study 1 (Paper 2 in Chapter 3) explores whether empathy influences the social bonding experience stemming from synchronising with a partner in adult musical novices (Sub-question 1a). In addition, Study 2 (Paper 3 in Chapter 4) focuses on children's musical interactions, investigating how empathy facilitates interpersonal synchrony (Sub-question 1b) and whether synchrony encourages social bonding and empathising following brief musical interactions (Sub-question 1c). Focusing on sub-questions of Research Question 2, Study 1 delves into how individuals' social perceptions, the sensory modalities involved in a musical engagement (whether observing visual stimuli or actively engaging with auditory stimuli) and the musical tempo facilitate or obstruct the role of empathy in moderating the bonding effects of synchrony (Sub-question 2a). Additionally, Study 2 explores whether leadership (leading or following a musical interaction), familiarity among partners and their gender influence the role of empathy in supporting synchrony (Sub-question 2b). In addition, the study investigates whether induced empathy among children amplifies their experience of synchrony's social outcomes (Sub-question 2c). The rationale for these sub-questions and their link to the bidirectional relationship between synchrony and empathy are discussed in-depth in the following sections of this chapter.

The synchrony-empathy relationship is specifically examined here in the context of musical interactions, i.e. when two or more individuals engage in shared music-making activities. This stems from the consideration that both synchrony and empathy play an important role in such social interactions. Participating in musical group actions requires a set of cognitive and interpersonal skills that allow individuals to socially and musically engage with others to attain a cohesive result (Cross et al., 2012; Overy & Molnar-Szakacs, 2009). Music is also thought to be perceived as actions behind musical signals. The mirror neuron system, involved in both empathising (Gallese, 2009) and imitating others' actions (Iacoboni, 2009), is proposed to attribute affect to these perceived actions during music-making (Overy & Molnar-Szakacs, 2009). This implies that music can convey social and emotional information about partners, facilitating temporal and emotional alignment. Therefore, a musical context

is a highly advantageous environment for examining the complex synchrony-empathy interplay (D'Ausilio et al., 2015).

Contextualising now the key terminology examined here, empathy is viewed as a dynamic process encompassing dispositional elements, as well as situational manifestations, dependent on a given empathic event and the individuals involved (de Vignemont & Singer, 2006). It essentially involves conscious and subconscious processes enabling individuals to automatically create shared representations of others' emotions and cognitions (often referred to as affective empathy) and consciously gain insight into their perspective (also known as cognitive empathy - Preston & de Waal, 2002). Under suitable conditions, this empathising process contributes to altruism and bonding among individuals (de Waal, 2008). As for interpersonal synchrony (also referred to as simply synchrony for brevity), the focus here is primarily on the intentional alignment of movements between individuals, particularly in the context of playing music or tapping with others. Nevertheless, insights from studies exploring behavioural and spontaneous aspects of synchrony, such as mimicry and imitation, are also incorporated. Lastly, although evidence from various disciplines is drawn, including behavioural and social psychology, the primary emphasis is on synchrony and empathy in the realm of music psychology. This allows the exploration of the implications of this research in relation to social development through music and the dynamic interplay between musical and social behaviour.

Below, the theoretical and empirical contributions of the thesis are presented, outlining the steps undertaken to examine its research questions and sub-questions. The final part of the chapter consolidates study findings and theoretical perspectives, discussing the significance of this research and proposing future research directions to illuminate further not only the synchrony-empathy relationship but also the intriguing interplay between musical and social behaviour.

Theoretical contribution

The initial contribution of this thesis involves a theoretical paper (Paper 1 in Chapter 2), which reviews and synthesises findings from various academic disciplines to offer a comprehensive perspective on the associations between synchrony and empathy. Following a contextualisation of key terminology, studies on each direction of the synchrony-empathy relationship are critically reviewed, examining research from various fields such as behavioural synchrony, music psychology, social

neuroscience and dance therapy. The paper reveals a positive mutual influence between empathy and synchrony, evident from an early age. For example, early synchronous interactions between mothers and infants can predict better empathic mechanisms in adolescence (Feldman, 2007), while dance therapy interventions incorporating synchronised movements and imitation encourage bonding and affective empathy between clients and therapists (Behrends et al., 2012). Furthermore, cognitive empathy has been found to support the predictive skills required to attain synchrony in adults (Novembre et al., 2019), while it might also play a role in simulating others' actions through music (Novembre et al., 2012), facilitating synchrony with their movements or the music (Overy & Molnar-Szakacs, 2009; Bamford & Davidson, 2019).

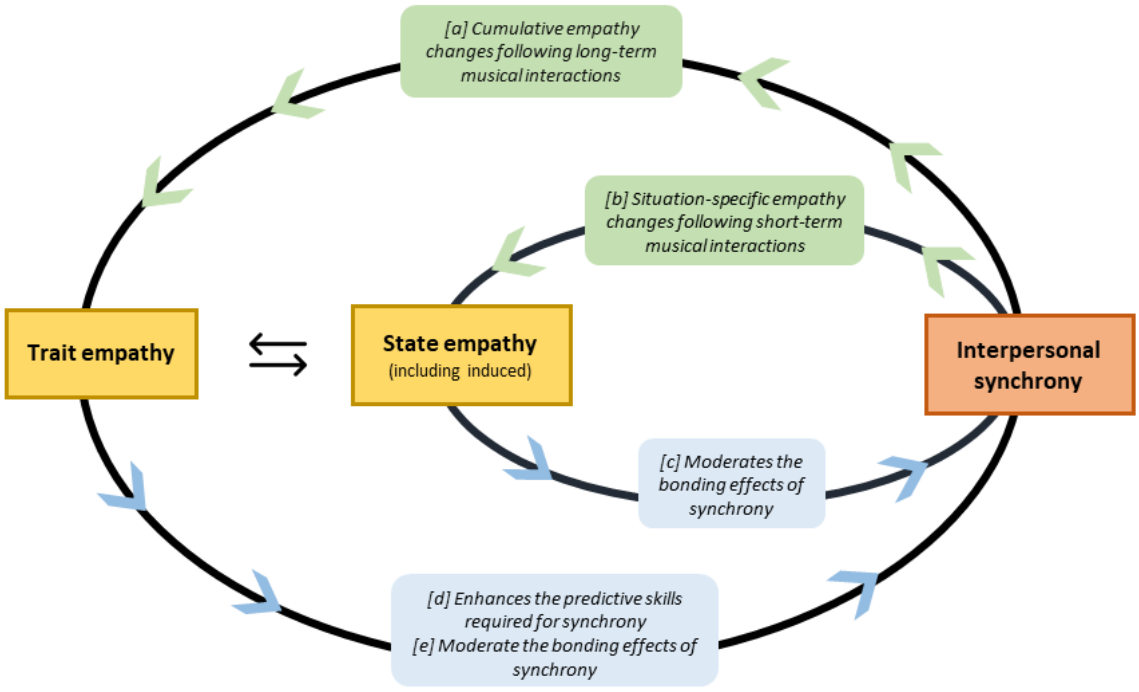
Further to consolidating these valuable findings, the paper highlights certain aspects requiring additional research before delving into the bidirectional nature of the synchrony-empathy relationship. These aspects notably involve understanding the mechanisms underlying synchrony's cumulative changes in trait empathy, its impact on state empathy, the timeframe required for measurable changes in synchronising and empathising and the potential generalisation of synchrony's effects on individuals observing but not actively participating in a given social or musical interaction. Additionally, the paper underscores a prominent absence of developmental research on how trait or induced manifestations of empathy support the attainment of synchrony in children. Indeed, while considerable attention has been given to the effects of synchrony on children's bonding, social skills, and empathy (e.g. Kirschner & Tomasello, 2010; Rabinowitch et al., 2013), the role of empathy in how synchrony is perceived and experienced at a young age remains ambiguous. Such important knowledge gaps are consolidated at the end of this review paper, forming a centralised guide for researchers to identify key areas requiring further investigation. These gaps have also informed the empirical studies of this thesis, as discussed in the section *"Empirical contributions"* below.

Following this literature review and drawing on existing evidence and relevant frameworks in social and music psychology, Paper 1 subsequently proposes the positive feedback loop model. This framework addresses Research Question 1 of the thesis conceptually (see *"Background, aims and main research questions"* section for research questions), bringing together previous postulations about a reciprocal relationship between empathy and synchrony (e.g. Levy & Feldman, 2019; Keller et al.,

2014; Novembre et al., 2019). At the core of the model lies the concept that during musical group interactions, empathy and interpersonal synchrony reinforce one another in a reciprocal manner. The ongoing practice of this interplay in a musical context can subsequently foster the simultaneous development of associated musical and social skills (Tzanaki, 2022). Paper 1 explains in detail the proposed rationale for generating such a positive feedback loop. Additionally, Figure 1.1 below illustrates the model as presented in the published version of the paper (Tzanaki, 2022). The alphabetical indexation has been slightly adapted here to link the empirical contributions of the thesis with the framework, as discussed later in this chapter.

Figure 1.1

The positive feedback loop of empathy and interpersonal synchrony in musical interactions (Tzanaki, 2022).



Note. The relationship between synchrony and the trait and state facets of empathy appear as separate loops to facilitate interpretation; however, the two processes are intertwined and part of the same positive feedback loop. The blue and green boxes indicate the effects of one process on the other and match the arrows' colour, representing the direction of the effects.

The positive feedback loop model delineates a dynamic process occurring in a wide range of musical interactions spanning from music ensembles with professional musicians to music education programmes involving child musical novices. The context, individual characteristics and relationships

among the interacting members play a significant role in the positivity of the loop, given that both synchrony and empathy are susceptible to social factors hindering or facilitating their practice. For example, one might find it difficult to empathise with an individual who has previously treated them poorly (Singer, 2009), while synchrony strengthens group cooperation more effectively when combined with shared intentions and goals (Reddish et al., 2013). Based on evidence related to the impact of social factors on empathy and synchrony, Paper 1 addresses Research Question 2, highlighting important factors that could significantly affect the functioning of the feedback loop. These factors serve as a reminder of the dynamic nature of musical interactions, where features such as individuals' characteristics and their prior social and musical experiences might influence their involvement and the outcome of their interaction (Clayton et al., 2020).

Concerning now the underpinning mechanisms allowing empathy and synchrony to enhance one another bidirectionally, the paper underscores the crucial role of perception-action coupling. Perception-action refers to how individuals perceive their environment and act in response to these perceptions or how they act in their environment and perceive it accordingly (Preston & de Waal., 2002). One way this coupling becomes apparent is by simulating others' actions and emotions in the brain, creating embodied representations as if these movements and emotions were produced or felt by the observer (Gallese, 2003). Simulating partners' actions plays a central role in interpersonal synchrony, supporting the prediction of their subsequent temporal behaviour (Keller et al., 2014). Similarly, observing others' experiences activates representations in the observer's brain that facilitate the sharing of feelings and contribute to empathy (Preston & de Waal, 2002). Given the important role of motor simulations in both empathising and synchronising with others, their bidirectional relationship may emerge from practising cognitive skills related to predicting others' behaviour and acting upon those predictions. Indeed, individuals with higher empathy have been found to generate stronger representations of observed actions (Novembre et al., 2012), which allows them to possess superior predictive skills and synchronise better with a partner (Novembre et al., 2019). Additionally, according to the predictive coding model (Shamay-Tsoory et al., 2019), individuals constantly create predictions about their environment based on past experiences and new sensory information. Therefore, practising synchrony with others in a musical environment may reduce prediction error (Overy & Molnar-Szakacs,

2009), activating the alignment reward system and fostering emotional alignment, connectedness and empathy (Cross et al., 2012). Overall, engaging in empathy and synchrony during musical interactions might encourage the practice of simulating and predicting others' actions and emotions, contributing to a positive feedback loop where exercising one process enhances the other and vice versa.

The evidence above emphasises the predictive dimensions of perception-action coupling that may support the emergence of the proposed feedback loop. Nonetheless, examining further parallels between empathy and synchrony, notably the skills required for adaptation and attention to others' actions and emotions (Keller et al., 2014), might shed light on additional mechanisms contributing to their interplay. For instance, the simulation of one's own and other's actions may support not only anticipation but also the adaptation mechanisms for synchronising with external auditory stimuli (van der Steen & Keller, 2013). Indeed, individuals with higher empathy have been found to adjust faster to tempo changes than those with lower empathy (Bamford & Davidson, 2019). Adaptation to others' affective states is similarly vital for empathising, enabling the automatic sharing of feelings and prompting individuals to consciously step into others' shoes (Preston & de Waal, 2002). In musical contexts, the mirror neuron system, which supports emotional empathising, can also attribute affect to musical signals, which are perceived as actions (Overy & Molnar-Szakacs, 2009). As a result, perception-action coupling here might further facilitate the temporal and affective alignment between partners, encouraging a conscious adaptation to others' musical behaviour and a seamless operation of the positive feedback loop. Apart from adaptation, attention to others' actions and feelings might also be an important mechanism to explore. Indeed, shifting focus away from oneself and attentively monitoring others' behaviour while preserving a clear self-other distinction is essential for interpersonal synchrony (Keller et al., 2014; Fairhurst et al., 2023). Similarly, such a process is also crucial for empathising to maintain a conscious distinction between own and others' states and prevent emotional distress (Cross et al., 2012; Decety & Lamm, 2006).

Considering the above, it is proposed that the aforementioned parallels enable a transfer of cognitive and affective skills across the synchronising and empathising processes (Rabinowitch, 2017), contributing to the establishment of their reciprocal relationship. In other words, synchronising musically with others might provide a context to practise empathy, while empathising can further

support the skills required to align and synchronise with others. However, further examination is needed here to gain insights into which specific mechanisms facilitate this skill transfer and the extent of their contribution. It is also important to clarify which dimension of empathy contributes to this process, delineating the role of its cognitive and affective manifestations. For example, considering that cognitive empathy supports the skills required to attain synchrony (Novembre et al., 2019), one might wonder what the role of affective alignment with a musical partner is in this process. Given the involvement of mirror neurons in empathising and attributing affect to information about partners conveyed by music (Overy & Molnar-Szakacs, 2009), it is also important to investigate to what extent the automatic affective sharing in musical interactions encourages temporal alignment and how this alignment facilitates the conscious and subconscious components of empathy.

The final part of Paper 1 focuses on the implications of the feedback loop model (Research Question 3) pertaining mainly to children's musical and social development. Following an empirical establishment of this reciprocal relationship in children, it could then be incorporated into music education programmes aiming to a) transcend group membership barriers and b) facilitate the simultaneous development of musical and social skills in children. Indeed, practising temporal and affective alignment with others can generate new social predictions about individuals previously considered outgroup members, fostering liking and connectedness with them (Shamay-Tsoory et al., 2019). It has also been argued that a musical environment can introduce flexibility and a sense of looseness, mitigating the formation of rigid group memberships that might stem from stringent coordination among in-group members (Rabinowitch, 2023; Cross et al., 2012). Additionally, engaging with others musically can improve individuals' musical skills and nurture essential social capacities for human interactions (Ilari et al., 2018; Phillips-Silver & Keller, 2012). Therefore, utilising the reciprocal synchrony-empathy relationship and reinforcing the practice of psychological processes, such as directing attention to others or aligning musically and emotionally with them, has the potential to a) increase understanding and connectedness across groups and b) allow for a skill transfer contributing to children's parallel musical and social development.

In conclusion, this review paper consolidates unidirectional evidence concerning the interplay between empathy and synchrony for the first time and highlights important aspects requiring further

examination. Through a critical review, the paper synthesises this information in a meaningful and contextually relevant manner within the realm of music, offering a foundation for future empirical research on the topic. Perception-action coupling is suggested to be at the core of the positive feedback loop, enabling processes that promote a skill transfer between synchronising and empathising with others. However, empirical work is required to establish the reciprocal effects of empathy and synchrony, delineating the mechanisms supporting a potential skill transfer and clarifying the specific components of empathy contributing at each stage of the temporal and emotional alignment of the feedback loop. Finally, the proposed model bears important implications, prompting the necessity for a deeper examination of the interplay between empathy and synchrony to fully understand the factors influencing it, as well as how it can be utilised in a musical context.

Empirical contributions

While constructed upon existing evidence and relevant frameworks, the feedback loop model remains predominantly theoretical. Yet, before investigating the potential of a reciprocal relationship and its implications, crucial unidirectional aspects of the model necessitate additional exploration and empirical support. For this purpose, this doctoral research involves two empirical studies examining unidirectional facets of the synchrony-empathy relationship, which were identified as crucial after reviewing the existing literature in Paper 1 (Chapter 2).

The first empirical study (Paper 2, Chapter 3) sheds light on aspect [b] of the feedback loop model (Figure 1.1 of this chapter), investigating the role of trait empathy in modifying the social bonding effects of synchrony in adults. While earlier work has associated higher trait empathy with stronger bonding following synchronous musical interactions (Stupacher et al., 2022), the review in Paper 1 reveals that this aspect has only been explored in passive musical interactions where participants do not actively synchronise with a partner. In addition, the majority of relevant studies are fully quantitative, without exploring qualitative aspects of empathising and how individuals' conceptualisations, prior experiences and the musical context influence the bonding mechanisms of synchrony. Drawing from these knowledge gaps, Study 1 investigates the role of empathy in experiencing bonding with virtual partners after synchronising with them and examines potential distinctions between observed and actively performed synchrony (Sub-question 1a; see "Background,

aims and main research questions" section). By adopting a mixed-methods approach, the study also explores the impact of participants' social perceptions, the musical tempo and the sensory modalities involved in perceiving partners' rhythm on empathy's effects (Sub-question 2a). Examining these aspects is crucial, providing insights into what influences one's experience of interpersonal synchrony in musical interactions. The study also aims to inform interventions utilising musical tasks to foster social connections and empathy regarding potential individual differences in the experience of these effects.

The second study (Paper 3, Chapter 4) focuses on children's musical interactions, examining aspects [a], [c] and [d] of the feedback loop model (Figure 1.1) not previously explored in younger age groups. These aspects encompass both directions of the synchrony-empathy relationship in children, each explored independently within the same experimental design (Sub-questions 1b and 1c). Furthermore, the potential effects of induced empathy and the role of leading or following a musical interaction, as well as familiarity between partners and their gender, are also examined, addressing Sub-questions 2b and 2c. The study tackles a significant lack of developmental work on these aspects of the feedback loop, as identified earlier in Paper 1, informing us about the potential implications of the synchrony-empathy bidirectional relationship. Furthermore, a more holistic approach to empathy is undertaken here, exploring not only the effects of trait empathy but also its situational manifestations when experimentally induced. This aims to inform the timeframe requirements of the feedback loop, illuminating its potential situation-specific changes that support more cumulative effects following a prolonged practice of the synchrony-empathy interplay.

The two studies involve only musical novices, defined here as individuals with minimal formal musical experience, with short-term training completed at an earlier age, or people not classified by themselves as musicians. This aims to provide a clearer understanding of the fundamental dynamics between empathy and synchrony in the general population without the effects of musical proficiency (Timmers et al., 2020; Cho, 2019). Furthermore, the decision to conduct one study with adults and the other with children has been driven by multiple considerations. Firstly, a variety of methodologies are tested, providing a comprehensive exploration of how empathy and synchrony co-exist in musical interactions across diverse populations. This also offers a broader perspective on the manifestations of

the synchrony-empathy relationship at different stages in life. Moreover, as Study 1 was conducted during the COVID-19 pandemic, we opted for an online format involving adults due to the potential challenges associated with engaging children in online tasks. As restrictions eased, priority was given to an in-person study with children, enriching insight into the developmental aspects of the feedback loop model. Engaging children in face-to-face music-making has also enhanced the ecological validity of the study, providing a better understanding of their real-time musical interactions.

The sub-sections below present the two studies in more detail, discussing their findings and methodological contributions. Following this, all study outcomes are discussed in association with the positive feedback loop model in the final section of this chapter, thereby synthesising the theoretical and empirical contributions of this doctoral research.

Study 1: "Unravelling the effects of empathy on social bonding following interpersonal synchrony through music: A mixed-methods approach"

The study by Novembre and colleagues in 2019, which first explored the impact of empathy on interpersonal synchrony in adults, substantially informed the positive feedback loop model (Figure 1.1[a]) by demonstrating that empathy supports the predictive skills required to attain alignment with another person. Besides, a subsequent study a few years later revealed an additional dimension of empathy's impact; its role in modulating the social bonding effects of synchrony through music (Stupacher et al., 2022). An extensive array of studies, thus far, have shown that synchrony can significantly influence human behaviour in social interactions (Rabinowitch, 2023), with the effects ranging from positive outcomes like social bonding and togetherness (e.g. Hove & Risen, 2009) to negative aspects such as social conformity (Wiltermuth, 2012). To better understand these outcomes, Stupacher et al.'s study (2022) investigated how individual differences in experiencing such social effects in musical settings might be explained by trait empathy. Their study involved participants observing pairs of stick figures moving to music or a metronome and being prompted to envision themselves in these interactions while assessing their social closeness to stick figures representing unknown people. Results indicated that synchronous stick-figure interactions exhibited stronger closeness than asynchronous. However, individuals with high empathy experienced these effects more

profoundly in interactions accompanied by music, whereas participants with lower empathy reported heightened closeness in interactions featuring a metronome.

Stupacher et al.'s findings (2022) illuminated an additional aspect of the positive feedback loop (Figure 1.1[b]), indicating that trait empathy plays a role in how individuals bond through musical interactions involving synchrony. Nonetheless, the study focused exclusively on passive engagements with music, leaving the influence of empathy in interactions requiring active interaction with a partner largely unexplored. Moreover, the study results showed that the effects of empathy relied on the presence of background music. This implied that music might have served as an emotion-inducing mechanism, eliciting more compassion and, thereby, bonding in highly empathic individuals (Huron & Vuoskoski, 2020). However, the role of specific musical elements that induce valenced responses, such as the musical tempo (Gagnon & Peretz, 2003), and its interaction with trait empathy was not explored. Lastly, the vast majority of studies exploring the social bonding effects of synchrony tend to employ solely quantitative methods without further exploring the potential impact of participants' thought processes and subjective conceptualisations. Given the complexity of processes entailing motor and emotional alignment (Shamay-Tsoory et al., 2019), it is essential to qualitatively investigate participants' experiences during such experimental tasks, uncovering mentalising processes that might influence how synchrony encourages social bonding.

Building upon these research gaps, the first empirical study of the thesis (Paper 2, Chapter 3) employs a mixed-methods approach to extend the investigation by Stupacher et al. (2022) on the role of empathy in modulating the social effects of synchrony. More specifically, the study utilises two experimental tasks and post-experiment interviews to investigate the following sub-questions

- **Sub-question 1a**: *Does trait empathy moderate the social bonding effects of interpersonal synchrony in active and passive musical engagements with non-adaptive virtual partners?*
- **Sub-question 2a:** *How do the type of musical engagement (active or passive) and the sensory modalities involved in it, as well as the tempo of background music and individuals' social perceptions, influence this process?*

The tasks of this study explore the above in two distinct musical settings: a) a paradigm involving passive observations of stick-figure movements along music, akin to Stupacher et al. (2022),

and b) a tapping task inspired by sensorimotor synchronisation paradigms (Repp, 2005) modified to simulate interactions with non-present human partners. This setup aims to illuminate potential changes in empathy's effects a) when participants passively interact with audio-visual stimuli by observing and imagining themselves as part of the stick figures' walking interactions, and b) when they actively engage with auditory stimuli, thereby adjusting their tapping to align with a partner. Furthermore, the post-experiment interviews allow for an in-depth exploration of participants' thought processes during the tasks. Specifically, they aim to identify social perceptions and mental states that participants attributed to their virtual partners during their musical interactions and how these attributions influenced their bonding experience.

Following a comprehensive linear mixed-effects model and thematic analysis of participants' task and interview responses, our integrated results (Chapter 3) support Stupacher et al.'s findings (2022), demonstrating that trait empathy influences the intensity of social bonding evoked following synchrony with the partner. Notably, participants with higher trait empathy reported stronger social affiliation when aligned with a partner than those with lower empathy. Additionally, although not statistically significant, these effects appear to be modality-dependent, i.e. relying on how one engages in a musical interaction. Indeed, separate analyses of the tasks and participants' interview responses reveal that partners' behaviour was perceived and experienced differently in each task, eliciting different levels of social affiliation. Tempo also played an important role, with slower tempi amplifying disconnection evoked from not attaining synchrony and faster tempi impacting participants' arousal levels, encouraging positive perceptions of partners. Additionally, the degree of partners' asynchrony influenced how participants perceived them. In particular, small deviations from the expected beat encouraged positive mental attributions about partners that fostered a sense of affiliation even when synchrony was not achieved. Altogether, the study findings suggest that the bonding effects of synchrony are not solely stimulus-driven but result from a blend of bottom-up and top-down processes influenced by individuals' empathy, prior experiences and the musical context.

In addition to the main findings, the study has made some noteworthy methodological contributions to the topic. Firstly, the tasks include a range of experimental conditions, exhibiting different degrees of synchrony for participants to interact with. By manipulating partners' temporal

behaviour and exposing participants to four diverse synchrony conditions, the study examines affiliative responses beyond the binary alignment-misalignment paradigm usually employed in relevant studies (Repp, 2005). Furthermore, due to COVID-19 restrictions during data collection, the study was conducted entirely online. However, the experimental design was adjusted accordingly to maintain the social effects of empathy and synchrony without requiring the physical presence of partners (Harris & Cross, 2021; Basile et al., 2022; Gvirts et al., 2023). This resulted in an online and accessible tapping task that created the impression of interacting with another human without requiring participants' in-person attendance. Lastly, the study introduces a novel mixed-methods approach to this topic, unveiling aspects of the relationship between empathy, interpersonal synchrony and social bonding that were previously only theoretically implied (Tunçgenç, 2023). By employing such a method and leveraging a large sample size, the study not only provides important insights but also advocates for a broader adoption of this methodology within the field of synchronisation studies.

Study 2: "Actions and feelings in sync: Exploring the reciprocal relationship between synchrony and empathy in children's dyadic musical interactions"

The second empirical study (Paper 3 in Chapter 4) turns to children's musical interactions, informing the developmental aspects of the positive feedback loop. Prior studies have primarily focused on the effects of synchrony and musical interactions on children's social behaviour and skills, with results indicating a positive impact on affective empathy (Rabinowitch et al., 2013), perceived similarity (Rabinowitch & Knafo-Noam, 2015) and prosocial behaviour (Cirelli et al., 2014; Kirschner & Tomasello, 2010). While such research is vital for its substantial implications, the reverse direction of those effects, i.e. the impact of social behaviour and personality traits on attaining synchrony in music-making activities, is often overlooked. In addition, individual differences in the experience of synchrony's social effects attributed to personality traits such as empathy (Stupacher et al., 2022; Tzanaki et al., 2024a) have not been investigated in children.

For these purposes, this study builds upon existing paradigms and evidence from studies involving adults to examine three building blocks of the synchrony-empathy feedback loop in children's dyadic interactions. Through an age-appropriate experimental design involving two tasks that resemble naturalistic music-making activities, the study explores the following aspects and research questions:

- **Aspect 1: The effects of trait empathy on children's interpersonal synchrony (Figure 1.1[d]):** *Does trait empathy facilitate interpersonal synchrony in children's dyadic musical interactions? (Sub-question 1b)*
- **Aspect 2: The effects of synchrony on children's social bonding and state empathy following brief musical interactions (Figure 1.1[b]):** *Can synchrony enhance children's social closeness, perceived similarity and state empathy in brief musical interactions? Sub-question 1c)*
- **Aspect 3: The role of trait and induced empathy in children's experience of social bonding following synchrony (Figure 1.1[e], [c]):** *Does trait or induced empathy influence the social bonding effects of interpersonal synchrony in children? (Sub-question 2c)*

The research was conducted in Greece, leveraging the candidate's teaching background and network connections with primary schools in the country, which facilitated a large sample size. One hundred and forty-four children aged between 10 and 12 from five primary schools were recruited to undertake the two musical tasks in pairs. The experimental design allowed the exploration of multiple directions of the synchrony-empathy feedback loop within a single study, reducing participant fatigue and minimising time demands on children's school commitments.

Focusing on the study tasks, the first replicated elements of Novembre et al.'s research (2019) to explore Aspect 1, i.e. the impact of trait empathy on children's ability to synchronise with a partner, an aspect not previously explored in young musical novices. The task involved dyads of children playing rhythmically on claves and synchronising their actions while singing a well-known children's song. In addition to empathy's effects, the study also investigated how leadership roles, i.e. being asked to lead or follow the musical interaction, as well as familiarity among partners and their gender, influence empathy's impact (Sub-question 2b). Certain aspects of Novembre et al.'s experiment have been adjusted here (Table 1.1), providing an age-appropriate task with higher ecological validity (D'Ausilio et al., 2015) and lower experimental control than in the original study. These adaptations mainly concern the inclusion of mixed-empathy pairs, face-to-face interactions, and a holistic approach to empathy, incorporating the investigation of affective and somatic empathy. The results (Chapter 4) indicate that similarly to adults, highly empathic children synchronised better than those with lower

empathy, especially in interactions where pairs' tapping was more unstable. Although an interaction between empathy and leadership roles was not found, as observed by Novembre et al. (2019), pairs' synchrony was found to be gender-dependent, with pairs of female participants performing better than male-male or mixed-gender pairs. Turning now to the second task, children participated in two-minute-long musical interactions examining the reverse direction of the synchrony-empathy relationship (Aspects 2 and 3). The task involved children listening to music via headphones and tapping along while looking at each other. For half of the participants, synchrony and empathy were experimentally manipulated to assess their impact on children's bonding and state empathy following the task. Synchrony was manipulated by changing the music tempo within pairs, while empathy was induced via a verbal message describing an unfortunate situation about partners. The results indicate that musical interactions encouraged social affiliation within pairs, with highly empathic children providing higher ratings than those with lower empathy. Contrary to the initial hypotheses, synchrony and empathy manipulation did not differentiate children's social bonding ratings, as participants across all experimental groups experienced higher social affiliation following the task than before. However, children in the synchronous condition reported experiencing higher state empathy, suggesting that synchrony facilitated understanding and mentalising between children even within a brief musical interaction. Furthermore, pairs with pre-existing familiarity provided higher bonding and state empathy ratings, indicating a mediating role of previous acquaintances in this process.

Table 1.1

Differences between Novembre et al.'s study (2019) and Task 1 and the rationale for these changes.

	Approach in Novembre et al. (2019)	Approach in Paper 3 (Tzanaki et al., 2024b; in preparation)	Rationale for this adaptation
1	The study involved adult musical novices.	The study involved child musical novices.	The research aim was to investigate the effects of trait empathy on children's synchrony, an aspect not previously explored.
2	Sample size: 58 adults, forming 29 pairs.	Sample size: 144 children, forming 72 pairs.	An a priori power analysis suggested a sample size of 109 participants for medium effect sizes (f2= .15) at a significance level (α) of .05 and 80% power (1-β).
3	The Interpersonal Reactivity Index (IRI; Davis, 1980) was used, focusing particularly on empathic perspective-taking.	The CASES questionnaire (Raine & Chen, 2018) explored the effects of cognitive, affective and somatic empathy.	The study opted for a holistic approach to trait empathy. Somatic empathy was added due to its association with motor simulation of others' actions and emotions.

4	Participants were paired with partners sharing a similar level of empathy. Two groups were then created, one with pairs of high empathy and one with pairs of low empathy.	Participants were randomly allocated to pairs. The only restriction was that they should be from different classrooms, minimising prior social interactions.	The design offered a more realistic approach to investigating the effects of empathy, minimising experimental control. As a result, a different statistical method was used.
5	Participants completed 64 trials in total.	Participants completed nine trials in total.	A larger sample size allowed for fewer trials, minimising participant fatigue.
6	Participants used E-music boxes (Novembre et al., 2015), transforming rotational movements into pre-programmed musical melodies.	Participants used claves and performed rhythmically (like tapping) while singing a song. They were encouraged to imagine themselves performing in a band.	The design sought to resemble naturalistic face-to-face music-making activities with percussion instruments.
7	A metronome at the beginning of each trial helped participants to initiate their musical interaction.	Children could communicate non-verbally to begin the trial without further input from the experimenter. Children were free to play at any tempo and their tapping's periodicity was calculated to account for any effects on synchrony.	This aspect aimed to increase ecological validity and reduce experimental control. The design sought to resemble more naturalistic, face-to-face music-making activities between children.
8	Participants of each pair were in separate rooms, relying only on auditory stimuli from their partners.	Participants engaged in face-to-face musical interactions, singing and performing together while looking at each other.	Again, this approach aimed to enhance the sense of more naturalistic music-making activities.
9	High- and low-pitched music was employed to aid participants in distinguishing between their own and others' performances.	Participants could discern their own performance from that of their partners' by observing their hands.	This adaptation, again, relates to the experimental design, which aims to resemble in-person music-making activities between children.
10	Participants maintained the same leadership roles within each block of trials.	Children completed three trials with no leadership roles and six trials while alternating roles.	This approach aimed to maintain participants' interest and minimise practice effects.

Although some of the study hypotheses were not fully supported, the current investigation has made some valuable contributions to the topic with regard to how empathy is approached. More specifically, empathy is viewed here as a multifaceted construct, entailing both trait and situational manifestations (Preston & Hofelich, 2012). Indeed, while individuals develop a certain level of trait empathy through social interactions, each event relies on a series of appraisal processes determining the extent of one's empathy in a specific situation (Decety & Lamm, 2006). This allows researchers to experimentally manipulate empathy (Miu & Baltes, 2012; O'Neil & Egermann, 2020) and examine its impact when empathy is induced or obstructed. The study here harnesses these dimensions to offer a comprehensive representation of empathy's effects and its interaction with synchrony, enriching the

model of their bidirectional relationship. Although the experimental manipulation applied did not differentiate children's bonding when interacted musically in Task 2, the study advocates for adopting similar multifaceted approaches in future research, acknowledging empathy's susceptibility to the context of an interaction and the people involved.

Finally, trait empathy is explored here through three manifestations (cognitive, affective, and somatic), an approach generally not adopted in this topic. Cognitive and affective empathy have garnered considerable attention in music psychology, whereas somatic empathy - the automatic bodily responses to one's actions or emotions (Raine & Chen, 2018) - has not been previously explored in this topic. Although the outcomes did not indicate an impact of somatic empathy, investigating this aspect introduces new exploratory avenues, especially in relation to motor representations involved in both synchrony and empathy (Fairhurst et al., 2013; Gallese, 2003). Additionally, the exploration of these three empathic facets, coupled with the study being conducted in Greece, necessitated the translation of an English self-reported questionnaire into Greek (CASES; Raine & Chen, 2018). This endeavour has yielded the development of a new tool for empathy-related research in Greek-speaking populations, enabling future cross-cultural investigations. Further information about this questionnaire and the process followed to translate and validate it can be found in the research report in Chapter 5.

Conclusion

This doctoral research has studied empathy and interpersonal synchrony as reciprocal processes in musical interactions involving adult and child musical novices. The thesis has unveiled new perspectives on the synchrony-empathy relationship, paving the way for future studies directly addressing the bidirectionality of this relationship. Revisiting the main research questions, Paper 1 (Chapter 2) has proposed a theoretical framework to address Research Question 1, supporting a positive feedback loop between synchronising and empathising in musical interactions. Through a continuous practice of temporal and emotional alignment with others and under appropriate circumstances (Research Question 2), a skill transfer between empathy and synchrony can enable the simultaneous and reciprocal enhancement of musical and social skills (Research Question 3). Along with emphasising important knowledge gaps and exploratory avenues, Paper 1 has provided a guide for future investigations seeking to empirically support the framework, examine the factors facilitating or

hindering the loop and test its implications. In addition to the research gaps highlighted by Paper 1 and addressed by the empirical studies, it is recommended that future research investigates further a) the role of affective empathy in its cognitive aspects supporting temporal and emotional alignment during musical interactions, b) the mechanisms underlying a skill transfer in this context, and c) the extent of this transfer in practical terms, examining a potential expansion beyond the musical context.

Turning now to Papers 2 and 3 (Chapters 3 and 4), the studies have contributed significantly to important sub-questions of Research Question 1, revealing that trait empathy supports interpersonal synchrony in children and influences the experience of social bonding stemming from synchrony in both adult and children's musical interactions. In addition, brief synchronous interactions were found to encourage state empathy in children, encouraging mentalising and attention to others' temporal movements. Further to these observations, the studies have identified some factors influencing these effects, suggesting that these could potentially impact the functioning of the feedback loop (Research Question 2). Specifically, Paper 2 revealed that the social outcomes of synchrony might be influenced by the sensory modalities involved in perceiving partners' temporal behaviour, the musical tempo, and characteristics attributed to partners based on their performance or participants' prior experiences. In addition, Paper 3 indicated that temporal regularity, familiarity between children and their gender influenced empathy's effects on attaining interpersonal synchrony or the role of synchrony in encouraging social bonding and state empathy.

The above factors resonate with prior studies on individual characteristics and relationships impacting empathy and synchrony (e.g. Miles et al., 2010; Singer, 2009; Keller et al., 2014), suggesting that they might support or obstruct the positive feedback loop (Research Question 2). For instance, it is plausible that familiarity between partners would encourage emotional alignment, facilitating a seamless loop operation. However, strong leadership traits or prior negative experiences with outgroup members might prompt mental attributions that amplify social disconnection, disrupting the loop (Shamay-Tsoory et al., 2019; Tzanaki, 2022). Nonetheless, as highlighted in Paper 1, practising the synchrony-empathy bidirectional relationship in a musical context has the potential to foster strong social connections, transcending such intergroup barriers. In other words, the continuous practice of the

feedback loop may foster perceived similarity and social connections, mitigating the adverse effects of factors negatively impacting empathy and synchrony when practised separately.

As previously stated, the empirical studies in Papers 2 and 3 focused on sub-questions of Research Questions 1 and 2 and not Question 3 concerning the implications of the feedback loop. This choice was made because the primary focus was investigating previously unexplored aspects of the synchrony-empathy relationship. Nonetheless, Paper 1 provides an in-depth discussion of the use of the model in supporting children's simultaneous musical and social development, as well as overcoming social disconnection among intergroup members. In addition, adopting mixed-methods research and utilising naturalistic experiments for children can inform the methodology of future investigations testing the implications of the loop in musical contexts. The thesis has also laid the groundwork for a prospective longitudinal study directly investigating the feedback loop process as a musical intervention and its long-term effects. The study could implement a pretest-posttest musical programme with repeated assessments of empathy and synchrony at various intervals over time. The programme could involve exercises encouraging temporal and emotional alignment between partners, facilitating attention, anticipation and adaptation to each other's actions and feelings (Keller, 2014; Cross et al., 2012). Additionally, by assigning individuals with different levels of empathy to separate groups and comparing the musical intervention with alternative forms of social engagement (as in Rabinowitch et al., 2013), researchers could gain further insights into the rate of changes and the specific contribution of music to these effects. Leveraging the findings from Study 2, which illuminated multiple aspects of the synchrony-empathy relationship, this longitudinal investigation could be conducted with primary school children, given the potential implications of the loop on their musical and social development. Finally, incorporating qualitative and quantitative explorations of participants' experiences could also inform us about the mechanisms facilitating the loop and the factors encouraging or disrupting its functioning.

The relationship between empathy and synchrony within musical contexts presents a promising avenue for understanding the interplay between musical and social behaviour. It is hoped that this doctoral research will inspire future investigations to opt for mixed-methods approaches and the use of naturalistic experimental designs to examine in-depth the social dynamics of musical interactions in the

general population. The present work also aspires to spark curiosity and encourage more investigations of potential bidirectional relationships within social and musical interactions, departing from solely examining unidirectional effects. Such an approach could uncover additional components of social cognition that also exhibit a reciprocal association with musical skills, thereby advancing our understanding of musical engagement and its significance in human lives.

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CHAPTER 2

Theoretical Paper: "The positive feedback loop of empathy and interpersonal synchronisation: Discussing a theoretical model and its implications for musical and social development." (Paper 1)

The paper has been published as:

Tzanaki, P. (2022). The positive feedback loop of empathy and interpersonal synchronisation: Discussing a theoretical model and its implications for musical and social development. *Music & Science*, 5. https://doi.org/10.1177/20592043221142715

Candidate's contribution:

The candidate developed the framework, conducted the literature review and composed the paper. The word "synchronisation" is used below as an alternative to the term "synchrony" used elsewhere in this thesis.

Abstract

The positive prosocial outcomes deriving from interpersonal synchronisation, as well as the contribution of social skills in attaining synchronisation with others in musical group interactions, are commonly explored independently, overlooking the possibility of a simultaneous bidirectional relationship between musical and social behaviour. This article focuses on the relationship between empathy and interpersonal synchronisation, critically reviewing each directionality of this intriguing link, namely, how empathy contributes to the socio-cognitive skills required to achieve synchronisation with others and how this synchronised interaction lays the groundwork for the development of empathy. Following this review and building upon relevant research in music and social psychology, a theoretical framework is proposed, arguing that during musical group interactions, empathy and interpersonal synchronisation create a positive feedback loop, enhancing one another in a reciprocal and simultaneous manner. The circumstances that encourage or obstruct this feedback loop, as well as its significant implications, are discussed. Finally, the present work highlights the importance of switching the research focus from unilateral to bidirectional relationships to gain a deeper understanding of the interrelation between musical and social behaviour.

Keywords: empathy; interpersonal synchronisation; feedback loop; musical development; musical interaction; social bonding; social development

Introduction

Musical group interaction, an immensely social activity that involves joint music-making by two or more individuals, requires the ongoing alignment of intentions and actions in order to accomplish shared musical goals. As a fundamental aligning process of musical interactions, interpersonal synchronisation necessitates continual observation and subsequent adaptation to another's rhythmic actions, with the aim of achieving precise motor alignment (Keller, 2014; MacRitchie et al., 2017). These socio-cognitive processes of interpersonal synchronisation present strong similarities to the cognitive processes of empathy, a social skill involving attention to, resonating and responding to others' emotions and thoughts, thereby leading to cognitive and emotional alignment (Rabinowitch, 2017). Indeed, research has revealed a relationship between the processes of empathising and synchronising between individuals, with cognitive empathy facilitating interpersonal synchronisation, and synchronisation contributing to the role of musical group interactions in fostering empathy (Novembre et al., 2019; Rabinowitch et al., 2013). Although these parallels imply a possible bidirectional relationship between empathy and interpersonal synchronisation, this notion has been neither theoretically nor empirically explored. Hence, possible significant musical and social implications of this reciprocal relationship may have been overlooked.

The present theoretical article begins with a brief contextualisation of interpersonal synchronisation and empathy, highlighting important aspects that will contribute to the upcoming discussion of the concept of empathy-synchronisation interplay. A critical review of each directionality of the empathy-synchronisation link will follow, outlining the mechanisms underlying these processes and drawing attention to some significant knowledge gaps that require further investigation. A theoretical framework is subsequently proposed, examining the conditions under which empathy and interpersonal synchronisation enhance one another in a reciprocal and simultaneous manner, thereby creating a positive feedback loop. Following that, a discussion of how this reciprocal relationship can be empirically approached will take place, along with proposals for potential next steps and exploratory avenues for future research. Finally, the implications of this feedback loop are examined with regard to how musical interventions might utilise this reciprocal relationship to overcome group membership barriers. In addition, given the significant role of early musical and social interactions in the

development of synchronisation and social skills respectively (Phillips-Silver & Keller, 2012; Levy & Feldman, 2019), the present article will also discuss how this positive feedback loop could facilitate the simultaneous development of musical and social skills in children's musical group interactions.

Contextualising interpersonal synchronisation and empathy

Interpersonal synchronisation as a social bonding mechanism

Interpersonal synchronisation, the temporal alignment of movements between two or more individuals, is an integral part of joint musical activities, requiring continuous monitoring and adapting to others' subsequent rhythmic actions (Keller et al., 2014). This complex process has attracted significant research interest in social and music psychology due to its capacity to foster prosocial behaviour and group cohesion (Rennung & Göritz, 2016; Vicaria & Dickens, 2016). This section will integrate knowledge from studies using overlapping and often interchangeable terms to describe this phenomenon, namely interpersonal entrainment (Clayton et al., 2020), coordination (Keller et al., 2014), synchrony (Cirelli et al., 2018) and temporal and affective entrainment (Phillips-Silver et al., 2012), in order to illuminate aspects contributing to its connection with social behaviour. Here, "interpersonal synchronisation" will be used as an umbrella term throughout the present article, with other terms such as coordination and synchrony being used as synonyms.

Building on previous research, Keller (2008, 2014) proposed that attaining precise interpersonal synchronisation in a musical group requires three fundamental cognitive-motor skills: a) attention, referring to monitoring one's own and others' rhythmic movements; b) anticipation, relating to the prediction of others' upcoming actions; and c) adaptation, characterised by timing variations that co-performers apply to mutually adjust to their partners' music. Behavioural and neuroscience research investigating the mechanisms underpinning these skills has indicated a significant role of perception-action coupling and motor (or action) simulation in this process (Novembre & Keller, 2014). Similarly to other social interactions, a shared neural network responsible for perceiving and producing an action (perception-action coupling; Keller et al., 2014) activates motor representations of observed actions as if they were produced by the observer (Gallese, 2019). This simulation process provides information about others' actions in the brain, contributing to the integration of self- and other-generated actions

(Novembre et al., 2012). This process, therefore, enables co-performers to create accurate temporal predictions and synchronise with their partners' performance (Novembre et al., 2014).

In addition to the aforementioned cognitive-motor skills, establishing interpersonal synchronisation requires a shared understanding of the musical performance (Clayton et al., 2020), active collaboration and shared intentionality to produce an aligned musical goal (Reddish et al., 2013). It also calls for flexibility in perceiving and responding not only to others' rhythmic actions but also to their emotional states (Cross et al., 2012). These essential processes emphasise the importance of considering interpersonal synchronisation as a multi-level social phenomenon, significantly influenced by its social context and the communication between the interacting members (Clayton et al., 2020; Kirschner & Tomasello, 2009). For example, when assigned to lead a musical interaction, participants tend to reduce their timing variations, thereby increasing musical predictability for their followers (Novembre et al., 2019). In addition, spontaneous interpersonal synchronisation has been shown to decrease when individuals are asked to interact with a partner who has arrived late (Miles et al., 2010). Social dispositions such as prosocial orientation also seem to affect performers' coordination capacities (Lumsden et al., 2012) and, as will be discussed in the following sections, trait empathy also plays a significant modulatory role in this process (Novembre et al., 2019).

Turning now to the social consequences of interpersonal synchronisation, this topic has attracted considerable research attention due to its significant social and educational implications. Moving, tapping or playing music in synchrony with others encourages group cohesion (Vicaria & Dickens, 2016) and prosocial behaviour (Mogan et al., 2017; Rennung & Göritz, 2016), even at an early age when motor coordination abilities have yet to develop (Trainor & Cirelli, 2015; Cirelli et al., 2014). A few examples of the positive social outcomes of interpersonal synchronisation in adult and children's joint musical and non-musical actions are increased cooperation (Wiltermuth & Heath, 2009), feelings of closeness (Stupacher et al., 2017), enhanced affiliation (Hove & Risen, 2009) and increased perceived similarity (Rabinowitch & Knafo-Noam, 2015). Interpersonal synchronisation may also have the capacity to bridge intergroup boundaries (Miles et al., 2011; Reddish et al., 2016), contributing to interventions aimed at mitigating intergroup biases (Tunçgenç & Cohen, 2016).

Regarding how these positive social outcomes emerge, Tarr and colleagues (2014) argue that synchronisation's ability to blur the line between self and other, combined with the release of endorphins during exertive joint actions, might explain the social bonding effects of interpersonal synchronisation. Furthermore, Phillips-Silver and Keller (2012) point out that emotion-sharing and affective entrainment during a joint musical action create strong bonds, laying the foundation for the development of both musical skills and prosocial behaviour. The latter mechanism will be further discussed in the following sections, elucidating how synchronisation may also enhance empathy (Rabinowitch et al., 2013; Koehne et al., 2016a). Before moving on to that discussion, however, it is essential to highlight some key aspects of empathy that will later contribute to our understanding of its relationship with interpersonal synchronisation.

The complex phenomenon of empathy

Despite the numerous definitions and debates about its manifestations and underlying systems, empathy is recognised as a fundamental component of social interactions (Singer, 2009), and practising empathy with others can result in ample prosocial and educational outcomes (Feshbach & Feshbach, 2009). Some key aspects of the cognitive and affective processes, underlying mechanisms, and dispositional and situative manifestations of empathy will be introduced below, providing an informative context for the upcoming discussion of the links between empathy and interpersonal synchronisation.

Empathy refers to both the affective and cognitive processes of sharing and understanding others' emotions and thoughts. Affective (or emotional) empathy enables a level of self-other overlap through a bottom-up process (Preston & Hofelich, 2012), allowing an individual to share the same emotions observed in another person (Singer & Lamm, 2009). Although the term affective empathy often overlaps with sympathy or compassion, the latter states are considered altruistic responses to someone's emotions, stemming from a preceding process of empathising (Eisenberg & Eggum, 2009). Regarding cognitive empathy, this concept is often presented as a synonym for perspective-taking, mentalising and theory of mind (Stietz et al., 2019) and involves the activation of representations of others' mental states through a top-down process. Namely, the empathiser consciously suppresses their own perspective (Davis, 2015) in order to understand the perceptions and feelings of another (de Waal

& Preston, 2017). Furthermore, during empathising, it is crucial for individuals to maintain a clear distinction between self- and other-generated emotions, as losing oneself in another's feelings might result in emotional distress (Decety & Lamm, 2006). This latter characteristic of empathy also differentiates it from emotional contagion, the automatic process of "catching" others' emotional states (Hatfield et al., 2009).

Considering the mechanisms underpinning empathy, a similar perception-action coupling that was earlier discussed in the context of interpersonal synchronisation also seems to play a fundamental role in empathy. According to the perception-action model of empathy (PAM), proposed by Preston and de Waal (2002), observing or imagining the emotional expressions and behaviour of others activates automatic representations of similar states, allowing the empathiser to experience the same emotions as the empathic target. This indicates that a perception-action mechanism allows individuals to understand not only others' motor actions (as in the case of interpersonal synchronisation) but also their feelings (Singer, 2009). In addition to this process, de Waal (2007; 2008) argues that higher cognitive levels of empathy may be built upon automatic and affective empathic processes that rely on this core mechanism of perception-action coupling (the Russian Doll model). This implies that understanding another individual's thoughts (cognitive empathy) requires a preceding level of emotional engagement with them (affective empathy), which allows empathisers to consider and actively help their empathic targets (de Waal & Preston, 2017; de Waal, 2007). In the upcoming discussion of the empathy-synchronisation feedback loop, the role of perception-action coupling, which may lay at the core of this reciprocal relationship, will be further considered.

Focusing now on the neural substrates of empathy, its cognitive and affective processes seem to rely on separate but interacting brain areas (Dvash & Shamay-Tsoory, 2014). While brain networks associated with affective empathy activate representations of others' emotional states in a bottom-up fashion, cognitive and top-down processes provide content and meaning to these representations, allowing individuals to imagine others' emotions and thoughts based on their own previous experiences (de Waal & Preston, 2017). In the last few decades, there has been significant research interest in the role of the mirror neuron system (MNS) in empathy. These neurons, activated when an action is observed or executed, are proposed to also support the simulation of others' emotional states (Iacoboni,

2009). Gallese (2003) argues that the MNS creates embodied representations of others' intentions and actions, therefore enabling individuals to perceive others as similar to themselves and laying the groundwork for intersubjectivity, the process of aligning one's own mental states with others' (Iacoboni, 2009). The MNS has also been proposed to facilitate the experience of affect in music listening. Molnar-Szakacs and Overy (2006) assert that individuals perceive music as a sequence of actions behind the musical signal, and the MNS contributes to representing and attributing affect to these actions. The mirror neurons, therefore, play a key role in linking perceived actions with emotional states, subsequently creating an emotional response to the music (Overy & Molnar-Szakacs, 2009).

A further important aspect of empathy requiring consideration concerns its manifestations. Empathy is often approached as a disposition (referred to as dispositional or trait empathy), with researchers often assessing intrapersonal differences within the population using self-reported questionnaires (Singer, 2009). As a personality trait, empathy presents gender and age differences, with women, for example, scoring higher than men on empathy questionnaires (Schulte-Rüther et al., 2008) and cognitive empathy declining with age (Stietz et al., 2019). There are, however, plenty of contextual or situational factors, such as the relationship between an empathiser and their empathic target, that might modulate an empathic response, hence indicating a more situation-specific manifestation of empathy (also referred to as situational empathy - de Vignemont & Singer, 2006; Davis, 2015). Individuals, for example, tend to empathise better with familiar than unfamiliar others, such as family members and friends (Preston & de Waal, 2002), as well as those they perceive as similar and whom they can identify with (de Vignemont & Singer, 2006). This latter tendency is evident in research examining correlations between empathy and group membership (Cikara et al., 2011), as it has been reported that empathy is more likely to lead to helping behaviour when the helper and target belong to the same cultural group (Stürmer et al., 2006). Altogether, these findings suggest that individuals appraise a given situation (Lamm et al., 2007) and exhibit empathy that does not only correspond to their empathic disposition but also depends on the context and the people involved in it (de Vignemont & Singer, 2006).

The aforementioned manifestations indicate that empathy is a flexible process that can be induced, experimentally manipulated and subsequently changed through practice (Allemand et al.,

2015), leading to significant educational implications that, for example, contribute to children's moral development (Feshbach & Feshbach, 2009; Eisenberg et al., 2010). From a developmental perspective, precursors of empathy can be found in infancy (Zahn-Waxler & Radke-Yarrow, 1990; Cadinu & Kiesner, 2000), but empathy is thought to remain malleable throughout the lifespan (Stietz et al., 2019). Nonetheless, with childhood and adolescence being significant periods for fostering empathy (Allemand et al., 2015), research has utilised empathy's flexibility to design and apply interventions that encourage empathy-building and foster prosocial behaviour (Eisenberg et al., 2010). These interventions utilise techniques, such as storytelling, dialogues and conflict resolution (Batson & Ahmad, 2009), to induce empathy by encouraging individuals to adopt others' perspectives intentionally (Davis, 2015). Such interventions (e.g. Roots of Empathy by Gordon and Fullan, 2008; Connolly et al., 2018) have been found to promote helping behaviour, reduce aggression and even improve attitudes toward outgroup members (Batson & Ahmad, 2009). As will be discussed in the following section, music-making and synchronisation may also have the capacity to modulate empathy, again potentially contributing to children's moral development (Rabinowitch, 2017).

The relationship between empathy and interpersonal synchronisation

In the following sections, each directionality of the relationship between empathy and interpersonal synchronisation is separately reviewed, and research exploring a variety of coordinated rhythmic behaviours, ranging from mother-infant synchronous interactions to interpersonal coordination in musical groups, is discussed. These sections aim to provide insights into the mechanisms that underlie the processes of empathising and synchronising with others, highlighting significant knowledge gaps that require further investigation. This will subsequently illuminate the theoretical model of empathy and interpersonal synchronisation that is proposed and analysed in the final section of the present article.

Direction 1: The effect of interpersonal synchronisation on empathy

Early-life synchronous interactions between parents and infants appear to play a significant role in the development of empathy. After monitoring children from the age of one to thirteen years old, Feldman (2007) found strong associations between mother-infant synchrony and empathy, suggesting that children's early experiences of synchrony can predict higher empathy in adolescence. Adopting a

similar longitudinal approach, Levy and colleagues (2019) showed that mother-infant synchrony in the first decade of a child's life helps in the neural maturation of the empathy mechanisms required for responding to others' distress (Levy & Feldman, 2019). These findings suggest that early synchronous interactions contribute to the plasticity of the empathic brain, paving the way for the development of social cognition.

Regarding the impact of synchronisation on empathy, also later in childhood, Rabinowitch et al. (2013) investigated the possibility of synchronous musical interactions enhancing empathy among primary school children. It was found that a nine-month-long music programme incorporating elements of movement, imitation and synchronisation enhanced children's affective trait empathy. Although the specific effects of interpersonal synchrony on empathy were not investigated, synchronisation is considered a fundamental component of musical group interactions, enabling the practice of empathising with others (Cross et al., 2012). Indeed, during joint musical actions, the members of a group engage in a series of cognitive and affective processes, such as imitation, synchronisation and shared intentionality (Cross et al., 2012), which allow them to experience a sense of intersubjectivity, defined here by Rabinowitch et al. (2011) as "a fluid sharing of intentions, emotions and cognitive processes" (p. 111). Joint music-making, therefore, entails the practice of aligning one's own emotions with others', fostering empathy in the long term (Cross et al., 2012), with interpersonal synchronisation contributing to this process by enabling emotion-sharing (Phillips-Silver & Keller, 2012) and self-other merging (Tarr et al., 2014). Nonetheless, to what extent interpersonal synchronisation alone gives rise to the enhancement of affective empathy-building and what conditions may facilitate this role have yet to be found.

Shifting the focus away from affective empathy, Baimel et al. (2015) argue that synchronisation engenders social cohesion and cooperation by enabling people to infer and reason about the mental states of others, hence fostering cognitive empathy. In order to explore this argument, the authors implemented a musical task with groups of participants rhythmically moving a cup while listening through headphones to a song at the same or different tempi from one another (Baimel et al., 2018). They found that, when synchronised, participants exhibited an increased tendency to consider the mental states of others; however, synchronisation did not enhance affective empathy. These results

imply that interpersonal synchronisation might mediate situational cognitive empathy, but it may require a longer period of synchronised interaction to bring about changes in affective trait empathy, as observed in the music programme by Rabinowitch et al. (2013). What remains unknown and warrants further investigation is whether interpersonal synchronisation can facilitate situation-specific *affective* empathy and foster *cognitive* trait empathy in the long term.

Further support for the role of synchronisation in facilitating access to others' mental states can be found in research involving people with autism spectrum disorder (ASD). In a study by Koehne et al. (2016a), participants with ASD and neurotypical individuals engaged in a Morse code task, undertaking either the role of the leader or the follower in a series of light signal exchanges. Leaders were asked to send sequences of light signals to their partners, with followers responding to light signals with finger-taps. In reality, all returning light signals were generated by a computer, manipulating the degree of synchrony. After every round, situational empathy was measured, with participants rating how much they understood the thoughts of their partners and shared their feelings. The results indicated that, when being followed by a synchronous partner, neurotypical leaders experienced higher situational cognitive empathy toward that partner than those with lower empathy, feeling like they could better understand their thoughts. Individuals with ASD, however, did not exhibit changes in cognitive empathy despite being able to detect differences in their partner's synchronisation. Nonetheless, ASD participants with higher dispositional cognitive empathy were better able to synchronise with a partner than those with low empathy. These results indicate that synchronising with a partner may lay the groundwork for tuning into their mental states, and the link between empathy and interpersonal synchronisation may not be fully absent in people with ASD (Koehne et al., 2016a).

A further research field recognising the contribution of interpersonal synchronisation to empathy enhancement is dance and movement therapy (DMT). DMT interventions often incorporate coordinated movements and imitation to strengthen the bond between client and practitioner and enhance empathy (Behrends et al., 2012). Empathy, in this context, is often referred to as kinaesthetic, highlighting the embodied nature of simulating and understanding others' mental and emotional states (Gallese, 2009; Praszkier, 2016). Based on existing DMT practices, Behrends et al. (2012) have proposed that the continuous practice of interpersonal synchronisation, along with imitation and

cooperation, can modify the embodied representations of others' motor actions, enhancing kinaesthetic and subsequently cognitive and affective empathy, which rely on the same perception-action mechanism for representing others' emotional states (Preston & de Waal, 2002). Indeed, in a survey with music students, Cho (2019) observed that those with ample experience in practising synchronisation in music groups in childhood reported higher levels of trait empathy in early adulthood. What remains unclear, however, is the extent to which interpersonal synchronisation relies on imitation and mimicry to positively affect empathy and whether the temporal aspects of synchronisation, i.e. being simultaneously "in time" with each other, contribute equally to this process (Phillips-Silver & Keller, 2012).

The evidence reviewed in this section suggests that interpersonal synchronisation may have the capacity to mediate and foster empathy; however, further work is required to clarify the exact role of synchronisation in this process. As highlighted above, future research is needed to determine whether interpersonal synchronisation can function as an independent mechanism for fostering empathy. To date, synchronisation has only been explored as a component of joint actions, interacting with and supporting other cognitive and affective processes occurring at the same time (Cross et al., 2012; Rabinowitch et al., 2013; Behrends et al., 2012). Future studies might explore whether mutual adaptivity, anticipation and awareness of one another, all of which are components of intentional synchronised actions (Keller et al., 2014), are sufficient to trigger changes in the capacity to empathise with others. It may be found, however, that interpersonal synchronisation requires a shared understanding of group goals and cooperation to achieve them in order to motivate empathic processes (Reddish et al., 2013; Clayton et al., 2020; Harris & Cross, 2021). What should also be established is a timeframe required for a synchronised interaction to have a measurable impact on empathy. The prolonged practice of synchronisation in groups has been found to positively impact trait empathy later in life (Cho, 2019; Koehne et al., 2016b). However, the influence of shorter programmes remains unclear. For example, although Rabinowitch et al. (2013) found a difference in emotional empathy following a nine-month-long music programme, Cespedes-Guevara and Dibben (2021) did not observe any significant changes after a year of musical training in children. Identifying a timeframe will

illuminate the implications of synchronisation in education and therapy and further elucidate its effectiveness in developing social skills and strengthening group cohesion (Mogan et al., 2017).

Another aspect requiring further investigation is the role of interpersonal synchronisation in triggering changes in situational empathy. It is recommended to further investigate state-specific changes in affective empathy following synchronous interactions, as this could shed light on the possibility of affective empathy mediating people's willingness to tune into others' mental states (de Waal & Preston, 2017). Moreover, it would be interesting to examine whether the positive effects of synchronisation on empathy can be generalised toward people who are not part of the synchronous interaction. Relevant research with adult participants has shown that following a synchronous interaction, the prosocial effects can indeed be generalised to non-interactive members (Reddish et al., 2014), but this seems not to be the case in infants (Cirelli et al., 2014), indicating an age difference in the use of synchrony to direct prosociality. Future work in exploring the generalised effects of synchronisation on empathy would help us to further understand the mediating role of interpersonal synchrony in social interactions and behaviour.

Direction 2: The impact of empathy on interpersonal synchronisation

In the last decade, research in music psychology and neuroscience has sought to explore the inverse directionality of the synchronisation-empathy link, namely, how empathy affects the ability to synchronise with others. This research interest might stem from the realisation that perception-action coupling supports both interpersonal synchronisation (Novembre & Keller, 2014) and empathic processes (Preston & de Waal, 2002; Gallese, 2009). In addition, the existing body of research suggests that a range of social-psychological factors, such as personality traits and social skills, can significantly influence interpersonal synchronisation (Keller et al., 2014). With empathy being an essential tool for effective communication and social competence, research has attempted to demonstrate how this fundamental social capacity influences synchronisation and gain a better understanding of the underlying mechanisms that support this relationship.

As already stated, both empathy and synchronisation have been associated with action (or motor) simulation, with a perception-action mechanism activating embodied representations of both observed actions and emotions in one's brain (Gallese, 2019). During a joint musical activity, one's

own action histories and motor repertoire are relied on, and action planning is activated, resonating with the observed actions of a co-performer. This process, therefore, facilitates the anticipation and prediction of these actions (Hadley et al., 2015; Timmers et al., 2020). While anticipating others' movements is an essential skill for interpersonal synchronisation during a musical performance, highly empathic people appear to create stronger embodied representations of observed actions (Novembre et al., 2012). This implies that people with higher trait empathy have augmented predictive skills, allowing them to synchronise better with their music partners. Novembre and colleagues (2019) tested this hypothesis by implementing an innovative turntable-based musical device (E-music box - Novembre et al., 2015), enabling individuals with no previous musical training to produce music in synchrony with others. The results showed that individuals with higher empathic perspective-taking abilities were better at predicting and synchronising with their partners' temporal actions, leading the authors to the conclusion that motor simulation may be the mechanism underlying this link between empathy, predictive capacities and synchronisation.

The role of motor simulation has been further explored in a Transcranial Magnetic Stimulation (TMS) study (Novembre et al., 2014) in which a double-pulse TMS (dTMS) was utilised to interfere with motor simulation in professional pianists' brains. Pianists were asked to play the right-hand part of various piano pieces while listening to a recording of the left-hand part. The results showed that dTMS applied to the right hemisphere impaired pianists' capacity to coordinate their playing with the recording when the left-hand part had been previously practised, and this impairment was stronger in individuals with higher cognitive empathy. This highlights further the significance of motor simulation in perceiving others' temporal actions to establish synchrony (Novembre & Keller, 2014). This view is further supported by Overy and Molnar-Szakacs (2009), whose model of Shared Affective Motion Experience (SAME) suggests that the mirror neuron system (MNS) is utilised to perceive and understand actions and emotions through music. In light of this model, Bamford and Davidson (2019) asked their participants to freely move their bodies to the music, adjusting to new music excerpts presented to them without previous notice. Individuals with higher dispositional empathy were found to be faster at readjusting their movements to the new music. This indicates that people with an enhanced disposition to empathise are also better at simulating and predicting temporal actions either through

music (Bamford & Davidson, 2019) or others' musical performances (Novembre et al., 2019), further highlighting the close connection between empathy and motor behaviour.

Considering how empathy enhances other aspects of interpersonal synchronisation, researchers have focused on musicians' tendency to reduce the variability of their temporal actions, making their music more predictable for their partners (Vesper et al., 2011). During a joint finger-tapping task, Dai et al. (2018) observed that dyads of individuals with higher cognitive empathy maintained lower timekeeper variance, increasing their predictability to preserve synchronisation. Conversely, Novembre et al. (2019) noticed that individuals who were assigned to lead a musical task increased their predictability regardless of their empathic levels. This suggests that assigning leadership roles may have a stronger effect than cognitive empathy on performers' tendency to increase their predictability. Nonetheless, Novembre et al. (2019) also revealed that followers with higher cognitive empathy were better at utilising the temporal information coming from their leaders, adapting more easily to their music. Indeed, higher empathy scores have been associated with increased adaptivity (Washburn et al., 2019), indicating that highly empathic individuals vary their temporal behaviour in order to adapt to their co-performers' actions. Altogether, these findings suggest that empathy facilitates co-performers' ability to adapt to their partners' music playing; however, further work needs to establish whether empathy plays any mediating role in leaders' tendency to make their performance more predictable.

The studies reviewed in this section have significantly furthered our understanding of how empathy supports the skills required to achieve interpersonal synchronisation. However, further research is required to determine the nature of the empathic processes involved in the enhancement of synchronisation. Research has primarily focused on cognitive empathy, perhaps because the voluntary empathic process of taking the perspective of another resembles the conscious process of predicting and adapting to others' musical performance. Nonetheless, this approach fails to consider the possible mediating role of affective empathy, as higher cognitive levels of perspective-taking are thought to build upon an involuntary and affective basis of emotional contagion, according to the Russian doll model of empathy (de Waal, 2008). This implies that adopting the perspective of another person and consequently predicting and synchronising with their actions in this context requires a certain level of automatic emotion-sharing that encourages stepping outside of oneself and understanding others' actions (de

Waal, 2008). This process remains undefined and warrants investigation to elucidate the circumstances that allow empathic capacities to enhance synchronisation with others. For example, it remains unknown whether psychological distance or disagreements obstruct the emotion-sharing between the members of joint actions, subsequently interrupting the impact of cognitive empathy on interpersonal synchronisation.

Furthermore, there is a significant lack of developmental research in this direction, perhaps because children and adolescents have not yet fully developed their entrainment and empathic skills. Nonetheless, research is necessary to shed light on how the cognitive-motor skills involved in synchronisation mature across the lifespan, as well as the extent to which their development builds upon socio-psychological factors (Ilari et al., 2018). Investigating empathy in children's musical interaction would also complement developmental research in rhythmic perception and production (e.g. Drake et al., 2000), highlighting the possible interplay between musical training, social skills and the motivation to synchronise with others (Kirschner & Tomasello, 2009). A suggested approach (also proposed by Wu and Lu (2021) would be to collect comparable data over a range of ages that correspond to key milestones in the development of empathy and synchronisation, such as: a) age five or six, when social interactions increase by attending school; b) age ten, when the ability to synchronise with a rhythmic sequence reaches similar levels to adults (Drake et al., 2000); and c) adolescence, when the brain regions involved in social cognition undergo dramatic changes (Blakemore, 2008). It is hypothesised that early engagement in synchronous interactions positively affects the development of empathy (Cho, 2019; Levy & Feldman, 2019), which subsequently enhances the development of cognitive-motor skills required for attaining interpersonal synchronisation. This hypothesis implies a bidirectional relationship between empathy and synchronisation that will be further discussed in the following section.

The positive feedback loop of empathy and interpersonal synchronisation: a theoretical framework

Having reviewed both directions of the empathy-synchronisation link, the findings suggest that the human capacities of synchronising and empathising are bidirectional. While dispositional empathy enhances the skills required for a successful synchronised interaction (Novembre et al., 2019), this interpersonal synchrony has the potential to increase empathy between co-performers (Rabinowitch et

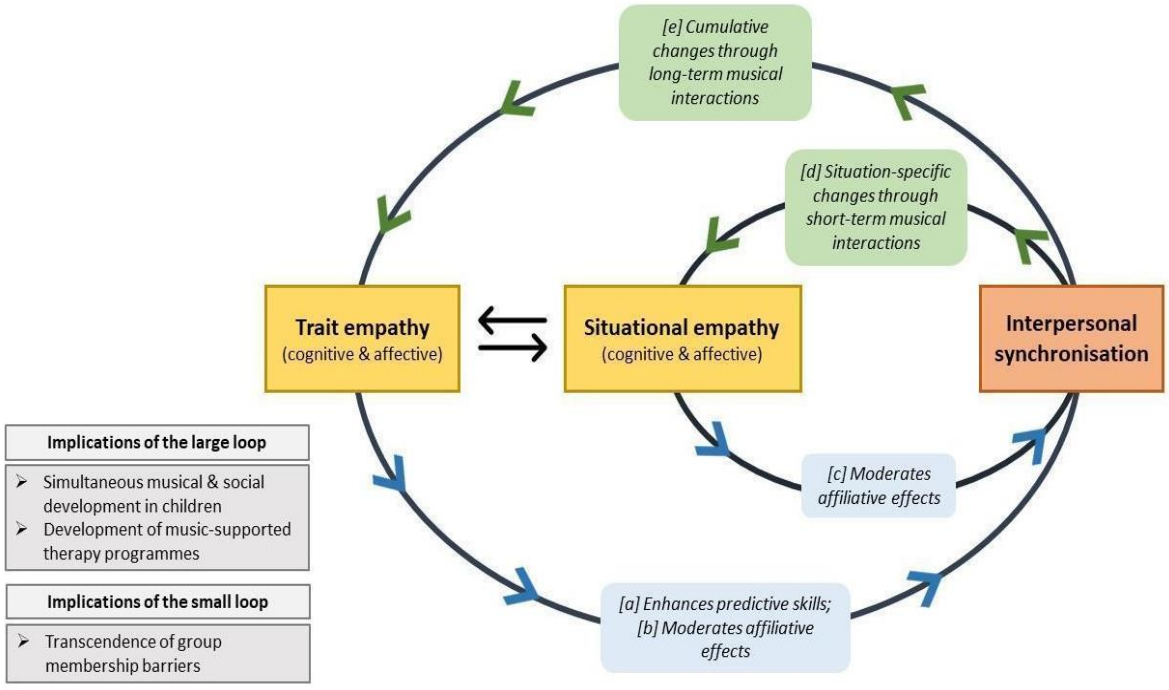
al., 2013). Researchers have already postulated such a possibility, with Keller et al. (2014) and Novembre et al. (2019) arguing that social factors such as empathy function as both influences and consequences of interpersonal synchronisation. In addition, Levy and Feldman (2019) assert that the neural processes of empathy and synchronisation may be "intimately and biologically intertwined in a multifaceted way" (p.2). This is further supported by research related to the chameleon effect, the automatic mimicry of others' movements and behaviours during social interactions. Chartrand and Bargh (1999) argue that perception-action coupling might serve as a mechanism for both processes of mimicking the observed actions of an interacting partner and subsequently empathising with them. Despite these postulations, this bidirectional relationship has not yet been empirically investigated, and it remains unknown whether empathy and synchronisation affect one another simultaneously. Based upon the evidence presented in the previous sections, a theoretical framework is proposed here, suggesting that during a musical interaction, empathy and interpersonal synchronisation create a positive feedback loop (Figure 2.1); namely, increasing one aspect of the loop results in the simultaneous enhancement of the other aspect and vice versa. The purpose of this framework is to support future empirical research, investigating a) how and when this bidirectional link occurs, considering the inter-individual and contextual factors that modulate this link, and b) its practical implications for musical and social development. This framework also hopes to inspire further research into the bidirectionality of musical and social behaviour, as such an approach could reveal aspects that may be overlooked when focusing only on unilateral relationships.

The present theoretical framework draws on ideas from relevant studies and models in music, empathy and social behaviour (Overy & Molnar-Szakacs, 2009; Clarke et al., 2015; Shamay-Tsoory et al., 2019), embracing the idea that empathy is a flexible process modulated by the environment of the interaction (Clarke et al., 2015). During a musical interaction, individuals' cognitive and affective trait empathy skills are utilised to enhance their predictive capacities (Figure 2.1[a]), allowing them to synchronise better with their co-performers (Novembre et al., 2019). Furthermore, as individuals with higher trait empathy are more susceptible to the affiliative effects of synchronous movements (Figure 2.1[b]; Stupacher et al., 2021), adopting an empathic perspective toward co-performers (situational empathy) might also moderate those social bonding effects of synchronisation (Figure 2.1[c]; see also

Cross et al., 2012 about the role of flexibility in musical group interactions). The attained interpersonal synchronisation between co-performers increases their perceived similarity (Rabinowitch & Knafo-Noam, 2015), contributing to an increase in subjective (or situational) empathy towards one another (situation-specific changes – Figure 2.1[d]; Koehne et al., 2016a; Atherton & Cross, 2020). The repeated practice of synchronising and empathising with others might also have longitudinal effects, generating cumulative changes in dispositional empathy Figure 2.1[e]), as observed in interventions for children (Rabinowitch et al., 2013), as well as adults (Leppma & Young, 2016). This enhanced empathy, in turn, amplifies interpersonal synchronisation and its positive prosocial effects, thereby creating a positive feedback loop. Figure 2.1 illustrates the relationships between "synchronisation - trait empathy" and "synchronisation - situational empathy" as two separate loops to facilitate its interpretation; however, the two processes are considered intertwined and part of the same positive feedback loop.

Figure 2.1

The positive feedback loop of empathy and interpersonal synchronisation along with its potential implications.



This bidirectional relationship between empathy and synchronisation is supported by the social alignment model, proposed by Shamay-Tsoory et al. (2019), who view motor synchrony, emotional

contagion and cognitive agreement as intertwined processes with shared neural underpinnings. According to this model, the coordination of movements and the emotion-sharing between individuals are "different manifestations of social alignment, influencing one another in a reciprocal manner" (p.174), "representing a core mechanism of connectedness" (p.176). Individuals align their motor movements, emotional states and perceptions with others in a similar manner, activating three neural systems. The first, a gap-detection system, allows individuals to monitor the interaction and create predictions about their motor, emotional and cognitive alignment with others based on information from the environment and previous experiences. If the initial predictions are correct, a second system (reward system) informs individuals that the optimal alignment has been achieved. If a misalignment is detected, an observation-execution mechanism (the third system) enables individuals to regulate their actions in order to attain alignment and update the gap-detection system. Based on these three common mechanisms, motor, emotional and cognitive alignment processes influence and complement each other in a bidirectional manner. This demonstrates both why people with higher empathy are better at synchronising with others (Novembre et al., 2019) and why synchronisation may facilitate intersubjectivity (Rabinowitch et al., 2011) and lead to higher empathy (Koehne et al., 2016a).

The social alignment model and its core mechanisms are compatible with evidence from research in music and empathy, indicating that both empathy and interpersonal synchronisation rely on embodied representations of others' actions and emotions. During a joint musical interaction, individuals observe their partners' motor behaviour and create predictions based on their own representations in order to achieve precise temporal coordination (Keller et al., 2014). Individuals use the same mechanism to access others' affective states, activating automatic representations of similar feelings (Preston & de Waal, 2002) and, hence, leading to higher perceived similarity and empathy (de Waal, 2008). Furthermore, according to the SAME model (Overy & Molnar-Szakacs, 2009), the mirror neuron system (MNS) enables listeners to perceive music as motor actions, activating affective representations of the performer's state. The activation of such embodied representations highlights the significance of the perception-action mechanism during empathising and synchronising with others, furthering our understanding of their reciprocal relationship. Empathy enables stronger representations of others' motor actions (Novembre et al., 2012), enhancing synchronisation with others and the music

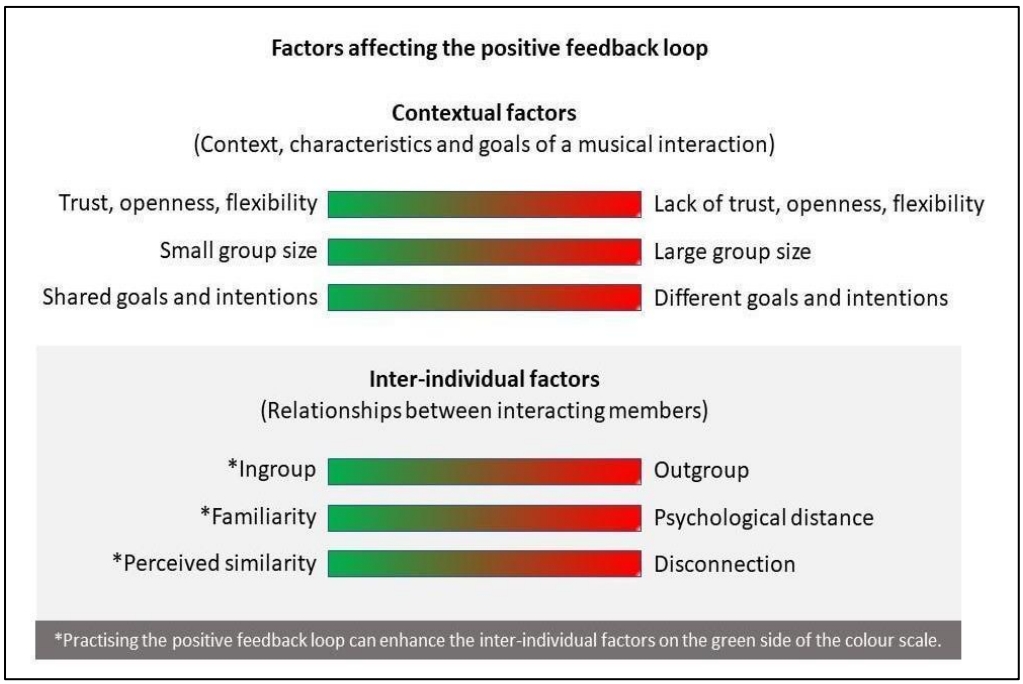
(Novembre et al., 2019; Bamford & Davidson, 2019). Simultaneously, the continuous practice of synchronous musical interaction and emotion-sharing may lead to stronger representations of others' affective states, fostering empathy in the long term (Cho, 2019).

Contextual and inter-individual factors affecting the feedback loop

Likely as a result of their being highly social processes, both empathy and interpersonal synchronisation appear to be influenced by similar social factors, further highlighting their intertwined nature (Shamay-Tsoory et al., 2019). For example, one may find it difficult to empathise and engage in a synchronised interaction with someone who has previously treated them poorly (Singer, 2009). Such social factors may involve the context, characteristics and goals of an interaction (hereafter referred to as contextual factors), as well as the relationship between the interacting members (inter-individual factors). The most significant factors that might modulate the empathy-synchronisation feedback loop are discussed below (Figure 2.2), illuminating the circumstances that allow or prevent this loop from occurring and remaining positive.

Figure 2.2

The contextual and inter-individual factors affecting the positive feedback loop of empathy and interpersonal synchronisation.



Note. The colour scale ranges from red (factors obstructing the positivity of the loop) to green (factors allowing the loop to flourish). Practising the feedback loop in musical interactions can reinforce the inter-individual factors on the green side of the scale.

Beginning with contextual factors, it could be argued that this feedback loop requires an environment of trust and openness to flourish. According to Cross et al. (2012), co-performers need to develop a level of flexibility which allows them not only to adapt to one another's rhythmic behaviour but also to shift their attention to others' emotional states. If co-performers are unable to exhibit flexibility, empathic capacities may fail to support synchronisation, or the synchronous interaction may not function as a channel for emotion-sharing and empathy. The group size may play an important role here, as smaller groups require attention to a smaller number of co-performers, leading to greater self-other merging (Tarr et al., 2014; Mogan et al., 2016). In addition to these factors, the feeling of pursuing shared goals and intentions within the group may be a prerequisite for positive social outcomes of interpersonal synchronisation (Clayton et al., 2020). Synchronisation combined with active cooperation to achieve shared goals has been reported to exhibit the strongest effects on social behaviour (Reddish et al., 2013). Working towards shared goals, therefore, increases the motivation for compromising on one's own goals (MacRitchie et al., 2018) in order to achieve an optimal synchronised interaction. The result of this attained alignment activates the reward system, making the environment of the interaction more predictable (Shamay-Tsoory et al., 2019). This may be an essential condition for co-performers to "openly and unrestrainedly... merge with others through the music" (Cross et al., 2012, p.7), laying the groundwork for empathy.

Moving on to the relationship between co-performers, empathy and interpersonal synchronisation can be notably influenced by inter-individual factors, such as perceived similarity and group membership, familiarity and psychological distance (Main et al., 2017; Cikara et al., 2011; de Vignemont & Singer, 2006; Singer et al., 2006; Miles et al., 2010). Shamay-Tsoory and colleagues (2019) explain that such factors influence motor, emotional and cognitive alignment as individuals create predictions about others based on their previous experiences. If, for example, previous interaction with an outgroup did not engender a positive outcome, this may influence predictions about outgroup members in future interactions with them. To date, studies examining the relationship between empathy and synchronisation have primarily investigated leadership. As mentioned, leaders self-report higher cognitive empathy towards their synchronised followers (Koehne et al., 2016a), and all leaders, regardless of their empathic level, make their music more predictable for their followers (Novembre et

al., 2019). Other parameters also warrant investigation, for example, interacting with a familiar person such as a friend or playing music with a less experienced co-performer who struggles to synchronise. This would shed light on factors that may obstruct the positivity of the feedback loop and on how the loop may assist in overcoming such obstacles. As will be discussed below, one may initially empathise less with an outgroup member; however, their synchronised interaction might increase their perceived similarity, fostering empathy and subsequently improving synchronisation.

Future research, exploratory avenues and implications of the feedback loop

The theoretical framework presented above aims to enhance future research that will empirically investigate the feedback loop between empathy and interpersonal synchronisation in musical group interactions. In the following section, some next steps for research are recommended, aspects requiring further attention are outlined, and three exploratory avenues that may inspire new intriguing approaches to this reciprocal relationship are proposed. Some significant implications of the feedback loop for musical and social development are also discussed in the final part of this article.

Empirical research on this bidirectional relationship would be significantly enlightened by first investigating the knowledge gaps identified in the separate review of each directionality. More specifically, future research would need to examine: 1) whether interpersonal synchronisation can function as an independent mechanism to enhance empathy; 2) the timeframe required for interpersonal synchronisation to exhibit measurable changes in trait empathy (Figure 2.1[e]); 3) the possible impact of synchronisation on situational empathy (Figure 2.1[d]); 4) whether such an increase in empathy could be generalised to non-interacting members of a musical interaction; 5) whether *affective* empathy also contributes to the enhancement of interpersonal synchronisation, and 6) the role of empathy in supporting synchronisation in children. Addressing these gaps would subsequently inform key aspects of the feedback loop, elucidating the circumstances that allow or prevent it from flourishing. Furthermore, amongst the numerous empirical approaches that can be applied to investigate this reciprocal relationship, it is suggested that a pretest-posttest intervention design is first implemented, whereby individuals with high and low levels of empathy are assigned to separate groups. This approach will allow monitoring of the extent to which different empathy levels amplify interpersonal synchronisation and how this synchronisation subsequently improves these empathy levels. A natural

progression of this research work would be to explore the contextual and inter-individual factors modulating the outcomes of this feedback loop (Figure 2.2). Future research could start by investigating the impact of group size and familiarity between co-performers, as these particular factors appear to be significantly influential upon interpersonal synchronisation and empathy, respectively (Mogan et al., 2017; Preston & de Waal, 2002). Finally, the possibility of highly empathic people being more susceptible to the positive effects of synchronisation on empathy remains speculative, and future research exploring this notion would significantly enhance our understanding of the influence of social skills upon musical abilities and the social consequences of music.

Apart from the aforementioned suggested next steps for future empirical research, there are some key points that warrant further consideration prior to exploring this reciprocal relationship. It is important for future studies to clarify the nature of empathic processes involved in this feedback loop by exploring a variety of experimental methods that capture changes in both trait and situational empathy and investigate the potential interplay between cognitive and affective empathy. It is plausible, for example, that cognitive perspective-taking facilitating the prediction of others' subsequent actions (Novembre et al., 2019) depends on the preceding activation of affective empathic processes (de Waal, 2008). This possibility could be explored by implementing a variety of measures for cognitive and affective empathy and monitoring any correlations. Another consideration is that the feedback loop may require a prolonged practice of its cognitive and affective processes to exhibit changes in musical and social behaviour (Figure 2.1[e]), and this could be addressed by comparing the effects of different timeframes (months or years). Prior to designing future empirical studies, such questions require attention in order to better inform appropriate methods and draw accurate conclusions.

Further to these important considerations, suggested below are three additional avenues for exploratory research that may enlighten not only the present theoretical framework but also future studies exploring the interplay between musical and social behaviour. The first suggestion concerns situational empathy and its ability to be experimentally manipulated (Allemand et al., 2015). So far, the vast majority of studies exploring empathy and interpersonal synchronisation has considered empathy primarily as a personality trait, investigating only inter-individual differences within the population. However, exploring the additional role of situational empathy and its impact following an experimental

manipulation could open up possibilities that would further our understanding of the reciprocal relationship of empathy and synchronisation (Figure 2.1[c]). Similar research in music listening has shown that inducing empathy by asking participants to adopt either a neutral or emotional perspective can play a significant role in how emotions are perceived during music listening (Miu & Baltes, 2012; O'Neill & Egermann, 2020). Based on such examples, future research could examine how knowing about co-performers' emotional states impacts interpersonal synchronisation and to what extent this correlates with co-performers' trait empathy levels. Researchers might also instruct participants to either imagine how their co-performers feel or remain objective to these emotions, thereby exploring how this may modulate their interpersonal synchronisation and its subsequent impact on empathy.

Another suggested exploratory avenue involves the investigation of observed or imagined synchronisation, i.e. watching or imagining a synchronised interaction without producing any movements. Stupacher and colleagues (2017) demonstrated that merely watching two stick figures walking in synchrony with the music and imagining being one of them can have a positive impact on feelings of closeness and affiliation toward the other stick figure. In line with these findings, participants in a non-musical study (Atherton & Cross, 2020) who imagined walking in synchrony with outgroup members exhibited increased subjective empathy and reduced negative attitudes towards these members. This evidence indicates that the processes of perceiving and actively attempting to achieve synchrony may be served by a common underlying mechanism (Prinz, 1997; Stupacher et al., 2017). Since empathy may arise even when the emotions of another person are only imagined (Stietz et al., 2019), future research could compare findings from produced and observed synchronisation, investigating how dispositional and situational empathy mediate the perception of synchronisation, as well as the affiliation-evoking effects stemming from an observed or produced synchronised interaction. The findings from this type of research could inform whether people with higher empathy are better at detecting asynchronies in an observed interaction and how this might influence the effects of synchronisation in fostering empathy.

A third suggested exploratory avenue draws attention to a developmental perspective on this feedback loop that could potentially reveal significant implications for music pedagogy, therapy and children's moral development (a summary of all implications is included in Figure 2.1). Phillips-Silver

and Keller (2012) have pointed out the strong associations between adult music ensemble skills and the practice of temporal and affective entrainment in early musical interactions. Considering this, the investigation of empathy and interpersonal synchronisation in children's music-making would complement not only existing music pedagogy techniques but also adult music group practices. In addition, looking into the link between empathy and synchronisation could inform research on motor coordination difficulties and emotion recognition (Cummins et al., 2015). Such research could further advance music-supported therapy interventions aimed at eliminating motor and emotional processing difficulties in disorders such as autism and dyslexia (Bamford & Davidson, 2019). Finally, widening the scope of the research into children's joint musical actions would further our general understanding of how synchrony and empathy develop in childhood and to what extent motor simulation skills depend on musical training. These findings would contribute to the design of music programmes that promote children's moral development, thereby highlighting music's role as a powerful means of connecting people and societies.

Focusing now on the implications of this relationship, applying the feedback loop in a musical context may have significant effects on shaping positive social attitudes towards others (Rabinowitch, 2020). Bringing together the positive effects of both empathy and synchronisation in bridging intergroup relations (Batson & Ahmad, 2009; Miles et al., 2010), the feedback loop may play an important role in transcending group membership barriers. According to the social alignment model (Shamay-Tsoory et al., 2019), the reciprocal system between motor, emotional and cognitive alignment is a learning process that serves to enable connectedness between the interacting individuals. This implies that practising this feedback loop may encourage liking and closeness. Music has been found to facilitate cross-cultural understanding (Clarke et al., 2015), reduce prejudice (Neto et al., 2016), overcome ethnic and socioeconomic boundaries (Good & Russo, 2016), and influence moral judgement (Ziv et al., 2012). In light of these findings, future research could engineer a new musical intervention (Rabinowitch, 2020) based on the reciprocal empathy-synchronisation link aimed at increasing similarity, closeness and empathy across intergroup members. During such a musical intervention, interpersonal synchronisation would initially enhance similarity across intergroup members (Reddish et al., 2016). This increased similarity would subsequently promote empathy which would, in turn,

amplify the experience of interpersonal synchronisation. The positive feedback loop would hence be established, giving further rise to its positive "generalised prosociality" effects (Reddish et al., 2016, p.3). Future research will need to examine this possibility and explore the contextual factors that would enable or inhibit this process.

A further implication of the feedback loop concerns the possible simultaneous development of musical and social skills in children. It has been proposed that music education in groups and ensembles may contribute not only to shaping synchronisation and other musical skills but also to developing vital social skills for human interactions (Ilari et al., 2018; Phillips-Silver & Keller, 2012). Designing and applying music interventions that facilitate a reciprocal relationship between empathy and interpersonal synchronisation may give rise to the simultaneous enhancement of rhythmic and empathy skills, hence playing a significant role in children's musical and social development. This approach could also inform existing music education programmes, encouraging the idea that group music-making is not merely a question of the ability to synchronise with peers but rather a social interaction where empathy and interpersonal synchronisation engage in a continuous interplay. Applying this feedback loop could also encourage the exploration of other important social skills, such as prosociality (Ilari et al., 2018) and effective communication, which may also present a reciprocal relationship with synchronisation and music-making in groups.

Conclusion

The purpose of this theoretical article was to build upon existing knowledge in the research fields of empathy and interpersonal synchronisation and provide an informative framework that will further our understanding of the reciprocal relationship between these fundamental social processes. By providing promising exploratory avenues and highlighting aspects that require further attention, the discussion of this theoretical framework has laid the groundwork for future research on the mechanisms underlying the interplay between empathising and synchronising. It is hoped that this theoretical work will encourage researchers to switch the focus from unilateral to bidirectional relationships, exploring further aspects of social cognition that might also present a reciprocal relationship with musical skills. Such work will open up new perspectives on how musical and social behaviours influence one another, providing a deeper understanding of music and its significance in our lives.

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CHAPTER 3

Study 1: "Unravelling the effects of empathy on social bonding following interpersonal synchrony through music: A mixed-methods approach" (Paper 2)

The paper has been submitted for publication in an open-access peer-reviewed journal as:

Tzanaki, P., MacRitchie, J., Timmers, R. & Dibben, N. *Unravelling the effects of empathy on social bonding following interpersonal synchrony through music: A mixed-methods approach.* [Manuscript submitted for publication]. Department of Music, The University of Sheffield.

A preprint of the manuscript is also available below:

Tzanaki, P., MacRitchie, J., Timmers, R. & Dibben, N. (2024). *Unravelling the effects of empathy on social bonding following interpersonal synchrony through music: a mixed-methods approach.* PsyArXiv. https://doi.org/10.31234/osf.io/zxc8v

Candidate's contribution:

The candidate contributed to the conceptualisation and design of the study, completed data collection and analysis, prepared tables and figures, interpreted the results, and wrote the paper.

Abstract

Interpersonal synchrony, the coordination of movements between individuals, has been extensively associated with strengthening social bonding. However, less is known about contextual or subjective factors amplifying or hindering these effects. This mixed-methods study examined the impact of trait empathy on the intensity of social bonding experienced following synchrony in active musical engagements, extending previous observations related to passive interactions. Through two experimental tasks and post-experiment interviews, we explored empathy's effects when non-musicians engage actively or passively in musical interactions with background music varying in tempo. The results associated higher trait empathy with increased social bonding following synchrony with a partner. Although not statistically significant, these effects tended to be modality-dependent, i.e. relying on how one engages in musical interactions. Tempo directly influenced the social bonding experience, potentially due to its impact on participants' mood. Lastly, interview responses revealed that during their musical interactions, participants attributed mental states to their partners, eliciting affiliation even when synchrony was not attained. Our findings support that, in addition to stimulus-driven responses, the synchrony-bonding link relies on top-down processes shaped by individuals' trait empathy, preferences and type of musical engagement that significantly influence the perception of synchrony and its ability to evoke social affiliation.

Keywords: empathy; interpersonal synchrony; individual differences; mixed-methods; online musical interactions

Introduction

The temporal alignment of movements among individuals, commonly known as interpersonal synchrony, plays a pivotal role in social and musical interactions (Gill, 2012). Extensive literature has associated this aligning process with positive effects on social behaviour, particularly in relation to social bonding (Vicaria & Dickens, 2016). Specifically, synchrony has been found to promote cooperation (Wiltermuth, 2009), strengthen affiliation in musical or non-musical settings (Hove & Risen, 2009; Bamford et al., 2023), prompt prosociality (Kirschner & Tomasello, 2010; Cirelli et al., 2014), and encourage interpersonal closeness even when one merely observes synchronous movements (Stupacher et al., 2017). Despite the ample evidence supporting synchrony's bonding effects, less is known about individual differences in experiencing such affiliation, i.e. whether one feels stronger or weaker bonding depending on personal traits, prior events or relevant skills. Uncovering what influences one's response to these effects is crucial, providing insights into individual experiences of synchrony in musical contexts, as well as informing interventions forging social relations in various settings (Behrends et al., 2012).

Current findings offer increased insight into how the context and characteristics of social interactions influence the effects of synchrony. For instance, the number of individuals interacting in group activities can determine the level of affiliation evoked (Mogan et al., 2017), with smaller groups allowing for greater attention to partners' movements, hence stronger feelings of togetherness (Tarr et al., 2014). Furthermore, active collaboration to achieve rhythmic coherence enhances cooperation to a greater extent than simply synchronising with a partner without shared goals (Reddish et al., 2013). Music also plays a substantial role, with individuals experiencing stronger bonding when interactions feature familiar, enjoyable and easy-to-follow background music, compared to a metronome (Stupacher et al., 2020). This evidence implies that the impact of synchrony on social bonding might be mediated by the content and settings of social interactions. Nonetheless, questions remain about how one's personality and prior experiences interact with such factors, thereby influencing synchrony's effects.

In a recent study, Stupacher and colleagues (2022) sought to address these questions, exploring the potential influence of empathy, namely the dispositional capacity to understand and share others' emotional states (Singer & Lamm, 2009). In their study, participants were asked to watch videos of two

stick figures walking, accompanied by a soundtrack of music or a metronome, while imagining one of the figures being themselves and the other being an unknown person. The stick figures' walking was manipulated, exhibiting different degrees of alignment with the music or metronome. After every video, participants rated how close they felt to the "other" stick figure. Results showed that highly empathic individuals experienced stronger closeness toward synchronous figures than those with lower empathy. However, this was evident only when the videos featured music, whereas individuals with lower empathy experienced heightened closeness when a metronome accompanied the videos. Together, Stupacher et al.'s findings emphasise the complexity of the synchrony-bonding link, underscoring that context-related factors, such as musical elements, interact with individuals' empathy, regulating the intensity of bonding evoked.

Empathy has garnered substantial attention in recent years in relation to synchronisation, with relevant studies reporting an interplay between synchrony and empathy's dispositional and situational manifestations. Notably, the perspective-taking aspects of trait empathy contribute to attaining synchrony, with highly empathic individuals presenting superior predicting capacities, allowing them to synchronise better with a partner (Novembre et al., 2019). Focusing on the reverse direction of the synchrony-empathy link, synchronised movements in music-making have been found to enhance children's trait empathy (Rabinowitch et al., 2013) and encourage state empathising in adults (Baimel et al., 2018). However, the latter effect might solely apply to certain groups of people, as synchrony was found not to encourage cognitive empathy in autistic individuals (Koehne et al., 2016). This suggests a potential mediating role of empathy in the mechanisms enabling synchronisation to influence social affiliation. Altogether, these findings imply a bidirectional relationship between synchronising and empathising, with empathy potentially modulating synchrony's bonding effects (Tzanaki, 2022; Stupacher et al., 2022; Novembre et al., 2019). Nevertheless, the extent of this modulation and its interplay with contextual factors within musical interactions are yet to be determined.

The present study aimed to advance our understanding of the role of empathy and other subjective and contextual factors in the relationship between synchrony and social bonding by employing a mixed-methods approach combining quantitative experimentation with qualitative interviews. In particular, we investigated whether the effects of trait empathy Stupacher et al. (2022)

found in relation to visually observed interactions (moving stick figures) extend to active tapping with non-present virtual partners and auditorily presented stimuli to synchronise with. Through a stick-figure (replicating Stupacher et al.'s design) and a finger-tapping task, the study investigated the effects of empathy not only when individuals observe and imagine being part of musical interactions but also when they actively adjust to partners' temporal behaviour (Keller, 2014 - hereafter, active and passive musical interactions). In addition, our investigation probed the mediating role of the tempo of music accompanying such interactions, contributing valuable insights into the interaction between background music and empathy previously observed (Stupacher et al., 2022). If relationships between empathy, synchrony and social bonding remain across these contexts, this would provide evidence for the robustness of the effects.

Further to this investigation, we qualitatively explored participants' conceptualisations and thought processes, a novel approach in this context. Research shows that the synchrony-bonding link is not simply a direct relationship (Stupacher et al., 2022) and that it might be mediated by how individuals perceive and conceive of relative synchrony and how, in turn, these perceptions afford empathy and social bonding. Previous studies have shown that top-down processes such as inferences about partners' intentions impact synchronisation performance (Miles et al., 2009; Mills et al., 2019), while social perceptions are thought to be formed based on both stimulus-driven information (in our case, perceived synchrony) and mental state attributions to others (Teufel et al., 2010). In addition, valenced responses have been found to influence judgments of social association, implying that relationships between synchrony and social bonding might be mediated by emotion (Bamford et al., 2023). Therefore, it is crucial to explore the role of such perceptions and any potential effects of emotional responses associated with synchronised behaviours in musical contexts to better understand the mechanisms allowing empathy to moderate the bonding stemming from synchrony. For this purpose, we conducted post-experiment interviews, investigating qualitatively how participants' perceptions of partners (either those represented by the stick figures or the virtual partners in the tapping task) prompted emotional responses, consequently influencing their affiliative reactions to synchrony.

Based on current literature, we hypothesise that individuals with higher trait empathy will experience stronger affiliation than those with lower empathy toward synchronous partners in both the

stick-figure (hereafter, observational) and the tapping task (H1). However, the visual features of the observational task might better facilitate the imagination of virtual partners and their intentions (Batson, 2009) than the auditory stimuli of the tapping task. Therefore, we anticipate highly empathic participants utilising this information more effectively (Novembre et al., 2012; Marzoli et al., 2011) and providing higher affiliation ratings in the observational task (H2). In addition, active engagement in the tapping task might resemble the embodied experience of music-making (Timmers et al., 2023), prompting stronger emotional responses (Cross et al., 2012). This might result in stronger bonding with synchronous partners and amplified disconnection from asynchronous partners in the tapping task across all empathy levels (H3). Lastly, with regard to tempo's effects in this process, we expect it to affect how synchrony is perceived and experienced. Therefore, we hypothesise that synchronous interactions featuring faster music will exhibit stronger social bonding (H4) due to fast music evoking higher arousal and positive emotional responses (Liu et al., 2018; Gagnon & Peretz, 2003), and highly empathic participants will experience these effects more profoundly (H5). In addition, slower tempi might further increase the cognitive load evoked by asynchronous interactions (Bamford et al., 2023), amplifying the disconnection experienced when interpersonal synchrony is not attained (H6).

Methods

The Department of Music Ethics Committee at the University of Sheffield (UK) approved the study. All experiments were conducted in accordance with the University's guidelines and relevant regulations. A preceding pilot study with seven participants informed the following methodology.

Participants

Eighty individuals, 54 of whom identified as female, completed the study. An a priori power analysis via G*Power 3.1 (Faul et al., 2009) indicated that 78 participants would be sufficient for detecting a medium effect size (f^2= .15) at a significance level of .05 with 80% power. Initially, 90 participants completed the study; however, ten were excluded due to either providing multiple answers per statement in the trait empathy questionnaire or not understanding aspects of the study as identified during the interviews. The majority of participants were between 25-34 years old, with 15% being younger (18-24) and 34% older. Professional musicians or individuals with extensive musical training for more than ten years were not recruited to prevent the potential influence of musical training on

synchronisation and cognitive empathy (Timmers et al., 2020; Cho, 2019). Consequently, 77.5% (n = 62) of the participants had less than two years or no musical training, and 13.8% had three to five years of experience. Finally, seven individuals reported five to ten years of training at a young age but did not identify as musicians.

The study was advertised on British and Greek social media platforms, enabling access to a broader participant pool. All questionnaires were administered in English; however, Greek-speaking participants were given the option to complete their interviews in their native language. In total, 42 interviews were completed in Greek and 38 in English, all conducted by the same experimenter (first author), proficient in both languages. The interview questions were initially composed in English and translated into Greek by the first author. Greek-speaking participants confirmed verbally their fluency and confidence in completing the questionnaires in English. As a gesture of appreciation for participants' involvement, a draw was held, offering five £10 shopping vouchers.

Materials

Demographics and trait empathy assessment

Participants completed a brief demographic questionnaire stating their age, gender and any prior musical training (Zhang & Schubert, 2019 - see Appendix). The demographic questionnaire was followed by the Interpersonal Reactivity Index (IRI - Davis, 1980), a self-reported measure of cognitive and affective empathy. Empathy was calculated as the overall score of four subscales: perspective-taking, fantasy, personal distress and empathic concern. Participants were not informed about the real purpose of this questionnaire to avoid potential effects on their performance and subsequent affiliation ratings. Both questionnaires were administered online via Google Forms. Due to a technical issue, some participants accidentally provided multiple answers to some IRI statements. Those with multiple answers in more than two statements were excluded. Data from ten participants who provided multiple answers to one statement remained in the analysis, and the average of their answers was used for that statement.

Social bonding ratings

Social bonding was examined in terms of three aspects of social affiliation: interpersonal closeness, perceived similarity and state empathy. Participants rated how close and similar they felt

toward their virtual partners and how much they empathised with them following every trial of the tasks (Table 3.1). These aspects were selected due to their strong links to interpersonal synchrony found in prior research, allowing for outcome comparisons across studies (Rabinowitch & Knafo-Noam, 2015; Stupacher et al., 2020; Baimel et al., 2018; Koehne et al., 2016).

Participants reported their feelings of closeness using the Inclusion of Other in the Self (IOS) scale (Figure 3.1 - Aron et al., 1992). This involved choosing a set of circles that best represented the level of closeness experienced between themselves (blue circle) and their virtual partner (black circle). Regarding perceived similarity, participants reported their feelings by answering Questions 2 and 3 in Table 3.1, inspired by Rabinowitch and Knafo-Noam (2015). The questions sought to explore whether synchronising with virtual partners led participants to perceive them as individuals with similar backgrounds, abilities and values (Graves & Elsass, 2005). Since the questions were meaningfully related, with high intercorrelation (see Table 3.1 for Cronbach's α and polychoric correlation coefficients), a composite perceived similarity score was calculated comprising an average rating of the questions.

Lastly, state empathy, the process of appraising a situation and exhibiting empathy corresponding to the context and people involved (Lamm et al., 2007; de Vignemont & Singer, 2006), was assessed via Questions 4 to 7 (Table 3.1), as seen in Koehne et al. (2016). The questions investigated how synchronisation allowed participants to understand their virtual partners' mental and emotional states, prompting bonding with them (Baimel et al., 2018; Koehne et al., 2016). An average score was calculated for state empathy following the same process as in perceived similarity. All questions (2 to 7) were answered on a 5-point Likert scale, ranging from 0 (Not at all) to 4 (Very much).

Figure 3.1

The Inclusion of Other in the Self (IOS) scale - Aron et al., 1992.

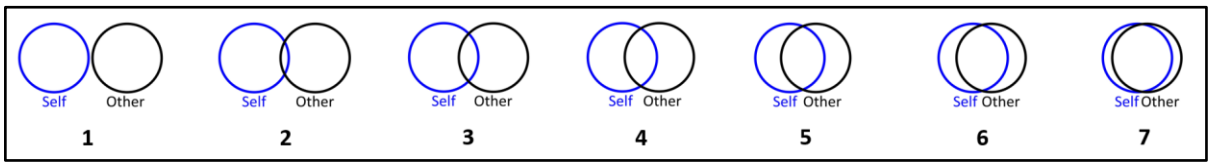


Table 3.1

The social bonding questionnaire

Questions	Social bonding aspect	Cronbach's α	Polychoric correlation coefficient	
			r(df)	*p*
1. Inclusion of Other in the Self (IOS) - Figure 3.1	Interpersonal Closeness	-	-	-
2. "Do you think the other participant is similar to you in character?"	Perceived similarity	.957	*r*(15) = .95	< **.001*** **
3. "Does the other participant remind you of yourself in any way?"				
4. "How much did you understand the thoughts and intentions of the other participant?"	State empathy (cognitive)	.846	*r*(63) = .57	< **.001*** **
5. "How much did you share the feelings of the other participant?"				
6. "Seeing the other participant happy would make me happy, too."	State empathy (affective)			
7. "Seeing the other participant sad would make me sad, too."				

Note. df: Degrees of freedom. Significance levels: $p<.001$***, $p<.01$**, $p<.05$*. Questions 2 to 7 were answered on a 5-point Likert scale, including the options: "Not at all", "A little", "Moderately", "Quite a bit", and "Very much".

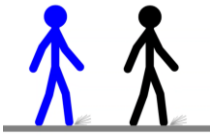
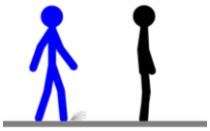
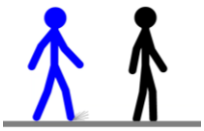
Stimuli

The observational task

The stick-figure paradigm used by Stupacher et al. (2022) was implemented here. Participants watched twelve 30-second-long videos of two stick figures walking along with music while imagining being the blue stick figure and the black one being an unknown person. In all videos, the blue "self" figure walked along with the beat of the music, as indicated by two bars of a metronome at the beginning of the video. The black figure's walking was manipulated based on four synchrony conditions, as presented in Table 3.2. This array of conditions aimed to prompt a range of affiliative responses, examining the impact of empathy beyond the binary alignment-misalignment paradigm usually employed in relevant studies (Stupacher et al., 2022; Repp, 2005). All videos were created using Pivot Animator v4.2.8 (Motus Software Ltd.). Each stride comprised 24 frames, with the figures completing 30 strides in total across all conditions. A dust cloud was added the moment the stick figures' feet made contact with the ground to heighten the rhythm of their walking (Stupacher et al., 2022).

Table 3.2

The synchrony conditions and how they are depicted in each task.

Conditions	Observational task & screenshots of the stick figures		Tapping task
1) Synchronous in-phase	Both stick figures walk along with the beat of the music, and their footsteps coincide, landing on the ground simultaneously.		The tapping sequences of the ostensible partner are aligned with the beat of the music.
2) Synchronous antiphase	The "other" (black) stick figure steps half a phase after the blue one on the off-beats of the music.		The tapping sequences retain the same Inter-Onset Interval (IOI) as the beat of the music, but they are shifted by half of an IOI.
3) Asynchronous in-phase	The stride of the "other" stick figure is intentionally delayed by four frames. The final result conveys the perception that the figure is slightly out of synchrony with the beat of the music.		Jitter was added to the tapping sequences, creating the impression of partners being unsure or unable to tap on the beat. Jitter was devised by calculating the average milliseconds (ms) of an IOI of a synchronised sequence and adding or subtracting 15% from each tap. To randomise these additions and subtractions, the first 40 elements of a Kolakoski sequence were used, creating an aperiodic series of 1s and 2s (Madison & Merker, 2004). For every "1", 15% of the IOI was added, and for every "2", 15% was subtracted (Launay et al., 2013).
4) Asynchronous antiphase	The "other" stick figure starts six frames before the blue one, giving the impression that it is slightly out of synchrony with the off-beats of the music.		A similar approach to Condition (3) has been adopted here, with jitter applied to a synchronised anti-phase tapping sequence.

Four interchangeable excerpts of instrumental funk music accompanied all videos (see Appendix for details). This music genre, known for its emphasis on rhythm and syncopation, was selected to manifest groove and the sense of the beat (Witek et al., 2014). The use of four music excerpts instead of a single piece was intended to sustain participants' interest and avert learning effects. The music excerpts were presented at three tempi: a) slow: 720 milliseconds (ms) inter-onset interval (IOI) = 83 beats per minute (bpm); b) moderate: 600 ms IOI = 100 bpm; and c) fast: 480 ms IOI = 125 bpm. The tempi were chosen by considering 600 ms as a comfortable tapping tempo for adults (Madison & Merker, 2004) and then increasing or decreasing this number by 20% for the fast and slow tempi, respectively using Audacity (3.2.1). A rolling design was used so that each participant heard one of four

stimulus sets where stimuli were equally distributed across conditions, tempi and music excerpts. This resulted in each participant being exposed to 12 out of the 48 stimuli available (4 conditions x 3 tempi x 4 music excerpts), with everyone completing the same number of conditions and tempi but with different music excerpts for every four participants (see Appendix for a detailed table). Videos with music at 100 bpm and 125 bpm were created by speeding up the 83 bpm videos using Windows Video Editor. The task was completed on SmartSurvey with the video files embedded via YouTube. This approach facilitated sharing task stimuli with participants through web links.

The tapping task

Participants engaged in 12 trials of finger-tapping interactions with ostensible non-present partners. They were instructed to tap along with the beat of background music while listening to pre-recorded tapping sequences of people who completed the same task before them. However, unbeknown to participants, the tapping sequences were devised based on four synchrony conditions, similar to the observational task (see Table 3.2 for a detailed description of the conditions). During the trials, participants were instructed to pay attention to their partners' tapping and imagine themselves completing the task at the same time as them. Participants were asked to tap on a surface in front of them using a pen or a pencil and their tapping was not recorded. They completed 30 taps in every trial and for all conditions, matching the number of the stick figures' strides in the observational task. A two-bar metronome at the beginning of each trial indicated the beat of the music that participants were required to maintain while tapping. The four conditions were presented in the same three tempi and four music excerpts as in the observational task. Participants completed different stimulus sets of conditions, tempi and music excerpts in each experimental task. The tapping sequences of the ostensible partners were created on Sonic Visualiser v4.3 and presented as bell sounds on top of the music. The task was completed on SmartSurvey with the audio files embedded via SoundCloud links.

Qualitative interviews

Following the two tasks, all participants completed a brief structured interview. The questions encompassed the following topics: (a) reflections on the tasks and feelings toward the virtual partners; (b) task preferences; (c) manipulation check for the tapping task; and (d) real aims of the study (see Appendix for a full list of the questions). Questions in topic (a) delved into participants' feelings when

interacting with tapping partners or stick figures perceived as synchronous or asynchronous, while topic (b) sought to elucidate any potential differences between tasks, providing a qualitative comparison between active and passive musical engagement. Participants' responses also served as a confirmation that they understood the tasks. Furthermore, given that participants were falsely informed that they were interacting with real people's tapping recordings, topic (c) aimed to examine whether they believed the cover story. Finally, the investigation of a role for empathy was not initially disclosed to avoid participants altering their behaviour. Therefore, topic (d) explored whether participants identified the real purpose of the study during the experiments. The interviews were recorded on Google Meet, and their audio was extracted for transcription purposes. The first author translated Greek quotes into English during code extraction.

Experimental procedure

Participants were invited individually to a Google Meet video call for a study investigating music and social interactions. Informed consent was obtained, and every session started with participants completing the demographic and IRI questionnaires before proceeding to the tasks. The tasks were completed online on SmartSurvey, with separate links sent to participants via the Google Meet chat box. The experimenter explained the content of the tasks and remained silent during the experiment while monitoring the process and documenting any connectivity or other issues reported. Participants were given the option to mute their microphones and switch off their cameras, being reassured that no data would be collected through the video call until the interview stage. They could, however, report any issues and ask for assistance at any time during the experimental tasks.

The order of the tasks was randomised to counterbalance any transfer effects. Before each task, two practice trials (synchronous in-phase and asynchronous anti-phase) were completed to familiarise participants with the process. Each task comprised 12 trials, and after every trial, participants answered the social bonding questions about the ostensible tapping partner or the unknown person represented by the "other" stick figure for that trial. The interviews followed the tasks, with every session lasting approximately 60 to 70 minutes (25 to 30 minutes per task plus ten minutes for the interview).

Data analysis

Quantitative analysis

Linear mixed-effects model (LME) analyses were conducted to investigate the main and interacting effects of synchrony (four conditions), trait empathy (total score as a continuous variable), tempo (slow, moderate and fast) and tasks (tapping and observational tasks) on ratings of closeness, perceived similarity and state empathy. Data was modelled using the lme4 package (R Core Team, 2021; Bates et al., 2020) in RStudio (RStudio Team, 2020), and separate models were built for each of the three social bonding variables. LMEs were chosen given their ability to allow fixed effects slopes to vary across participants and their capacity to handle complicated interactions (Matthews et al., 2019). Despite not fully meeting some of the parametric assumptions due to the nature of the dependent variables (see Appendix for more details about the assumption tests), LMEs appear robust against such violations (Norman, 2010; Gibson et al., 2011), and their use with Likert scale data has been previously validated (Norman, 2010; Rothermich et al., 2021; Kizach, 2014). Moreover, alternative approaches, such as ordinal data analyses, are more susceptible to false positive (Type 1) errors (Kizach, 2014). Nonetheless, to corroborate our findings, we conducted secondary analyses utilising cumulative mixed-effects models (CLMMs) through the "ordinal" package in RStudio (Christensen, 2018), as outlined in Matthews et al. (2019). The analyses revealed similar result patterns to the LME models, albeit with some nuanced variations in the significance levels. The results of this CLMM analysis are reported in the Appendix.

To identify the impactful random effects of each model, we started with a maximal structure (Barr et al., 2013; Bates et al., 2015; Bolt, 2016) and gradually simplified the models by assessing the significance of each random effect using restricted maximum likelihood (REML). More specifically, the maximal structure included a random intercept and slopes for synchrony, tempo, and task varying within participants, as well as random intercepts for trials, songs, stimulus sets and the order in which participants completed the tasks (tapping or observational task first). Where models failed to converge, the random effect with an estimated variance near zero was removed. Using likelihood ratio tests via the ANOVA function in R, we progressively compared each model's fit with a reduced one, excluding one-by-one random effects that explained the least variance in the dependent variable. Comparisons

were based on the Akaike (AIC) and Bayesian Information Criterion (BIC), the estimated deviances (-2 log-likelihood; -2LL), chi-square estimates and their associated p-values. The latter were obtained using the Satterthwaite (1946) approximation (1946) in the lmerTest R package (Kuznetsova et al., 2017). Where the model difference was not statistically significant ($p > .05$), the simplest model with a lower AIC and BIC value was chosen.

A similar approach was followed to determine the optimal fixed-effects structure, albeit using a maximum likelihood (ML) estimation instead of REML. Starting with a maximal structure allowing for a 4-way interaction between all predictors (synchrony, empathy, tempo and tasks), separate reduced models were run with all possible lower-order interactions (3- and 2-way), as well as no interactions while comparing their goodness of fit using likelihood ratio tests. Interactions and main effects of predictors that did not improve the fit of the models were gradually removed based on p-values (Schmidt et al., 2016) and the simplicity of the models (AIC and BIC values). Post-hoc comparisons and trends were subsequently performed to identify the direction of the effects observed in the final models, using the R packages "emmeans" (Lenth, 2021) and "ggplots2" (Wickham, 2016).

Qualitative analysis.

Eighty interviews, each lasting approximately ten minutes, were transcribed verbatim. Responses to questions in topics (c) and (d) (manipulation check for the tapping task and real aims of the study) were examined to identify any grounds that may require exclusion from the analysis. An inductive thematic analysis was then applied to responses to questions in topics (a) (reflections on the tasks and feelings toward the virtual partners) and (b) (task preferences). The thematic analysis was conducted by the first author using Braun and Clarke's (2021) principles, allowing for an iterative process whereby they first generated codes from familiarisation with the data, and then themes were considered in stages. Initial themes were reviewed and discussed with the second author prompting a further stage of data organisation and theme development. Final themes and descriptions were written by the first author, with feedback incorporated from all authors.

Results

Quantitative results

The final best-fitting models (Table 3.3) allowed for random intercepts for "participants" and random slopes for "task" to vary for each participant. We refrained from reporting the main effects of predictors involved in significant interactions below, as their impact was influenced by these interactions. Nonetheless, their parameter estimates are detailed in the Appendix.

Table 3.3

The best-fitting models of closeness, perceived similarity and state empathy

Dependent variable	Fixed effects	Random effects	AIC	BIC
Closeness	(Condition * Task) + Tempo	(1+Task|Participant)	17705.7	17783.6
Perceived similarity	(Condition * Empathy) + (Condition * Task) + Tempo	(1+Task|Participant)	17512.8	17612.9
State empathy	(Condition * Empathy) + (Condition * Task) + Tempo	(1+Task|Participant)	16590.1	16690.2

Note. AIC: Akaike information criterion; BIC: Bayesian information criterion. The asterisks indicate an interaction between predictors. All models allowed for random intercepts for "participants" and random slopes for "task" to vary within each participant.

Effects of trait empathy

Empathy did not improve the fit of the *closeness* model (Table 3.3) and was therefore excluded. However, the *perceived similarity* and *state empathy* models indicated a significant interaction between empathy and the experimental conditions (see Appendix for parameter estimates). Post-hoc analysis (Table 3.4 & Figure 3.2) revealed that higher trait empathy was associated with stronger increases in perceived similarity and state empathy in Condition 1 (synchronous, in-phase).

Table 3.4

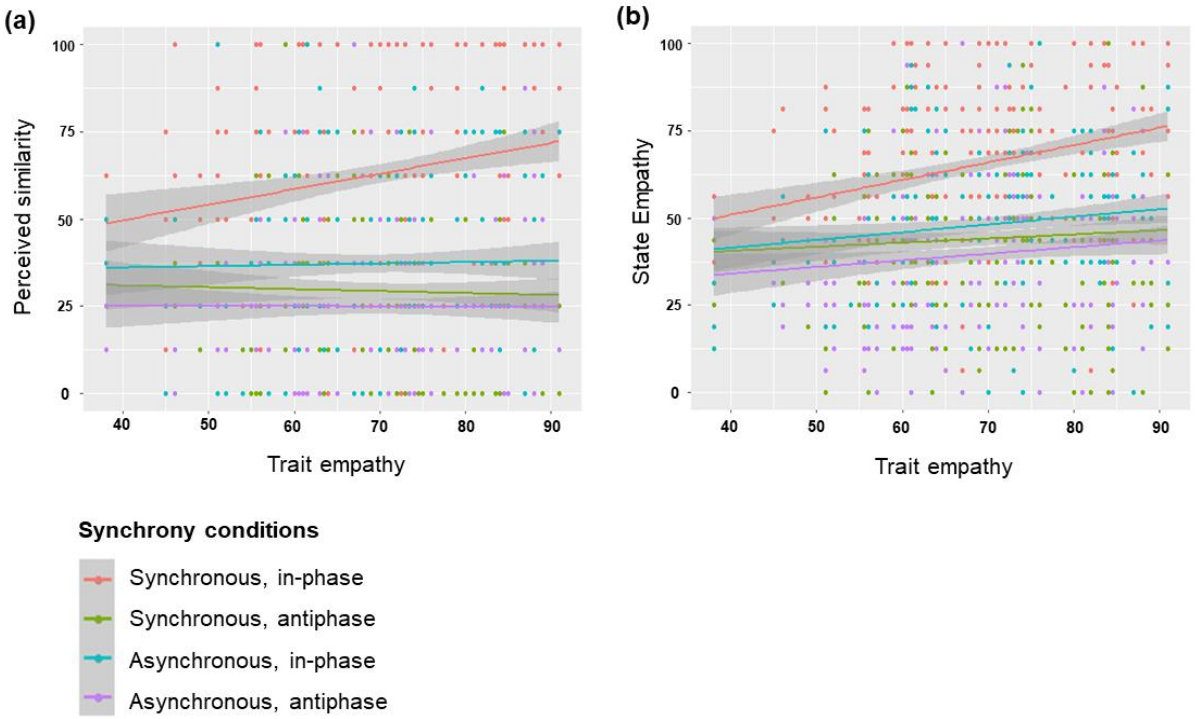
Estimated Mean Trend (EMtrend) of empathy for each synchrony condition on perceived similarity and state empathy.

Model	Condition	EMtrend (Empathy)	*SE*	95% CI	*df*	*t*	*p*	η_p^2
Perceived similarity	Synchronous, in-phase (Cond. 1)	**0.48**	**0.16**	**[0.15, 0.81]**	**135**	**2.93**	**.003****	**0.01**
	Synchronous, antiphase (Cond. 2)	-0.01	0.16	[-0.34, 0.31]	135	-0.06	0.94	0.01
	Asynchronous, in-phase (Cond. 3)	0.08	0.16	[-0.24, 0.41]	135	0.49	0.62	0.01
	Asynchronous, antiphase (Cond. 4)	0.03	0.16	[-0.29, 0.36]	135	0.20	0.83	0.01
State empathy	Synchronous, in-phase (Cond. 1)	**0.49**	**0.15**	**[0.19, 0.80]**	**115**	**2.62**	**.001****	**0.009**
	Synchronous, antiphase (Cond. 2)	0.11	0.15	[-0.19, 0.42]	115	-3.92	0.45	0.009
	Asynchronous, in-phase (Cond. 3)	0.22	0.15	[-0.08, 0.52]	115	-2.84	0.15	0.009
	Asynchronous, antiphase (Cond. 4)	0.18	0.15	[-0.11, 0.49]	115	-3.18	0.22	0.009

Note. The table indicates that the dependent variables varied significantly in Condition 1 (Synchronous in-phase) as empathy increased. SE: Standard errors associated with the estimated coefficients; CI: Confidence intervals; *df*: Degrees of freedom; *t*-values and *p*-values associated with the estimates. Significance levels: $p<.001$***, $p<.01$**, $p<.05$*; η_p^2*:* Partial eta-squared, a measure of effect size for the interaction between empathy and the synchrony conditions.

Figure 3.2

Linear predictions of (a) perceived similarity and (b) state empathy in relation to participants' trait empathy for every synchrony condition.



Note. Shaded areas represent 95% Confidence Intervals (CI). The figure was produced using the ggplot package (Lenth, 2021) in RStudio (RStudio Team, 2020) (Version 2023.06.0).

A secondary analysis with separate models for each task was conducted to investigate the exclusion of trait empathy from the *closeness* model (Table 3.5). Only the observational task model included a significant interaction between empathy and Condition 2 when compared with Condition 1 (p<.01 - see Appendix for a full report). Post-hoc analysis of that model showed that individuals with higher empathy experienced higher closeness to synchronous in-phase stick figures (Condition 1) and lower closeness to synchronous antiphase figures (Condition 2) than those with lower empathy. Nonetheless, none of these observations were statistically significant (Table 3.6). Figure 3.3 illustrates the linear predictions of closeness for each task in relation to participants' trait empathy for every synchrony condition. Although empathy was omitted from the tapping task model, its linear predictions are depicted here to emphasise the observed tendencies in the observational task.

Table 3.5

The best-fitting models of closeness for each task.

Task	Dependent variable	Fixed effects	Random effects	AIC	BIC
Observational	Closeness	(Condition * Empathy) + Tempo	(1+Condition|Participant) (1|Order)	8795.7	8868.7
Tapping	Closeness	(Condition * Tempo)	(1+Condition|Participant)	8928.3	9006.2

*Note***.** AIC: Akaike information criterion; BIC: Bayesian information criterion. The asterisks indicate an interaction between predictors. Both models allowed for random intercepts for "participants" and random slopes for "condition" to vary within each participant. The observational task model also included a random intercept for the order of tasks (i.e. which task was completed first).

Table 3.6

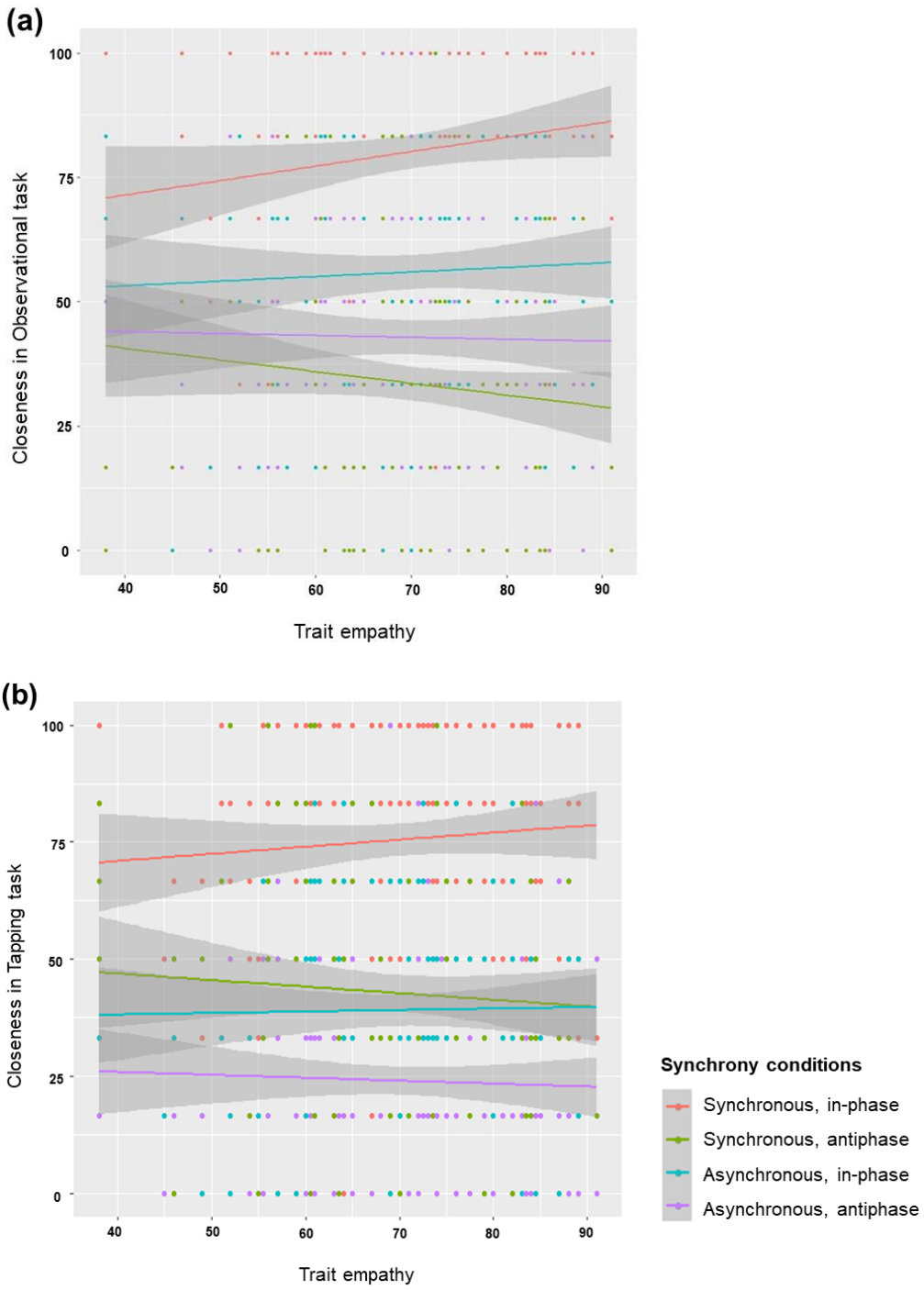
Estimated Mean Trend (EMtrend) of empathy for each synchrony condition on closeness for the observational task.

Model	Condition	EMtrend (Empathy)	*SE*	95% CI	*df*	*t*	*p*	η_p^2
Closeness in observational task	Condition 1	0.27	0.20	[-0.13, 0.67]	100	2.93	0.18	0.03
	Condition 2	-0.25	0.19	[-0.64, 0.13]	149	-0.06	0.19	0.03
	Condition 3	0.07	0.19	[-0.31, 0.46]	147	0.49	0.71	0.03
	Condition 4	-0.05	0.20	[-0.47, 0.35]	100	0.20	0.77	0.03

Note. SE: Standard errors associated with the estimated coefficients; CI: Confidence intervals; *df*: Degrees of freedom; *t*-values and *p*-values associated with the estimates. Significance levels: $p<.001$***, $p<.01$**, $p<.05$*; η_p^2*:* Partial eta-squared, a measure of effect size for the interaction between empathy and the synchrony conditions.

Figure 3.3

Linear predictions of closeness in relation to participants' trait empathy for every synchrony condition in each task separately.



Note. Shaded areas represent 95% Confidence Intervals (CI). The figure was produced using the ggplot package (Lenth, 2021) in RStudio (RStudio Team, 2020) (Version 2023.06.0).

Comparing responses between tasks

All three best-fitting models of the primary analysis (Table 3.3) included a significant interaction between conditions and the tasks (see Appendix for parameter estimates). Post-hoc comparisons showed that participants responded differently to each condition depending on the task, with all differences being significant ($p < .05$, Table 3.7) apart from Condition 1 in the state empathy model. Figure 3.4 illustrates these differences, showing that participants reported higher closeness (η_p^2=0.06), similarity (η_p^2=0.04) and state empathy (η_p^2=0.03) for Conditions 1, 3 and 4 in the observational task than the tapping task. Conversely, Condition 2 (synchronous antiphase) prompted higher social bonding in the tapping task. The estimated marginal means (EMmeans) and confidence intervals (CI) are reported in the Appendix.

Table 3.7

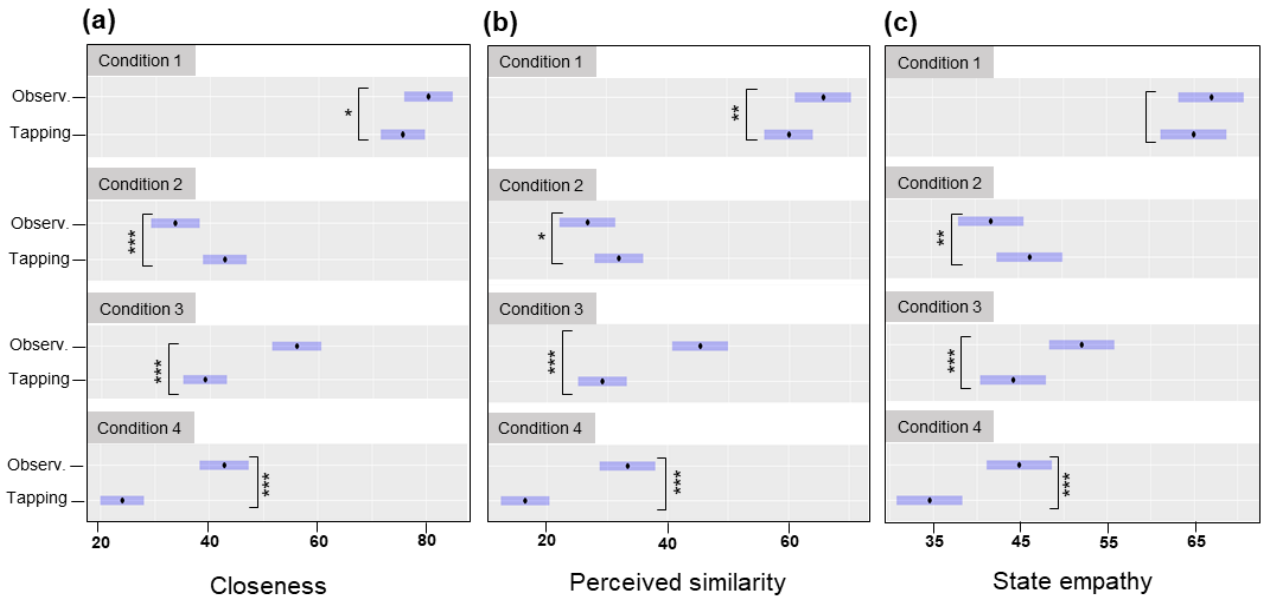
Post-hoc comparisons between tasks for each synchrony condition.

Social bonding	Conditions	Contrast	Estimate	*SE*	*df*	*t*	*p*
Closeness	**Cond. 1**	**Tapping - Observ.**	**-4.72**	**2.38**	**421**	**-1.98**	**0.04***
	Cond. 2	**Tapping - Observ.**	**9.10**	**2.38**	**421**	**3.82**	**<.001*****
	Cond. 3	**Tapping - Observ.**	**-16.88**	**2.38**	**421**	**-7.10**	**<.001*****
	Cond.4	**Tapping - Observ.**	**-18.77**	**2.38**	**421**	**-7.89**	**<.001*****
Perceived Similarity	**Cond. 1**	**Tapping - Observ.**	**-5.68**	**2.12**	**588**	**-2.67**	**.007****
	Cond. 2	**Tapping - Observ.**	**5.16**	**2.12**	**588**	**2.43**	**.01***
	Cond. 3	**Tapping - Observ.**	**-16.09**	**2.12**	**588**	**-7.59**	**<.001*****
	Cond.4	**Tapping - Observ.**	**-16.93**	**2.12**	**588**	**-7.98**	**<.001*****
State Empathy	Cond. 1	Tapping - Observ.	-2.03	1.69	515	-1.20	0.22
	Cond. 2	**Tapping - Observ.**	**4.43**	**1.69**	**515**	**2.627**	**.008****
	Cond. 3	**Tapping - Observ.**	**-7.92**	**1.69**	**515**	**-4.698**	**<.001*****
	Cond.4	**Tapping - Observ.**	**-10.31**	**1.69**	**515**	**-6.119**	**<.001*****

Note. Estimate: The estimated coefficients for each comparison; SE: Standard errors associated with the estimated coefficients; CI: Confidence intervals; *df:* Degrees of freedom; *t*-values and *p*-values associated with the estimates. Significance levels: *p*<.001***, *p*<.01**, *p*<.05*.

Figure 3.4

Estimated Marginal Means (EMmeans) and Confidence Intervals (CI) for the effects of each condition in each task.



Note. "Observ." refers to the observational task. The values of EMmeans and CI are reported in the Appendix. The length of the bars represents the confidence intervals around the estimated means (mid-points). The brackets indicate the post-hoc comparisons between tasks, and the asterisks refer to the significance levels: $p < .001$***, $p < .01$**, $p < .05$*. The figure was produced using the "plot" function in the emmeans package [59] in RStudio [47] (Version 2023.06.0) and edited on Microsoft PowerPoint 2021.

Effects of tempo

In all primary models, music at 125 bpm exhibited significantly higher closeness ($p<.001$, $\eta_p^2=0.008$), similarity ($p< .001$, $\eta_p^2=0.01$) and state empathy ($p< .001$, $\eta_p^2=0.008$) compared to 83 bpm (Table 3.8 & Figure 3.5). This indicates that participants experienced stronger bonding when engaging in trials with faster background music (compared to tempo at 83 bpm), and this was irrespective of the task or synchrony condition.

Table 3.8

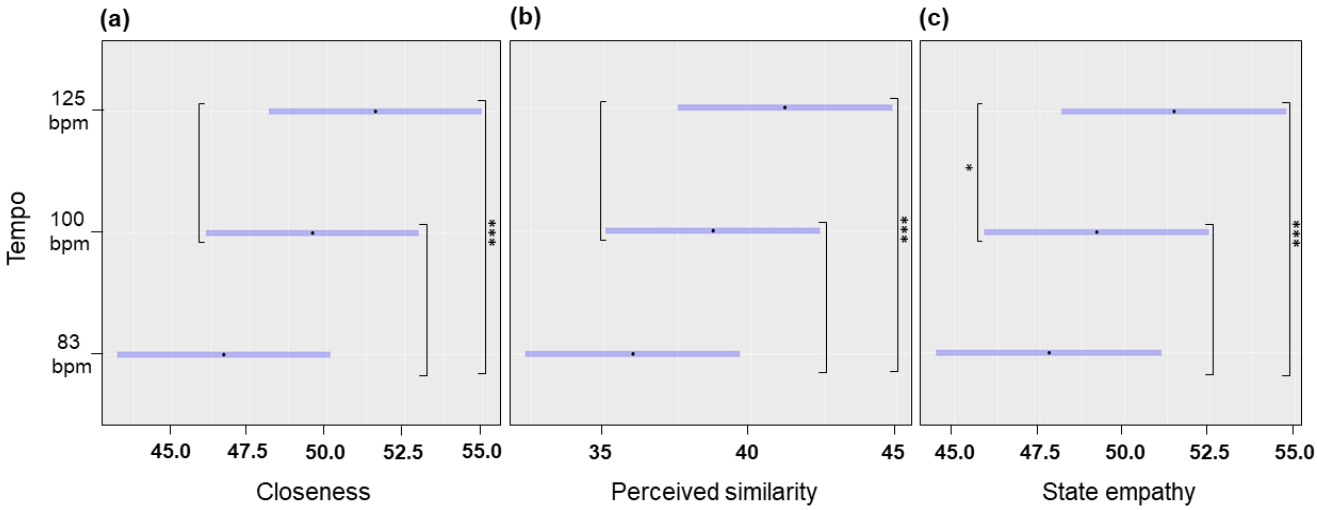
Post-hoc comparisons between levels of tempo in every social bonding model.

Model	Tempi comparisons	Estimate	*SE*	95% CI	*df*	*t*	*p*
Closeness	83 bpm- 100 bpm	-2.85	1.28	[-5.84, 0.15]	1767	-2.22	.06
	100 bpm - 125 bpm	-2.02	1.28	[-5.02, 0.97]	1767	-1.58	.25
	83 bpm - 125 bpm	**-4.87**	**1.28**	**[-7.86, -1.87]**	**1767**	**-3.81**	**<.001*** **
Perceived similarity	83 bpm- 100 bpm	-2.73	1.21	[-5.58, 0.11]	1771	-2.25	.06
	100 bpm - 125 bpm	-2.46	1.21	[-5.31, 0.38]	1771	-2.02	.10
	83 bpm - 125 bpm	**-5.20**	**1.21**	**[-8.04, -2.35]**	**1771**	**-4.28**	**<.001*** **
State Empathy	83 bpm- 100 bpm	-1.41	0.94	[-3.62, 0.80]	1771	-1.49	.29
	100 bpm - 125 bpm	**-2.27**	**0.94**	**[-4.48, -0.05]**	**1771**	**-2.40**	**.04***
	83 bpm - 125 bpm	**-3.67**	**0.94**	**[-5.88, -1.46]**	**1771**	**-3.89**	**<.001*** **

Note. Estimate: The estimated coefficients for each comparison; SE: Standard errors associated with the estimated coefficients; CI: Confidence intervals; *df:* Degrees of freedom; *t*-values and *p*-values associated with the estimates. Significance levels: *p*<.001***, *p*<.01**, *p*<.05*.

Figure 3.5

Estimated Marginal Means (EMmeans) and Confidence Intervals (CI) for the effects of each tempo level.



Note. (a) closeness, (b) perceived similarity and (c) state empathy. The values of EMmeans and CI are reported in the Appendix. The length of the bars represents the confidence intervals around the estimated means (mid-points). The brackets indicate the post-hoc comparisons between tempi, and the asterisks refer to the significance levels: *p*<.001***, *p*<.01**, *p*<.05*. The figure was produced using the "plot" function in the emmeans package (Schmidt et al., 2016) in RStudio (RStudio Team, 2020) (Version 2023.06.0) and edited on Microsoft PowerPoint 2021.

Qualitative results

The thematic analysis aimed to identify the mental states participants attributed to their partners and how these attributions influenced their social bonding experience. Additionally, it sought to discern the extent to which participants put themselves into their partners' shoes and whether this empathic process influenced social affiliation. Table 3.9 summarises the prevailing themes, sub-themes, and examples of participants' responses.

Theme 1: Less pronounced asynchrony fosters compassion, whereas significant deviations amplify social disconnection.

Participants' responses to engaging with partners perceived as synchronous or asynchronous (such terms were only used after being mentioned by participants) revealed their efforts to identify patterns in partners' temporal behaviour. Interacting with partners tapping or walking on alternating beats (Condition 2 - antiphase) was perceived by some as "perfect" (P9) and "more interesting" (P79) than in-phase synchrony, encouraging feelings of satisfaction and connection (Sub-theme 1a). However, when a pattern was not identified, and participants realised they were interacting with a non-synchronous partner, their ratings were influenced by the degree of perceived asynchrony. In particular, when a partner was "slightly off" (P59), participants perceived them as individuals making an effort to synchronise, thereby experiencing sympathy towards them (Sub-theme 1b). Conversely, partners being "wildly off" (P59) were believed to deliberately misalign with the music, a perception that hindered participants' bonding experience (Sub-theme 1c). Altogether, participants' responses revealed that perceived asynchrony does not always prevent social bonding. Minor deviations from expected temporal behaviour can elicit perceptions fostering sympathy, while significant variations create the impression of an uncooperative partner, fostering feelings of disconnection.

Theme 2: The type of musical engagement and the sensory modalities involved influence social bonding.

Active or passive musical engagement also prompted variations in participants' social perceptions. Some reported that the visual elements of the observational task facilitated their ability to imagine their partner when compared to the auditory tapping stimulus, allowing participants to "grasp a [better] feel of the situation" (P60) and imagine actual walking interactions (Sub-theme 2a).

Nonetheless, most individuals preferred the tapping task due to its interactive nature. Specifically, actively engaging with partners amplified the sense of their presence, reinforcing feelings of social connection and closeness stemming from perceived synchrony. Therefore, despite lacking a visual representation of virtual partners, the self-involving nature of the tapping task facilitated connection and bonding with synchronous partners (Sub-theme 2b). However, these characteristics potentially elicited the opposite effects in interactions with seemingly asynchronous partners. Participants noted a heightened ability to detect asynchronies in the tapping task, an experience contributing to more rigid perceptions of their partners. Conversely, observing fluid bodily movements, resembling dancing between participants and their partners, allowed for a broader range of movements to be perceived as synchronous, leading to lenient interpretations of partners' behaviour (Sub-theme 2c). This suggests that perceived asynchrony in the tapping task intensified social disconnection, whereas the observational task prompted more tolerant social perceptions, lessening the negative effects of asynchrony.

Theme 3: Mental attributions foster social bonding despite perceived asynchrony.

Responses from individuals who elaborated on their feelings about non-synchronous partners revealed their attempts to put themselves into their partners' shoes. Despite the absence of physical presence, some participants imagined actual people behind the tapping or stick figures, attributing to them mental states that fostered bonding beyond perceived asynchrony. Specifically, participants tried to justify their partners' asynchronous behaviour, attributing it to unfortunate circumstances or characteristics they also present, such as anxiety or difficulty keeping the beat. These justifications might have prompted feelings of similarity that could have enhanced bonding even when partners were not synchronised (Sub-theme 3a). Furthermore, several participants referred to the state affective empathy questions (6 & 7 - Table 3.1), reporting empathising with individuals regardless of their performance quality (Sub-theme 3b). Similarly, other participants reported feeling connected to partners simply because they participated in the same study (Sub-theme 3c). Altogether, participants' responses revealed their attempts to empathise with the people behind the tapping and walking interactions, attributing to them shared characteristics that fostered sympathy and a sense of similarity despite their asynchronous performance.

Theme 4: Insufficient information or no partner's physical presence challenges the social bonding experience.

Another prevailing theme arose from responses describing difficulty in answering the social bonding questions. Notably, some participants found it difficult to assess their feelings toward virtual partners due to insufficient information about their character (Sub-theme 4a). Some others appeared reluctant to judge their partners based solely on their task performance or felt that perceived synchrony did not influence their responses (Sub-theme 4b). Finally, some participants faced a challenge imagining their partner's presence, making the social bonding questions seem irrelevant (Sub-theme 4c). In summary, these responses indicate that for some, perceived synchrony alone was insufficient to shape social perceptions, or they could not exhibit empathy without their partners' physical presence.

Theme 5: Preferred tempo facilitates social bonding through synchrony, whereas disliked music impedes these effects.

Although not explicitly asked about the music accompanying the tasks, some participants reported that faster tempi boosted their mood, whereas slow tempi made trials feel tiring or boring (Sub-theme 5a). A deeper look into their responses revealed that background music at a preferred tempo encouraged affiliation toward partners or amplified synchrony's bonding effects. Similarly, disliked music, or a tempo perceived as mismatched with participants' mood during the tasks, hindered social connection, even when synchrony was seemingly attained (Sub-theme 5b).

Table 3.9

Themes, sub-themes and examples from participants' interview responses

Themes	Sub-themes	Example
1: Less pronounced asynchrony fosters compassion, whereas significant deviations amplify social disconnection.	**a)** Antiphase temporal behaviour encourages social bonding.	P76: "When it was not on me but it was doing the complimentary, I liked it so much, that's where the satisfaction was, I felt the connection there."
	b) Perceptions of "slightly off" partners being prompt compassion.	P39: I feel like it's like someone who's not so very not necessarily used to the beat, but you know they're trying it. They got some kind of sense of it. I felt quite connected. I guess you would be empathetic, you know, that they're trying to get in there like a little bit."
	c) Perceptions of "wildly off" partners amplify disconnection.	P59: "People who were wildly off, I was just thinking, well, you did not even try…I suddenly didn't care how they felt because, realistically, they're not doing as they're told."
2: The type of musical engagement and the sensory modalities involved influence social bonding.	**a)** Imagination and bonding enhanced by visuals resembling walking.	P60: "It's easier to grasp a feel of the situation when you're seeing it." P70: I liked the stick figures because it felt like I'm walking on the road with the other person.
	b) Active engagement in the tapping task facilitates imagination and bonding.	P32: "I was making the movements, and I had the rhythm and was thinking that was synchronising with someone who is a real person. That had an effect on my decisions and how close I felt to the other person."
	c) Perceptions of partners depending on the type of stimulus.	P10 about the tapping task: "In the tapping task, although we were in the same room hypothetically and did the same task, I didn't have the same empathy, maybe because it was more...I became more rigid" P68 about the observational task: "The figures were not synchronised, but the 2nd figure was on the rhythm in a different way, just in a different way, so it didn't bother me as much that it did something different to the other figure." P44 about the observational task: I found like trying to focus on the blue person, imagining that to be me and then thinking about the other person is quite an interesting task to kind of relate with those objects and how it felt like when we were matching in movement, like dancing in the video
3: Mental attributions foster social bonding despite perceived asynchrony	**a)** Participants justify their partner's asynchrony.	P10: "I answered that I "match" a bit with the other person, or it reminds me a bit of myself because they make an effort to follow...Because I have been many times…unable to get into the rhythm. Even when they were unsuccessful or made a mistake on the rhythm, I felt that okay, I match with them even a little bit."
	b) Participants experience empathy regardless of perceived asynchrony.	P30: "I would always put quite a lot [in the state empathy questions] because I don't want, like, I think, I would feel sad or happy if I see the other person sad or happy regardless of how they walk or how they ring the bell so yeah." P41: "I semi-consciously answered that I would feel happy if I saw them happy and a bit sad if I saw them sad because I understand that the way that someone perceives music doesn't define their personality. It's a skill that some people have, and some people don't; it's built as we go along."
	c) Participants seek shared characteristics that bond them with their partners.	P64: "They must be somewhat similar to me, a bit similar because they've agreed to take part, so there's a connection there."

4: Insufficient information or no partner's physical presence challenge the social bonding experience.	**a)** Insufficient information	P10: "In the other questions, they were a bit more vague - how can you understand from 15 seconds of dancing or tick-tick some things about the character of the other person? So I was more spontaneous; I wasn't thinking about it too much."
	b) Reluctant to judge based on perceived synchrony or no experienced differences.	P78: "The question about whether the other person is like you is a question I wouldn't ask because I wouldn't judge if someone dances like me or has the same synchronisation as me. So I personally would like to say, "not at all" in all of those, but I didn't do it because, okay, maybe they had some commonalities with me."
	c) Difficulty answering without partners' physical presence.	P74: "I might have responded differently if it was a real person, but I don't get on well being told to imagine another person because it could be anybody, and I don't know."
		P62: It's indifferent thinking if they're sad, I'm sad I don't know it's relevant, you know, to the task. That's what I'm saying. Unless I know them and see them what's going on then. I can't really from this music exercise alone. I can't tell whether I can sympathise or feel with that person.
5: Preferred tempo facilitates social bonding through synchrony, whereas disliked music impedes these effects.	**a)** Direct effects of fast/slow tempo on mood.	P19 (Fast tempo): "I was like a bit more invigorated with it and felt, yeah, that it matched how I wanted to feel today."
		P86 (Slow tempo): "When it was going slower, that tired me up like I was waiting for the next video."
	b) Preferred and disliked music/tempo.	P78 (Preferred tempo): "I believe that the piece of music plays a role as well, e.g. for me, I like fast tracks and when it is more danceable, so depending on my mood and what I want to listen… If, for example, it was a faster track and we matched, I would feel them closer to me than if it was a slow one and we matched."
		P79 (Disliked tempo): "The slower ones, even if I was in line with them, I felt less kind of connected."

Discussion

The study employed a mixed-methods approach to investigate how trait empathy influences synchrony's bonding effects in musical engagements involving active or passive interactions with virtual partners and background music varying in tempo. Additionally, the qualitative interviews explored the social perceptions that participants attributed to their virtual partners and how these influenced the experience of social affiliation. This approach advances our understanding of the empirically observed relationships between synchronisation, empathy and social bonding, enabling the investigation of factors that mediate or are responsible for the observed relations.

Effects of trait empathy

The quantitative results supported our first hypothesis (H1), demonstrating that individuals with higher trait empathy experienced stronger social bonding than those with lower empathy when interacting with synchronous partners in both tasks. However, this only applied to perceived similarity

and state empathy and not to closeness, in contrast to Stupacher et al.'s findings (2022). Secondary analyses looking into this contradiction revealed that higher trait empathy was associated with stronger closeness for Condition 1 (synchronous, in-phase) and amplified disconnection for Condition 2 (synchronous, antiphase) in the observational (as in Stupacher et al. 2022) but not in the tapping task. However, this finding was not statistically significant. Looking at Figure 3.4, all participants tended to report higher ratings for Condition 1 and lower ratings for Condition 2 in the observational than in the tapping task; therefore, the outcome of these secondary analyses, although not significant, implies that highly empathic individuals might have experienced these effects to a greater extent.

A potential explanation of this finding, aligning with our rationale for hypothesis H2, lies in the visual aspects of the observational task. Empathy utilises internal simulations of others' actions (de Waal, 2008), enabling affective responses that foster emotional connection. Highly empathic individuals have also demonstrated greater accuracy at decoding musicians' expressive intentions presented via audiovisual stimuli (Wöllner, 2012). It is possible, therefore, that the stick figures offered a clearer representation of partners' bodily motions, with those with higher empathy utilising this information better to decode partners' intentions. The observational task also illustrated both "self" and "others'" movements, facilitating the imagination of actual walking interactions, as revealed by interview responses composing Sub-theme 2a (Table 3.9). Given the proposed shared neural basis for imagination and empathy (Gaesser, 2013), individuals with higher empathy were potentially better at imagining walking with their partners. Therefore, in-phase interactions enhanced their perceived psychological proximity, leading to higher reports of closeness, whereas antiphase movements exhibited the opposite effects. Such empathic motor imagery was less strong for the auditory condition, despite the close relationship between rhythm and movement in music and participants' limited musical performance experience may play a role here.

Turning to the effects on perceived similarity and state empathy, our findings are consistent with previous research suggesting that individuals appraise a given situation and their relationship with a partner before exhibiting empathy (Lamm et al., 2007). It is plausible that perceived synchrony with a virtual partner created an environment of shared understanding and mentalising (Baimel et al., 2018), boosting participants' feelings of similarity with partners. Concurrently, perceived synchrony fostered

feelings of similarity (Rabinowitch & Knafo-Noam, 2015), encouraging participants to empathise with those perceived as similar (de Vignemont & Singer, 2006). Given that empathic responses are determined by both dispositional elements and situational appraisals (de Vignemont & Singer, 2006), synchrony enabled individuals with higher empathy to experience the aforementioned effects to a greater extent.

This interpretation appears consistent with Themes 1b and 3 from the qualitative data, demonstrating that participants appraised the musical interactions utilising information from partners' temporal behaviour and attributed characteristics and developing social perceptions that fostered affiliation. Sub-theme 1b revealed that participants inferred from less pronounced asynchrony that their virtual partners were making an effort to synchronise, an assumption that prompted sympathy for them. In addition, Theme 3 revealed participants' efforts to put themselves into their partners' shoes, justifying their asynchrony or seeking shared characteristics to bond beyond perceived alignment. The themes indicate that, in addition to bottom-up information through perceived synchrony, participants utilised their cognitive empathy to understand their partners' intentions (Teufel et al., 2010). As a result, individuals with higher empathy potentially utilised the social cues of synchrony better (Cirelli et al., 2014), perceiving synchronous partners as more similar and easier to understand.

Active and passive musical engagement

There was no evidence supporting an interaction between trait empathy and the type of musical engagement, as previously hypothesised (H2). Nonetheless, post-hoc analyses of the observed interaction between synchrony and tasks, along with participants' interview responses in Theme 2, revealed that they experienced higher bonding in the observational than in the tapping task for three out of the four conditions (Figure 3.4). These results could be attributed to the auditory nature of the tapping task. Previous research has shown that individuals synchronise their movements more accurately to auditory than visual stimuli (Iversen et al., 2015), suggesting an amplified sensitivity to timing discrepancies when rhythm is perceived via auditory cues. Indeed, as Sub-theme 2c showed, participants could notice more synchrony-related variations in the tapping task, contributing to rigid perceptions of the tapping partners. In addition, the tapping task created the impression of actively working towards a shared goal with a partner, possibly resulting in participants feeling annoyed when

partners were not conducive to that. Simultaneously, the stick-figures movements resembled walking or dancing interactions (Sub-theme 2a), allowing for more movements to be perceived as synchronous, leading to more lenient social perceptions (Sub-theme 2c). Additionally, the observational task did not require active contribution to a common goal, thereby not undermining participants' affiliation when a partner was perceived as less cooperative.

An alternative interpretation stems from the audiovisual features of the observational task, offering a better representation of the virtual partners, as highlighted earlier. Previous research has demonstrated that synchronisation accuracy improves when individuals interact with social stimuli representing real people or situations (Honisch et al., 2021; Howard et al., 2021). This aligns with Theme 4 from the qualitative data, where participants reported difficulty assessing their bonding feelings without relevant information (Sub-theme 4a) or partners' presence (Sub-theme 4c). These themes underscore individuals' need to engage with real partners or stimuli conveying social information before assessing any experienced affiliation. Considering these, it is possible that the stick figures' movements offered additional information about virtual partners, facilitating the imagination of their intentions (Theme 2a) and leading to stronger bonding.

Finally, the quantitative analysis revealed stronger bonding effects for the synchronous antiphase condition in the tapping than in the observational task. This aligns with sub-theme 1a from the qualitative data, where participants described alternating tapping as more interesting and satisfying than in-phase tapping. It is possible that the active engagement resembled an actual music-making experience, with musical partners performing different but complementary parts of a larger rhythmic pattern. This experience might have, therefore, led to positive evaluative responses and, thereby, bonding with "antiphase" partners.

Background music and tempo

The significant main effect of tempo in all models supports hypothesis H4 and resonates with prior research emphasising music's pivotal role in the social outcomes of joint actions (Stupacher et al., 2020). As hypothesised, music at 125 bpm prompted higher social bonding compared to 83 bpm across all conditions and tasks, an effect potentially finding its roots in the impact of fast tempi on emotions (Gagnon & Peretz, 2003). It is plausible that faster music acted as a reward mechanism by boosting

participants' moods, leading to positive perceptions of virtual partners (Fiveash et al., 2023; Kokal et al., 2011). This is supported by participants' interview responses in Sub-theme 5a, reporting that faster tempi enhanced their mood while slower tempi fatigued them, potentially affecting their affiliative responses. Nonetheless, the relatively small effect size here necessitates further research to determine the implications of these findings.

Although the linear models did not demonstrate an interaction between tempo, synchrony and empathy to support hypotheses H5 and H6, Sub-theme 5b of the qualitative analysis revealed that music at a preferred tempo potentially enhanced synchrony's bonding impact, an effect also observed in Stupacher et al. (2020). On the contrary, disliked music hindered social bonding, even when synchrony was seemingly attained. These findings add to the notion that during musical interactions, individuals utilise bottom-up information, such as perceived synchrony while appraising the context of their interaction to experience social affiliation (Teufel et al., 2010). Therefore, preferred music potentially contributed to participants' top-down appraisals, influencing the impact of bottom-up stimuli and, subsequently, the social outcomes of synchrony (Tunçgenç, 2023).

Implications

Our findings highlight the importance of employing mixed-methods research to investigate complex relationships between factors that influence the outcomes of synchrony through music. A recently proposed framework (Rabinowitch, 2023) suggests that the nature of synchrony's social effects relies on a balance between tight temporal alignment and looseness in meaning and expression during joint interactions, while music-making should not be separated from its context and the perspectives or expectations of those involved (Timmers et al., 2023). Indeed, the present mixed-methods approach uncovered important mediating factors such as individuals' mood, preferences and mentalising that need to be considered in future research. Consequently, exploring qualitatively participants' conceptualisations and the appraisal processes occurring during experimental tasks is recommended to fully understand what contributes to synchrony altering social behaviour through music.

The observed impact of empathy on how synchrony facilitates social bonding also offers empirical evidence for a bidirectional relationship between synchronising and empathising, previously proposed by the positive feedback loop model (Tzanaki, 2022). According to this framework, empathy

and synchrony can enhance one another simultaneously under appropriate circumstances, and the present study empirically confirmed the impact of empathy on synchrony's capacity to affect social bonding. Despite the small effect sizes, our findings could significantly inform interventions utilising the synchrony-empathy link to encourage children's simultaneous musical and social development, as well as foster bonding across inter-group members (Espinosa et al., 2023; Tunçgenç & Cohen, 2016).

Limitations and future research

Although assistance was available throughout, no additional measures were taken to verify Greek-speaking participants' fluency in English and the impact of their interpretations on their responses. Furthermore, three participants reported internet connection problems, potentially leading to subtle video or audio delays. While acknowledging such setbacks commonly experienced in online studies, we believe they have not adversely affected our results, given the ability of linear mixed-effects models to account for individual variability. Finally, the large number of trials left some participants feeling fatigued. This is common in lab-based studies requiring repeated measures to decrease participant variability and increase statistical power (Vickers, 2003). To minimise participant fatigue while ensuring statistical power, we did not randomise the order of social bonding questions. Nonetheless, we acknowledge that this approach presents limitations in potentially inducing learning effects or impulsive responses.

Further to investigating empathy as a total score of participants' responses to IRI, looking into each subscale separately could be beneficial for future research. Previous studies have shown that empathic concern predicts spontaneous movement to music (Zelechowska et al., 2020), perspective-taking facilitates synchrony with a partner (Novembre et al., 2029), and fantasy influences the intensity of emotions experienced with sad music (Vuoskoski & Eerola, 2012). Therefore, each dimension might contribute differently to synchrony's social outcomes. Finally, forthcoming research could replicate the present tasks using human stimuli and live scenarios with two participants. One could hypothesise that synchronising with videos of actual people tapping or walking might facilitate sensorimotor coupling, reinforcing the effects of synchrony (Howard et al., 2021) and the role of empathy.

Conclusion

The study demonstrated that the social effects of synchrony are not simply a matter of stimulus-response but rather a combination of bottom-up and top-down processes, with individuals' conceptualisations and mentalising playing a significant role in the experience of social affiliation. Individuals' trait empathy was found to influence the intensity of social bonding evoked from interpersonal synchrony, with results implying that this might be modality-dependent, at least for individuals with limited musical experience. Finally, the study highlighted the importance of employing mixed-methods approaches in this context, as they can provide appropriate context to quantitative findings and valuable insights into participants' experiences that might otherwise be overlooked.

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Appendix

Demographics questionnaire

No	Question	Available responses
1	"What is your age?"	18-24 / 25-34 / 35-44 / 45-54 / 55-64 / 65 and over Prefer not to say
2	"Which of the following describes how you think of yourself?"	Female / Male / Prefer not to say / Other (Free text)
3	"Do you consider yourself a musician?"	Yes / No / Maybe
4	"Have you ever had any formal musical training or other musical experience (e.g. learning to play an instrument by yourself)? If yes, please provide details regarding when and how long for."	Free text

Music excerpts

No	Title	Artist	Copyright information
1	Funk Interlude	Dysfunction_AL	(c) Copyright 2016. Licensed under a Creative Commons Attribution-Noncommercial (3.0) license. http://dig.ccmixter.org/files/destinazione_altrove/53756 Ft: Fourstones - Scomber (Bonus Track)
2	Funk to blame	Martijn de Boer (NiGiD)	(c) Copyright 2018. Licensed under a Creative Commons Attribution-Noncommercial (3.0) license. http://dig.ccmixter.org/files/NiGiD/58126 Ft: unreal_dm
3	Staying positive	spinningmerkaba	(c) Copyright 2019. Licensed under a Creative Commons Attribution-Noncommercial (3.0) license. http://dig.ccmixter.org/files/jlbrock44/59438 Ft: greg_baumont
4	Your Call	Kevin MacLeod (incompetech.com)	Licensed under a Creative Commons By Attribution (4.0) license

Stimulus sets

Participants completed 12 trials in each task, encountering all four synchrony conditions in three tempi. Notably, the musical excerpts were repeated in all synchrony and tempi conditions for every four participants, resulting in four stimuli sets. Each set was presented in four randomised orders, leading to a total of 16 combinations. The table below illustrates the four stimulus sets.

Stimulus sets	Tempo	Condition 1	Condition 2	Condition 3	Condition 4
Stimulus set 1	83 bpm	Your Call	Funk Interlude	Funk to blame	Staying Positive
	100 bpm	Funk Interlude	Funk to blame	Staying Positive	Your Call

	125 bpm	Funk to blame	Staying Positive	Your Call	Funk Interlude
Stimulus set 2	83 bpm	Staying Positive	Your Call	Funk Interlude	Funk to blame
	100 bpm	Your Call	Funk Interlude	Funk to blame	Staying Positive
	125 bpm	Funk Interlude	Funk to blame	Staying Positive	Your Call
Stimulus set 3	83 bpm	Funk to blame	Staying Positive	Your Call	Funk Interlude
	100 bpm	Staying Positive	Your Call	Funk Interlude	Funk to blame
	125 bpm	Your Call	Funk Interlude	Funk to blame	Staying Positive
Stimulus set 4	83 bpm	Funk Interlude	Funk to blame	Staying Positive	Your Call
	100 bpm	Funk to blame	Staying Positive	Your Call	Funk Interlude
	125 bpm	Staying Positive	Your Call	Funk Interlude	Funk to blame

Interview questions

No	Interview questions in English	Interview questions in Greek
1	Can you tell me about your experience today? Feel free to mention anything you liked or didn't like or any thoughts you had during the study.	Μπορείς να μου πεις για την εμπειρία σου σήμερα; Μπορείς να αναφέρεις οτιδήποτε σου άρεσε ή δεν σου άρεσε ή όποιες σκέψεις μπορεί να είχες κατά τη διάρκεια της έρευνας.
2	How did you feel when the other participant was doing something similar to you, and how was it when they didn't? (Do not mention "synchronous" or "asynchronous" unless mentioned by interviewees first).	Πώς ένιωσες όταν ο άλλος συμμετέχοντας έκανε κάτι παρόμοιο με σένα και πως ήταν όταν έκανε κάτι διαφορετικό; (Μην αναφέρεις "συγχρονισμένος" ή "μη συγχρονισμένος" εκτός κι αν το αναφέρει πρώτος ο συμμετέχοντας).
3	Which task did you enjoy more? And why?	Ποια άσκηση (τασκ) σου άρεσε πιο πολύ; Και γιατί;
4	About the questions you answered after every tapping and video trial - How was it answering these questions about the other participant? / How did you find these questions?	Όσον αφορά τις ερωτήσεις που απάντησες μετά από κάθε χτύπημα ή βίντεο - Πως ήταν το να απαντήσεις σε αυτές στις ερωτήσεις για τον άλλον συμμετέχοντα; / Πως βρήκες τις ερωτήσεις;
5	Some of the tapping recordings (the bells) we used were created by actual people, others were generated by a computer, and others were a mix of both. These were randomly allocated to every participant. Which type of tapping, do you think, was allocated to you/ you heard?	Κάποια από τα χτυπήματα (οι καμπανούλες) που χρησιμοποιήσαμε ήταν από πραγματικούς ανθρώπους, κάποια ήταν φτιαγμένα στον υπολογιστή και κάποια ήταν ένα μιξ. Η κάθε περίπτωση επιλέχτηκε τυχαία για κάθε συμμετέχοντα. Τι πιστεύεις ότι άκουσες εσύ;
6	Do you think the present project investigates something different to what I told you earlier?	Πιστεύεις ότι η έρευνα μελετάει κάτι διαφορετικό από αυτό που σου είπα νωρίτερα;
7	(Optional) Is there anything else you would like to add?	(Προαιρετικό) Υπάρχει κάτι άλλο που θα ήθελες να προσθέσεις;

Assumption tests for linear mixed-effects models (LMEs)

The final models were subjected to tests for the assumptions of 1) normality of residuals, 2) linearity, and 3) homoscedasticity. The tests involved creating and assessing Quantile-Quantile (Q-Q) plots depicting residuals, plots illustrating the relationship between residuals and fitted values, and Scale-Location (Spread-Location) plots for assessing homoscedasticity. The analyses were performed using the R package "lattice" (Sarkar, 2008) in R Studio (RStudio Team, 2020). The code utilised to conduct these tests can be found here: https://doi.org/10.15131/shef.data.24960687

Key for the following tables

Short name	Explanation
Task 1	The tapping task
Task 2	The observational task
Condition 1	Synchronous in-phase
Condition 2	Synchronous antiphase
Condition 3	Asynchronous in-phase
Condition 4	Asynchronous antiphase
Tempo 1	83 bpm
Tempo 2	100 bpm
Tempo 3	125 bpm
EmpTotal	Total Score of Empathy

Cumulative mixed-effects models (CLMMs)

The file containing the code used to run CLMMs with the data of the study in R Studio (RStudio Team, 2020) can be found here: https://doi.org/10.15131/shef.data.24960687. The table below presents the summary() output for the cumulative models of a) closeness, b) perceived similarity, and c) state empathy.

a) Closeness

Predictors	*β*	*SE*	*z*	*p*
Condition 2	**-2.62**	**0.17**	**-14.59**	**<.001*** **
Condition 3	**-2.83**	**0.17**	**-15.89**	**<.001*** **
Condition 4	**-4.10**	**0.19**	**-21.55**	**<.001*** **
Task 2	**0.56**	**0.20**	**2.76**	**.005** **

Tempo 2	**0.20**	**0.10**	**2.00**	**.045***
Tempo 3	**0.41**	**0.10**	**3.98**	**<.001*****
Condition 2 * Task 2	**-1.23**	**0.24**	**-5.02**	**<.001*****
Condition 3 * Task 2	**0.65**	**0.24**	**2.72**	**.006****
Condition 4 * Task 2	**0.97**	**0.24**	**3.96**	**<.001*****

Note. Reference levels: Condition 1 (synchronous, in-phase) for conditions; Task 1 (tapping) for tasks; Tempo 1 (83 bpm) for tempi. Significance levels: *p*< .001***, *p*< .01**, *p*< .05*.

b) Perceived similarity

Predictors	*β*	*SE*	*z*	*p*
Condition 2	0.61	0.74	0.82	.407
Condition 3	-0.12	0.74	-0.16	.870
Condition 4	-0.81	0.75	-1.07	.282
EmpTotal	**0.03**	**0.01**	**2.05**	**.040***
Task 2	**0.53**	**0.18**	**2.95**	**.003***
Tempo 2	**0.22**	**0.10**	**2.18**	**.028***
Tempo 3	**0.45**	**010**	**4.35**	**<.001*****
Condition 2 * EmpTotal	**-0.04**	**0.01**	**-3.87**	**<.001*****
Condition 3 * EmpTotal	**-0.03**	**0.01**	**-3.16**	**.001****
Condition 4 * EmpTotal	**-0.04**	**0.01**	**-3.76**	**<.001*****
Condition 2 * Task 2	**-0.98**	**0.23**	**-4.12**	**<.001*****
Condition 3 * Task 2	**0.75**	**0.23**	**3.19**	**.001****
Condition 4 * Task 2	**1.01**	**0.23**	**4.19**	**<.001*****

Note. Reference levels: Condition 1 (synchronous, in-phase) for conditions; Task 1 (tapping) for tasks; Tempo 1 (83 bpm) for tempi. Significance levels: *p*< .001***, *p*< .01**, *p*< .05*.

c) State empathy

Predictors	*β*	*SE*	*z*	*p*
Condition 2	0.60	0.74	0.80	.421
Condition 3	-0.36	0.75	-0.48	.628
Condition 4	-0.46	0.75	-0.61	.538
EmpTotal	**0.04**	**0.02**	**2.14**	**.032***
Task 2	0.28	0.19	1.47	.140
Tempo 2	0.00	0.10	0.02	.976

Tempo 3	0.16	0.10	1.56	.117
Condition 2 * EmpTotal	**-0.02**	**0.01**	**-2.72**	**.006****
Condition 3 * EmpTotal	-0.01	0.01	-1.50	.132
Condition 4 * EmpTotal	**-0.02**	**0.01**	**-2.25**	**.024***
Condition 2 * Task 2	**-0.48**	**0.24**	**-2.02**	**.042***
Condition 3 * Task 2	0.23	0.24	0.97	.330
Condition 4 * Task 2	0.34	0.24	1.44	.148

Note. Reference levels: Condition 1 (synchronous, in-phase) for conditions; Task 1 (tapping) for tasks; Tempo 1 (83 bpm) for tempi. Significance levels: *p*< .001***, *p*< .01**, *p*< .05*.

Primary data analysis

A file containing the code used to run the primary data analysis in R Studio (RStudio Team, 2020) can be found here: https://doi.org/10.15131/shef.data.24960687.

Parameter estimates for all predictors in all primary models

The tables below display the results obtained from the summary() function for all best-fitting models of the primary analysis (a) closeness, b) perceived similarity and c) state empathy). These include the main effects of predictors involved in significant interactions, which were not reported in the Results section.

a) Closeness:

Predictors	*β*	*SE*	*df*	*t*	*p*
(Intercept)	**72.91**	**2.16**	**266.04**	**33.64**	**<.001*** **
Condition 2	**-32.77**	**2.08**	**1759.04**	**-15.76**	**<.001*** **
Condition 3	**-36.38**	**2.08**	**1759.04**	**-17.49**	**<.001*** **
Condition 4	**-51.45**	**2.08**	**1759.04**	**-24.74**	**<.001*** **
Task 2	**4.72**	**2.36**	**416.23**	**1.99**	**.046***
Tempo 2	**2.84**	**1.27**	**1759.11**	**2.23**	**.025***
Tempo 3	**4.87**	**1.27**	**1759.04**	**3.82**	**<.001*** **
Condition 2 * Task 2	**-13.81**	**2.94**	**1759.04**	**-4.69**	**<.001*** **
Condition 3 * Task 2	**12.15**	**2.94**	**1759.04**	**4.13**	**<.001*** **
Condition 4 * Task 2	**14.04**	**2.94**	**1759.13**	**4.77**	**<.001*** **

Note. Reference levels: Condition 1 (synchronous, in-phase) for conditions; Task 1 (tapping) for tasks; Tempo 1 (83 bpm) for tempi. Significance levels: *p*< .001***, *p*< .01**, *p*< .05*.

b) Perceived similarity

Predictors	*β*	*SE*	*df*	*t*	*p*
(Intercept)	**23.42**	**11.61**	**133.91**	**2.01**	**.045***
Condition 2	6.57	8.99	1759.99	0.73	.464
Condition 3	-2.67	8.99	1759.99	-0.29	.766
Condition 4	-12.00	8.99	1759.99	-1.33	.182
EmpTotal	**0.48**	**0.16**	**131.53**	**2.99**	**.003****
Task 2	**5.67**	**2.11**	**581.28**	**2.69**	**.007****
Tempo 2	**2.73**	**1.20**	**1759.99**	**2.26**	**.023***
Tempo 3	**5.19**	**1.20**	**1759.99**	**4.29**	**<.001*****
Condition 2 * EmpTotal	**-0.49**	**0.12**	**1759.99**	**-3.97**	**<.001*****
Condition 3 * EmpTotal	**-0.40**	**0.12**	**1759.99**	**-3.23**	**.001****
Condition 4 * EmpTotal	**-0.45**	**0.12**	**1759.99**	**-3.61**	**<.001*****
Condition 2 * Task 2	**-10.83**	**2.79**	**1759.99**	**-3.88**	**<.001*****
Condition 3 * Task 2	**10.41**	**2.79**	**1759.99**	**3.73**	**<.001*****
Condition 4 * Task 2	**11.25**	**2.79**	**1759.99**	**4.03**	**<.001*****

Note. Reference levels: Condition 1 (synchronous, in-phase) for conditions; Task 1 (tapping) for tasks; Tempo 1 (83 bpm) for tempi. Significance levels: $p < .001$***, $p < .01$**, $p < .05$*.

c) State empathy

Predictors	*β*	*SE*	*df*	*t*	*p*
(Intercept)	**28.36**	**10.81**	**113.65**	**2.62**	**.009****
Condition 2	8.05	6.98	1760.00	1.15	.249
Condition 3	-1.35	6.98	1760.00	-0.19	.845
Condition 4	-8.64	6.98	1760.00	-1.23	.216
EmpTotal	**0.49**	**0.15**	**111.68**	**3.28**	**.001****
Task 2	2.03	1.67	509.04	1.21	.226
Tempo 2	1.40	0.93	1760.00	1.49	.134
Tempo 3	**3.67**	**0.93**	**1760.00**	**3.90**	**<.001*****
Condition 2 * EmpTotal	**-0.38**	**0.09**	**1760.00**	**-3.92**	**<.001*****
Condition 3 * EmpTotal	**-0.27**	**0.09**	**1760.00**	**-2.84**	**.004****
Condition 4 * EmpTotal	**-0.31**	**0.09**	**1760.00**	**-3.18**	**.001****
Condition 2 * Task 2	**-6.45**	**2.16**	**1760.00**	**-2.97**	**.002****
Condition 3 * Task 2	**5.88**	**2.16**	**1760.00**	**2.71**	**.006****

Condition 4 * Task 2	**8.28**	**2.16**	**1760.00**	**3.81**	**<.001*** **

Note. Reference levels: Condition 1 (synchronous, in-phase) for conditions; Task 1 (tapping) for tasks; Tempo 1 (83 bpm) for tempi. Significance levels: *p*< .001***, *p*< .01**, *p*< .05*.

Estimated Marginal Means and Confidence Intervals

In addition to Figures 3.4 and 3.5, the tables below report the results of the emmeans() function, showing their relevant estimated marginal means (EMmeans) and confidence intervals (CI). These refer to the post-hoc analysis conducted to investigate the significant interaction between tasks and synchrony conditions (Task | Condition), as well as the significant main effect of tempo in all models - a) closeness, b) perceived similarity and c) state empathy.

a) Closeness

EMmeans for "closeness" in each task per condition

Condition	Task	EMmean	*SE*	*df*	*CI*
Condition 1	Task 1	75.5	2.05	214	[71.4, 79.5]
	Task 2	80.2	2.27	172	[75.7, 84.7]
Condition 2	Task 1	42.7	2.05	214	[38.7, 46.7]
	Task 2	33.6	2.27	172	[29.1, 38.1]
Condition 3	Task 1	39.1	2.05	214	[35.1, 43.1]
	Task 2	56.0	2.27	172	[51.5, 60.5]
Condition 4	Task 1	24.0	2.05	214	[20.0, 28.1]
	Task 2	42.8	2.27	173	[38.3, 47.3]

Note. Results are averaged over the levels of Tempo. Degrees of freedom method: Kenward-Roger. Confidence level used: 0.95

EMmeans for "closeness" in each tempo level

Tempo	EMmean	*SE*	*df*	*CI*
Tempo 1	46.7	1.73	121	[43.2, 50.1]
Tempo 2	49.5	1.73	121	[46.1, 52.9]
Tempo3	51.5	1.73	121	[48.1, 55.0]

Note. Results are averaged over the levels of Condition and Task. Degrees of freedom method: Kenward-Roger. Confidence level used: 0.95

b) Perceived similarity

EMmeans for “perceived similarity” in each task per condition					
Condition	Task	EMmean	*SE*	*df*	*CI*
Condition 1	Task 1	60.2	2.03	199	[56.2, 64.2]
	Task 2	65.9	2.34	152	[61.3, 70.5]
Condition 2	Task 1	31.9	2.03	199	[27.9, 35.9]
	Task 2	26.7	2.34	152	[22.1, 31.3]
Condition 3	Task 1	29.2	2.03	199	[25.2, 33.2]
	Task 2	45.3	2.34	152	[40.6, 49.9]
Condition 4	Task 1	16.5	2.03	199	[12.5, 20.5]
	Task 2	33.4	2.34	152	[28.8, 38.0]

Note. Results are averaged over the levels of Tempo. Degrees of freedom method: Kenward-Roger. Confidence level used: 0.95

EMmeans for “perceived similarity” in each tempo level				
Tempo	EMmean	*SE*	*df*	*CI*
Tempo 1	36.0	1.85	112	[32.3, 39.6]
Tempo 2	38.7	1.85	112	[35.0, 42.4]
Tempo3	41.2	1.85	112	[37.5, 44.8]

Note. Results are averaged over the levels of Condition and Task. Degrees of freedom method: Kenward-Roger. Confidence level used: 0.95

c) State empathy

EMmeans for “state empathy” in each task per condition					
Condition	Task	EMmean	*SE*	*df*	*CI*
Condition 1	Task 1	64.9	1.92	143	[61.2, 68.7]
	Task 2	67.0	1.90	145	[63.2, 70.7]
Condition 2	Task 1	46.3	1.92	143	[42.5, 50.1]
	Task 2	41.8	1.90	145	[38.1, 45.6]
Condition 3	Task 1	44.2	1.92	143	[40.4, 48.0]
	Task 2	52.1	1.90	145	[48.3, 55.8]
Condition 4	Task 1	34.6	1.92	143	[30.8, 38.3]
	Task 2	44.9	1.90	145	41.1, 48.6]

Note. Results are averaged over the levels of Tempo. Degrees of freedom method: Kenward-Roger. Confidence level used: 0.95

EMmeans for "state empathy" in each tempo level				
Tempo	EMmean	*SE*	*df*	*CI*
Tempo 1	47.8	1.67	103	[44.5, 51.1]
Tempo 2	49.2	1.67	103	[45.9, 52.5]
Tempo3	51.4	1.67	103	[48.1, 54.8]

Note. Results are averaged over the levels of Condition and Task. Degrees of freedom method: Kenward-Roger. Confidence level used: 0.95

Secondary data analysis

A file containing the code used to run the secondary data analysis in R Studio (RStudio Team, 2020) can be found here: https://doi.org/10.15131/shef.data.24960687.

Parameter estimates for all predictors in the separate "closeness" models for each task

The tables below report the summary() function results for the "closeness" models (Table 3.5) for a) the tapping task and b) the observational task separately.

a) LME Closeness model for the tapping task

Predictors	*β*	*SE*	*df*	*t*	*p*
(Intercept)	**70.00**	**3.12**	**306.86**	**22.42**	**<.001*** **
Condition 2	**-34.58**	**3.65**	**864.91**	**-9.45**	**<.001*** **
Condition 3	**-32.50**	**3.76**	**769.89**	**-8.62**	**<.001*** **
Condition 4	**-45.83**	**3.94**	**394.32**	**-11.61**	**<.001*** **
Tempo 2	**9.37**	**3.62**	**799.99**	**2.58**	**.009** **
Tempo 3	7.08	3.62	799.99	1.95	.050
Condition 2 * Tempo 2	-3.12	5.12	799.99	-0.61	.541
Condition 3 * Tempo 2	-9.16	5.12	799.99	-1.79	.073
Condition 4 * Tempo 2	-8.75	5.12	799.99	-1.70	.087
Condition 2 * Tempo 3	8.54	5.12	799.99	1.66	.095
Condition 3 * Tempo 3	-2.50	5.12	799.99	-0.48	.625
Condition 4 * Tempo 3	-8.12	5.12	799.99	-1.58	.113

Note. Reference levels: Condition 1 (synchronous, in-phase) for conditions; Tempo 1 (83 bpm) for tempi. Significance levels: $p < .001$***, $p < .01$**, $p < .05$*.

b) LME Closeness model for the observational task

Predictors	*β*	*SE*	*df*	*t*	*p*
(Intercept)	**59.56**	**14.56**	**98.24**	**4.09**	**<.001*** **
Condition 2	-9.70	12.61	844.32	-0.76	.441
Condition 3	-10.28	13.60	278.94	-0.75	.450
Condition 4	-14.16	15.12	91.67	-0.93	.351
EmpTotal	0.27	0.10	99.11	1.35	.179
Tempo 2	1.56	1.66	799.52	0.94	.347
Tempo 3	3.17	1.66	799.18	1.90	.057
Condition 2 * EmpTotal	**-0.52**	**0.17**	**844.32**	**-2.96**	**.003****
Condition 3 * EmpTotal	-0.19	0.19	278.94	-1.03	.300
Condition 4 * EmpTotal	-0.33	0.21	91.73	-1.55	.122

Note. Reference levels: Condition 1 (synchronous, in-phase) for conditions; Tempo 1 (83 bpm) for tempi. Significance levels: $p < .001$***, $p < .01$**, $p < .05$*.

CHAPTER 4

Study 2: "Actions and feelings in sync: Exploring the reciprocal relationship between synchrony and empathy in children's dyadic musical interactions" (Paper 3)

Forthcoming publication as:

Tzanaki, P., Eerola, T. & Timmers, R. (2024). *Actions and feelings in sync: Exploring the reciprocal relationship between synchrony and empathy in children's dyadic musical interactions.* [Manuscript in preparation]. Department of Music, The University of Sheffield.

Candidate's contribution:

The candidate contributed to the conceptualisation and design of the study, completed data collection and analysis, prepared tables and figures, interpreted the results, and wrote the paper.

Abstract

Drawing from a recently proposed framework supporting a bidirectional relationship between empathy and interpersonal synchrony in musical interactions, the present study investigated three novel aspects of this relationship within children's music-making engagements. Seventy-two pairs of primary school children participated in two musical tasks, examining a) the impact of children's trait empathy on achieving interpersonal synchrony, b) synchrony's effects on social bonding and state empathy following brief musical interactions, and c) the role of trait and experimentally-induced empathy in moderating the bonding effects of synchrony. Findings revealed that cognitive and affective empathy contributed to children's ability to synchronise with one another, particularly when partners' temporal performance was unstable. Furthermore, brief synchronous musical interactions promoted state empathy within pairs; however, perceived asynchrony during a brief interactional task was not sufficient to diminish the bonding effects of musical engagement. Moreover, pairs' gender composition and familiarity within pairs emerged as confounding factors, influencing interpersonal synchrony and the intensity of its social outcomes. This is the first empirical study investigating multiple aspects of the interplay between empathising and synchronising in children, paving the way for future exploration of the mechanisms allowing for a bidirectional relationship. The study outcomes aim to inform musical interventions leveraging the interplay between empathy and synchrony to nurture children's simultaneous musical and social development.

Keywords: interpersonal synchrony; trait empathy; induced empathy; state empathy; socio-emotional development; musical development; social bonding; bidirectional relationship

Introduction

In recent decades, empirical research has highlighted the advantages of musical interactions in shaping children's socio-emotional development, focusing particularly on the positive effects of interpersonal synchrony. For instance, coordinating movements with others has been found to encourage social closeness and similarity among primary school pupils (Rabinowitch & Knafo-Noam, 2015) and promote prosociality in toddlers (Cirelli et al., 2014). Further to these findings, an influential study a decade ago (Rabinowitch et al., 2013) demonstrated that long-term engagement in synchrony and other forms of alignment in musical interactions cultivates the development of affective empathy in children, a crucial skill for social interactions. This finding uncovered an additional role of synchrony, namely its capacity to enable emotional alignment between partners during music-making interactions. This alignment can thereby foster social connections and encourage empathy among children (Cross et al., 2012; Tzanaki, 2022).

While the aforementioned studies showcase an early-in-life impact of synchrony on social relationships and the ability to empathise, evidence from studies in adults' musical interactions suggests a more complex relationship between synchrony and empathy. Novembre and colleagues (2019) observed individuals with high cognitive dispositional empathy synchronising better with their musical partners than those with lower empathy, suggesting that empathy facilitates the internal simulation and subsequent prediction of others' behaviour. This insight has been further reinforced by Bamford and Davidson (2019), who found that those with high empathy are better at re-aligning their movements to music changing unexpectedly. This implies that brain areas responsible for empathising might also be involved in perceiving and understanding temporal changes through music (Overy & Molnar-Szakacs, 2009), thereby supporting synchrony with others. Furthermore, while synchrony has been found to encourage social bonding and empathising in adults (Vicaria & Dickens, 2016; Baimel et al., 2018), two recent studies demonstrated the involvement of empathy in experiencing social affiliation following synchronous interactions. Specifically, highly empathic individuals experienced stronger bonding than those with low empathy when they observed (Stupacher et al., 2022) or actively interacted (Tzanaki et al., 2024) with virtual partners moving or tapping in synchrony with music. These observations suggest

that empathy might play a crucial role not only in understanding others' feelings and mental states but also in perceiving synchrony and experiencing its bonding effects.

This interplay between synchrony and empathy finds its roots in various parallels drawn between these two social processes. Empathy indeed requires one to imagine and align with others' emotional states by putting oneself into their shoes (Singer & Lamm, 2009), while, similarly, synchrony in music-making necessitates predicting and adapting to others' upcoming movements to produce a coherent outcome (Keller, 2014). During both empathising and synchronising, the interacting individuals engage in deliberate or unconscious imitation of one another's expressions and movements while monitoring their own actions and feelings to maintain self-other differentiation (Decety & Lamm, 2006; Fairhurst et al., 2023). Further parallels can be found in studies conducted outside the realm of music. For instance, synchronising with a partner's bodily movements has been found to encourage state empathy, facilitating the sharing of others' mental states (Baimel et al., 2018; Koehne et al., 2016). These findings reinforce the social alignment model (Shamay-Tsoory et al., 2019), which regards motor coordination and the alignment of emotional and cognitive states in social interactions as processes influencing one another bidirectionally. These reciprocal relationships have been utilised in dance therapy, leveraging techniques such as mirroring and behavioural synchrony to enhance cognitive alignment among partners, thereby fostering emotional connection and empathy (Behrends et al., 2012; Castro Jaramillo & Panhofer, 2022).

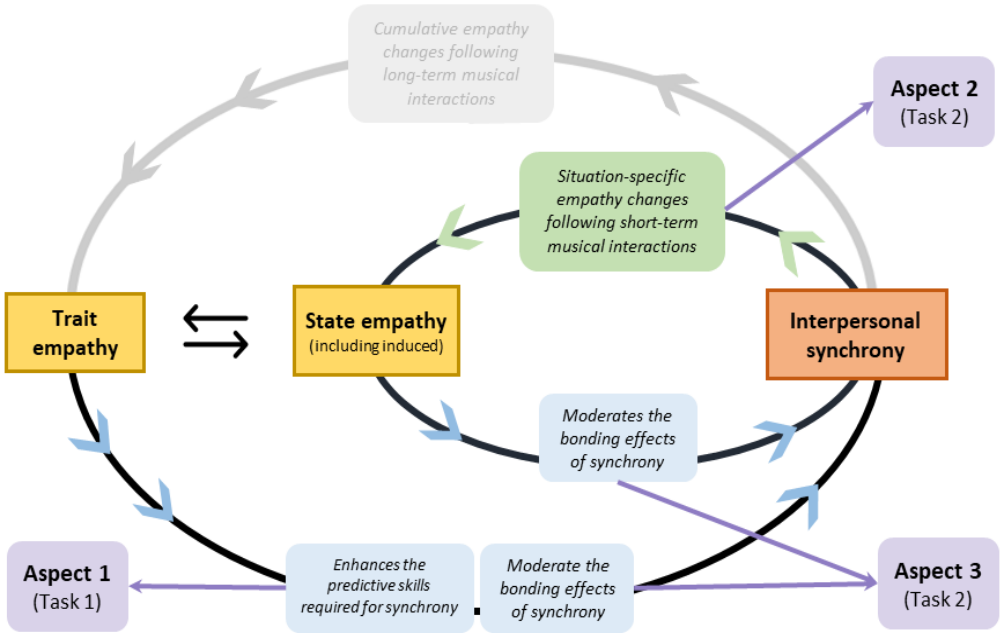
Drawing on such parallels, a theoretical model pertaining to musical interactions was recently developed (Tzanaki, 2022), suggesting that during music-making, synchrony and empathy establish a positive feedback loop, reinforcing one another in a reciprocal manner. More specifically, it has been hypothesised that musical partners utilise their empathic skills to predict and synchronise with their partners' movements (Novembre et al., 2019), while their attained synchrony enhances perceived similarity and affiliation, thereby fostering mentalising and empathy (Baimel et al., 2018). This enhanced empathy, in turn, supports partners' interpersonal synchrony (Novembre et al., 2019) and strengthens its subsequent social bonding effects (Tzanaki et al., 2024). This reciprocal relationship bears significant implications, particularly for children. For example, musical interventions could harness this feedback loop to concurrently enhance children's musical and social skills and promote

interpersonal similarity, surpassing barriers associated with group membership (Tzanaki, 2022). Nonetheless, the model is constructed on evidence primarily from studies in adults, with the implied bidirectional effects remaining largely theoretical. Moreover, there is limited research on the development of crucial unidirectional aspects of the loop, necessitating further exploration before delving into the bidirectional nature of the empathy-synchrony relationship and its implications.

The present study sought to empirically investigate three unidirectional aspects of the relationship between empathising and synchronising, as highlighted by the aforementioned model. This research focused particularly on children's musical interactions to elucidate the development of those processes and their subsequent interplay. Through two experimental tasks (Task 1: *"Free synchrony task"*; Task 2: *"Manipulated synchrony task"*) involving pairs of primary school children, the aspects explored aimed to solidify the empirical basis of the feedback loop model (Tzanaki, 2022), paving the way for future research into its bidirectional nature. Figure 4.1 presents an adapted version of the loop model, highlighting the aspects and research questions being addressed in this study (Table 4.1).

Figure 4.1

The positive feedback loop model (Tzanaki, 2022) adapted to highlight the aspects explored in the present study.



Note. The green and blue boxes match the colours of the arrows to indicate the direction of the effects investigated. The purple boxes and arrows indicate the three aspects explored in the present study. The greyed-out section is part of the model but was not investigated in this study.

Table 4.1

Aspects, research questions, and hypotheses of the present study

Aspect investigated	Research questions	Hypotheses	Task
Aspect 1: The effects of trait empathy on children's interpersonal synchrony	1) Does trait empathy facilitate interpersonal synchrony in children's dyadic musical interactions?	1) Children with higher empathy will synchronise better with their partners.	Task 1: "Free synchrony task"
	2) If yes, which empathic facet (cognitive, affective, somatic) contributes more to these effects?	2) Cognitive and somatic empathy will contribute to children's interpersonal synchrony by supporting the internal simulation of partners' actions and their subsequent temporal alignment (Iacoboni, 2009).	
	3) What is the role of leadership? Do highly empathic children, performing as followers, synchronise better with their partners than those with lower empathy?	3) Leadership assignments will interact with empathy, with highly empathic children synchronising better when instructed to follow.	
Aspect 2: The effects of interpersonal synchrony on children's social bonding and state empathy following short-term musical interactions	4) Does interpersonal synchrony enhance social bonding (closeness, perceived similarity and state empathy) following brief musical interactions?	4) Interpersonal synchrony will enable children to bond with their partners (a) and exhibit state empathy (b).	Task 2: "Manipulated synchrony task"
	5) What are the effects of interpersonal synchrony on children's experience of state empathy following brief musical interactions?		
Aspect 3: The role of empathy (trait and induced) in children's experience of social bonding following interpersonal synchrony.	6) Does trait empathy influence the social bonding effects of interpersonal synchrony in children?	5) Children displaying higher empathy levels will experience stronger social bonding when synchronised with a partner.	Task 2: "Manipulated synchrony task"
		6) Affective empathy will play a more significant role in these effects, considering its association with experiencing others' emotional states.	
	7) Does induced (experimentally manipulated) empathy influence these social bonding effects of synchrony?	7) Children in the induced empathy group will report higher social affiliation following interpersonal synchrony than those not exposed to the fictional story.	
	8) Do the effects of induced empathy change depending on children's trait empathy (is there an interaction between trait and induced empathy)?	8) Children with higher levels of trait empathy will respond more strongly to the empathy manipulation message and experience stronger bonding with their synchronous partners.	

Aspect 1: The effects of trait empathy on children's interpersonal synchrony

Aspect 1 was investigated by Task 1 (*"Free synchrony task"*), replicating elements of Novembre et al.'s study (2019). Specifically, the task explored the role of trait empathy in facilitating

children's interpersonal synchrony during dyadic musical interactions. This novel aspect, not previously investigated in young musical novices, aimed to shed light on the development of children's empathic skills and their involvement in predicting and adapting to partners' temporal behaviour. Similarly to the original study (Novembre et al., 2019), the task additionally explored the effects of leadership in this process, assessing how leading or following a dyadic musical interaction impacts children's predictive skills and their subsequent motor alignment with their partners.

Moreover, while Novembre et al.'s study focused solely on empathic perspective-taking, here we employed a multifaceted approach, extending our exploration to encompass affective and somatic empathy (Blair, 2005). Affective empathy involves the sharing of others' emotional states and is an essential element of musical interactions, cultivating strong social connections (Cross et al., 2012). Furthermore, somatic empathy relates to the automatic bodily responses to one's actions or emotions (e.g., spontaneously smiling when seeing someone laughing; Raine & Chen, 2018) and is considered a prerequisite for affective and cognitive empathy (Van der Graaff et al., 2016). This somatic manifestation holds additional significance for the present study, given the involvement of motor simulations of others' actions in both synchronising (Novembre et al., 2012) and empathising (Iacoboni, 2009). Therefore, taking a broader perspective on empathy sought to illuminate aspects of empathy's role that might be overlooked when focusing solely on cognitive empathy.

Two further noteworthy changes in this task, compared to Novembre et al., concern the pairs' empathy levels and the nature of their musical interaction. Firstly, Novembre et al. (2019) formed pairs of participants with similar levels of trait empathy and created two groups, one with high and one with low-empathy pairs. While this approach enabled more effective comparisons across groups, it introduced a level of control that may not be reflective of real-world conditions. Instead, we randomly allocated children to pairs and utilised regression analysis to explore the impact of each partner's empathy on their pair's synchrony. This method better reflected the complexities of real musical and social interactions, thereby enhancing the ecological validity of the task. Furthermore, individuals within each pair in Novembre et al. (2019) undertook the task in separate rooms, relying solely on auditory cues from one another. In contrast, participants in the current study completed the task while facing each other, engaging with both visual and auditory input from their partners as in naturalistic

music-making situations. The additional visual cues aimed to increase the amount of information available about partners' temporal behaviour (e.g. hand movements; Novembre et al., 2019) and potentially enhance the motor simulations of partners' actions. Therefore, the task sought to reveal further effects of empathy on the predictive skills required to attain synchrony.

Building upon Novembre et al.'s findings (2019), we hypothesised that children with higher trait empathy would synchronise better with their partners compared to those with lower empathy (Hypothesis 1). Delving into each empathic facet, and in addition to the cognitive empathy effects observed by Novembre et al. (2019), we also anticipated somatic empathy to contribute to children's synchrony (Hypothesis 2) by supporting motor simulation of partners' actions (Iacoboni, 2009). Lastly, we hypothesised that leadership assignments would interact with empathy, with highly empathic children synchronising better when instructed to follow (Hypothesis 3).

Aspect 2: The effects of synchrony on children's social bonding and state empathy following short-term musical interactions

Aspect 2 focused on the reverse direction of the empathy-synchrony link, namely the effects of interpersonal synchrony on children's experience of social bonding and state empathy. While Rabinowitch and colleagues (2013) observed changes in children's trait empathy following a 9-month-long musical programme, it remains unclear whether short-term musical engagements would exhibit similar effects. Prior research has indicated that brief interactions involving coordinated movements can encourage closeness and perceived similarity in children (Rabinowitch & Knafo-Noam, 2015); however, such evidence stems from research outside the realm of music, leaving the effects of synchrony in short-term musical interactions unexplored. In order to address this literature gap, the present study explored via Task 2 (*"Manipulated synchrony task"*) whether two-minute-long musical dyadic interactions would be adequate to foster social bonding among previously unacquainted children.

In addition, given the brief nature of such musical interactions, investigating potential changes in children's trait empathy (as in Rabinowitch et al., 2013) would be inappropriate. Instead, we explored the impact of synchrony on situational or state empathy, drawing from relevant studies in adults (e.g., Baimel et al., 2018; Koehne et al., 2016). This approach viewed empathy as a multifaceted and dynamic

phenomenon, subject not only to dispositional manifestations but also to individuals' appraisals of a given situation (Lamm et al., 2007). Therefore, we anticipated that short-term synchronous music-making would facilitate this appraisal process (Tzanaki et al., 2024), enabling children to bond and empathise with their partners when synchronising with them (Hypothesis 4).

Aspect 3: The role of empathy (trait and induced) in children's experience of social bonding following interpersonal synchrony.

The final aspect remained in the same direction of the empathy-synchrony relationship as in Aspect 2, investigating potential individual differences in experiencing social bonding following short-term musical interactions. Expanding on relevant research in adults (Stupacher et al., 2022; Tzanaki et al., 2024), we explored whether trait empathy (cognitive, affective and somatic) heightens children's experience of social bonding and state empathy following synchronous musical interactions. Investigating this aspect sought to inform relevant programmes and interventions by identifying what factors can further support the social impact of interpersonal synchrony. We hypothesised that children displaying higher trait empathy levels would experience stronger social bonding and state empathy than those with low empathy when synchronising with a partner (Hypothesis 5). In addition, affective empathy was expected to play a more significant role in these effects, considering its association with experiencing others' emotional states (Hypothesis 6).

Lastly, in addition to exploring its dispositional effects, we examined how experimentally induced empathy might amplify the bonding effects of synchrony. Specifically, participants were exposed to a fictional story about their partners, aiming to redirect attention to partners' emotional states and strengthen state empathy. This experimental manipulation, not previously examined in this context, aimed to further illuminate the role of empathy in facilitating social bonding through synchrony. We hypothesised that children in the induced empathy group would report higher social affiliation following synchronous music-making than those not exposed to the fictional story (Hypothesis 7). Furthermore, we anticipated observing an interaction between trait and induced empathy, with children with higher trait empathy responding more strongly to the empathy manipulation message and experiencing stronger bonding with their synchronous partners (Hypothesis 8).

Methods

The study was approved by the Department of Music Ethics Committee at the University of Sheffield (UK). Data collection was carried out in Greece, leveraging the first author's teaching background in the country, which provided access to a broad network of schools. All materials and experimental procedures were administered in Greek. A preceding pilot study with eight bilingual (Greek and English) pupils from the Greek School of Sheffield was conducted to verify the appropriateness of the following methodology for the intended age group.

Participants

Pupils from Grades 5 and 6 (equivalent to Years 6 and 7 in the UK) were recruited from five primary schools in Heraklion (Greece). An a priori power analysis in G*Power 3.1 (Faul et al., 2009) suggested that a sample size of 109 participants would be sufficient to detect medium effect sizes (f^2= .15) at a significance level (α) of .05 and 80% power (1-β). Initially, 164 children completed the study; however, after excluding participants who did not comprehend aspects of the study or left multiple items of the study questionnaires unanswered, the final sample size for Task 1 comprised 144 children (72 pairs) and 138 (69 pairs) for Task 2 (see Appendix for a detailed report of the exclusion process). Parental/caregiver consent, as well as assent from children, were obtained prior to the study.

Participants' ages ranged from 10 to 12 years (Task 1: *M*=11.04 years, *SD*=0.73; Task 2: *M*=11.05 years, *SD*=0.72). This range was selected based on research indicating that children at this age can adequately synchronise with rhythmic stimuli (Drake et al., 2000), have developed a certain level of empathy (Stietz et al., 2019), and are able to follow instructions. This age range also aligned with previous relevant studies, allowing for potential outcome comparisons (Rabinowitch et al., 2013; Rabinowitch & Knafo-Noam, 2015). Additional demographic information about participants can be found in Table 4.2. Participants were randomly allocated to pairs without controlling for gender. However, approximately half of the pairs were same-gender (male-male or female-female), while the rest were mixed-gender (Table 4.2).

Table 4.2

Summary of participants' characteristics derived from the demographics questionnaire.

Characteristic	Options	Task 1	Task 2
N	Participants / Pairs	144 / 72	138 / 69
Age		*M*= 11.04 years, *SD*= 0.73	*M*= 11.05 years, *SD*= 0.72
Gender	Female / Male participants	77 (53.5%) / 67 (46.5%)	74 (53.6%) / 64 (46.4%)
	N of mixed-gender pairs	37 pairs	36 pairs
	N of female-female pairs	20 pairs	19 pairs
	N of male-male pairs	15 pairs	14 pairs
Musical experience/ training	No prior experience	70.1%	70.3%
	Less than a year / only at school*	17.4%	17.4%
	1-5 years of experience	9%	9.4%
	More than 5 years of experience	3.5%	2.9%
Familiarity within pairs (previous acquaintances)	Not knowing each other at all	35.4%	35.5%
	Knowing each other a little bit	38.1%	39.1%
	Knowing each other quite a bit	17.3%	16.6%
	Knowing each other well	5.5%	5%
	Knowing each other very well/ are friends	3.4%	3.6%

Note. M: Mean, SD: Standard Deviation. Children in Greece tend to attend after-school music clubs, conservatoires or music lessons with private tutors. Music at primary schools often includes 45-minute weekly theoretical lessons (e.g. the history of music) or musical games in groups. The practice of musical instruments at school is very rare. Some schools offer the option of joining a choir.

Materials

Demographics and trait empathy assessment

A demographics questionnaire (see Appendix) collected information about participants' age, school year, musical interests and prior experiences with music (Table 4.2). Participants also completed the Cognitive, Affective and Somatic Empathy Scales (CASES - Raine & Chen, 2018), designed to assess positive and negative dimensions of children's cognitive, affective and somatic empathy. The questionnaire encompassed 30 statements describing everyday scenarios, with participants assessing how much the items reflected their experiences using a 3-point Likert scale ("*Rarely", "Sometimes", "Often")*. The original English version of CASES was translated into Greek and validated for the present study (see Tzanaki, 2024; in preparation). The term "empathy" was not explicitly mentioned;

instead, participants were told that the questionnaire explored their feelings in various everyday situations.

Participants with three or more missing responses in CASES or two gaps within the same subscale (cognitive, affective or somatic) were excluded from the analysis. All other single missing values were replaced with the mean of ratings provided within that particular subscale. A total score for each subscale and an overall empathy score were computed for each participant.

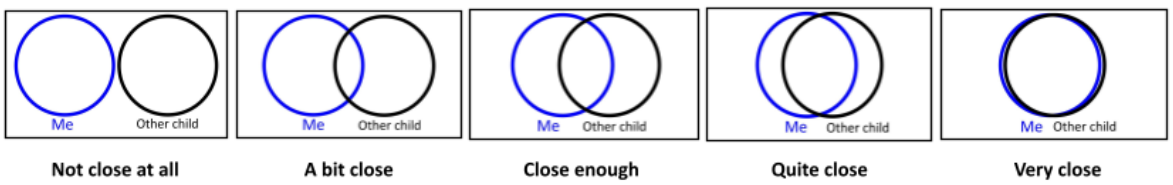
Social bonding assessment for Task 2

A self-reported questionnaire assessed participants' feelings of bonding with their musical partners in Task 2, facilitating the exploration of Aspects 2 and 3. Specifically, the questionnaire (Table 4.3) assessed children's feelings of closeness, perceived similarity with their partner and ability to empathise with them (state empathy) before and after their musical interaction in Task 2. These specific facets of social bonding were selected due to their correlation with interpersonal synchrony observed in prior studies (Tzanaki et al., 2024; Koehne et al., 2016; Rabinowitch & Knafo-Noam, 2015). The questionnaire was administered twice, first before and then after the musical interactions of Task 2. The order of questions was randomised the second time to mitigate impulsive responses.

Looking now into each social bonding facet, closeness was evaluated using the Inclusion of Other in Self (IOS) scale (Aron et al., 1992) as adapted for primary school children by Rabinowitch and Knafo-Noam (2015). Participants were introduced to five sets of circles (Figure 4.2) representing gradual levels of closeness between themselves (black circle) and their partner (blue circle). Children were individually asked to choose the set of circles that best illustrated how close they felt to their musical partner. Descriptive phrases accompanied the circles to facilitate understanding.

Figure 4.2

The Inclusion of Other in Self (IOS) Scale (Aron et al., 1992) as adapted for the present study.



Perceived similarity, the process of observing common qualities, abilities and values with another individual (Grave & Elsass, 2016), was assessed via Questions 2-4 (Table 4.3), inspired by Rabinowitch and Knafo-Noam (2015). The questions focused on children's character and musical preferences and were rated on a 3-point Likert scale (*"Yes", "Maybe", "No"*). Finally, Questions 5-8 (Table 4.3), inspired by Koehne et al. (2016), explored children's ability to empathise with their partners (state empathy). As these questions had not been previously used with children of this age, they underwent review by two primary school teachers and were tested in a pilot study, confirming their comprehension and suitability for the intended age group. The state empathy questions were answered on a 3-point Likert scale, as with perceived similarity.

Two composite social bonding scores for each participant were computed as the total score of their ratings provided before and after Task 2 (see Table 4.3 for Cronbach's α coefficients). Additionally, separate state empathy scores were calculated for each child to explore the effects of synchrony on this particular affiliative aspect.

Table 4.3

The social bonding questionnaire and Cronbach's alpha coefficients assessing internal consistency.

Questions	Social bonding aspect	Pre-task Cronbach's α	Post-task Cronbach's α
1. Inclusion of Other in the Self (IOS): Figure 4.2	Closeness	.63 *(for questions 1-8, assessing social bonding)*	.72 *(for questions 1-8, assessing social bonding)*
2. Do you think the other pupil has the same hobbies as you do?	Perceived similarity		
3. Do you think they like the same type of music as you?			
4. Do you think the other pupil is similar to you in character?			
5. Do you think you can guess the other pupil's thoughts?	State empathy	.51 *(for questions 5-8, assessing state empathy)*	.62 *(for questions 5-8, assessing state empathy)*
6. Do you think you can understand how the other pupil is feeling at the moment?			
7. If you saw the other pupil happy, would That make you feel happy?			
8. If you saw the other pupil sad, would that make you feel sad?			

Note. Values greater than .5 demonstrate acceptable internal consistency, given that the questionnaire contains less than 10 items (Pallant, 2013).

Familiarity within pairs

Both tasks were completed in pairs randomly formed with pupils from different classrooms within the same school to ensure minimal prior social interactions. To further determine the extent of familiarity within each pair, we asked participants to indicate this individually on a 5-point Likert scale, ranging from 0 ("*We do not know each other at all"*) to 5 (*"We know each other well and are good friends"*).

Stimuli & equipment for Task 1: "Free synchrony task"

The first task involved pairs of participants singing the Greek version of *"Twinkle Twinkle Little Star"* while performing rhythmically on wooden claves. The song was chosen due to its widespread familiarity and simple rhythmical structure. Wooden claves with attached contact microphones (OTraki AD-35) were used for the task. Participants' strokes were recorded on Steinberg Cubase 11 via a Steinberg UR22 MKII audio interface connected to an HP Spectre x360 laptop. The recordings were subsequently exported as audio files (.wav) for analysis.

Participants also undertook a baseline task, performing in synchrony with a five-bar steady metronome using the wooden claves of Task 1. After three bars, the metronome gradually diminished in volume over two bars while participants maintained the tempo for three additional bars. Their final eight-bar performance was recorded on Audacity (3.2.1) and saved as .wav files for subsequent analysis. The metronome was set to 120 beats per minute (bpm), a tempo previously identified as comfortable for rhythmical performance within this age group (Drake et al., 2000).

Stimuli & equipment for Task 2: "Manipulated synchrony task"

The second task required manipulating the level of synchrony within pairs to examine its effects on social bonding. Using Audio-Technica ATH-M20x headphones, participants listened to excerpts of a Greek children's song (see Appendix for details) while instructed to play on the beat of the music using small percussion instruments. Six bars of a metronome, two before the song began and four more into the music, aimed to help children identify the beat. The volume of the final bar gradually decreased, enabling children to continue playing without the metronome's support. Children were offered a selection of claves, tambourines, wooden scrapers and maracas to choose from for this task. In addition, the volume and position of the headphones were adjusted individually to ensure participant comfort.

Pairs were randomly allocated to either the synchronous or asynchronous condition, both involving four 30-second-long trials. In the synchronous condition, all trials presented the song at 120 bpm for both children, whereas in the asynchronous condition, a slower version (90 bpm) was presented to one of the participants, alternating in every trial. The musical stimuli were created and produced in Audacity (3.2.1).

In order to induce empathy for Task 2, half of the pairs listened via their headphones to a 30-second-long message explaining that their musical partners lost their favourite toy/game on that day and encouraging them to imagine their emotional state. This empathy manipulation message was delivered in Greek, and a translated version into English can be found in the Appendix. Prior to the present study, the message was discussed with two primary school teachers who confirmed its appropriateness for this age group.

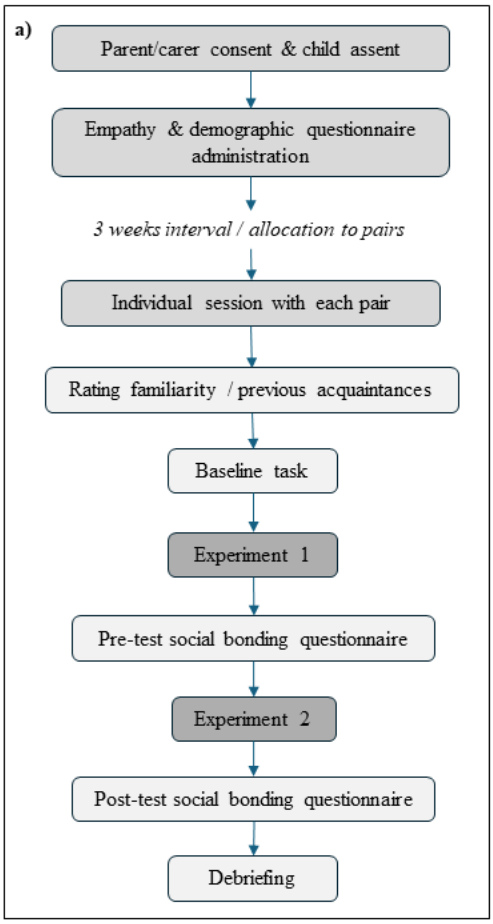
Experimental procedure

Figure 4.3 illustrates the experimental procedure. The study commenced with the experimenter (first author) administering the demographics and CASES questionnaires on paper forms to children who provided parental/caregiver consent and assent. The experimenter remained present during completion, providing assistance where required. The forms were subsequently digitised, and pairs of children from different classrooms within the same school were randomly formed.

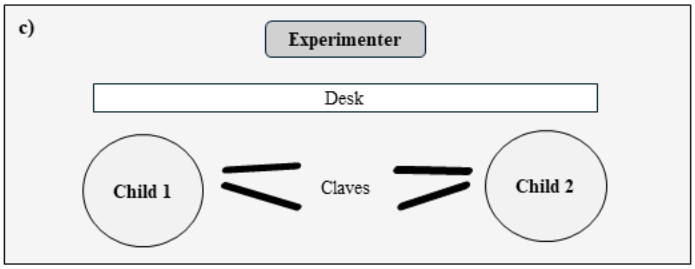
The two experimental tasks were conducted separately for each pair in a quiet room within their school at a scheduled time approved by their classroom teachers. Figure 4.3 presents the room setup. Each session started with participants rating how well they knew each other before completing the baseline task individually. This baseline assessment evaluated children's rhythmic accuracy and consistency, informing the study outcomes about potential confounding effects stemming from individuals' challenges in sensorimotor synchronisation.

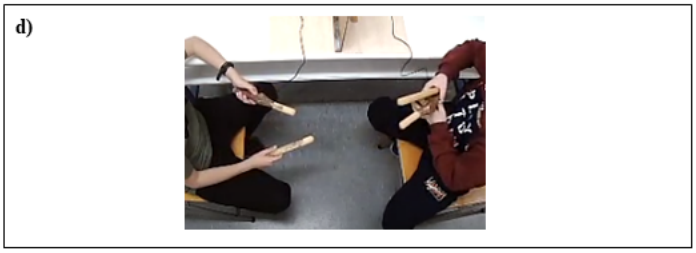
Figure 4.3

Experimental procedure, variables, room setup and a screenshot from an experimental session.



b)	Experiment 1	Experiment 2
Independent variables	Individuals' trait empathy (3 facets) Leadership roles Individuals' temporal regularity	Time (pre/post) Synchrony manipulation Empathy manipulation Trait empathy (3 facets)
Dependent variables	Absolute asynchrony	Social bonding State empathy
Confounding variables	Individuals' rhythmic accuracy Individuals' rhythmic consistency Familiarity Gender Pairs' gender composition Prior musical training	Familiarity Gender Pairs' gender composition Prior musical training





Note. a) The experimental procedure of the study. b) All variables related to the two tasks. c) A panoramic perspective of the room setup. Participants were encouraged to look at each other during their musical interactions. Claves were used in Task 1 and replaced with other percussion instruments for Task 2. d) The screenshot is from a video recording of one of the experimental sessions in Task 1.

Subsequently, the experimenter guided children through Task 1, aiming to assess their interpersonal synchrony. First, participants practised singing the Greek *"Twinkle Twinkle Little Star"* with the experimenter assisting by singing parts of the song and displaying the lyrics on paper. Following this, pairs were instructed to imagine being part of a music band and sing together while playing on the beat using their wooden claves. To ensure participants would perform in synchrony, they were instructed to "copy" each other, avoiding the term "synchronise" as it was considered not age-appropriate. Children's singing aimed to serve as a reference point, reinforcing the experience of naturalistic musical group interactions (Rabinowitch et al., 2013).

Participants completed nine trials in total. After three trials of singing and playing together, leadership roles were assigned for the remaining six trials. When acting as a leader, participants were instructed to sing and initiate the clave performance, while followers were required to copy the leader's performance without singing. Leadership roles were alternated between participants, with each participant completing three trials per role. The task lasted approximately 10 minutes.

Following Task 1, participants completed the pre-task social bonding questionnaire (Table 4.3) whereafter they chose a percussion instrument for Task 2. The aim of Task 2 was to create synchronous or asynchronous musical interactions, assessing synchrony's effects on social bonding and state empathy and the role of induced and trait empathy in this process. The task commenced with a practice trial, in which children listened to the task song at 120 bpm and performed individually on the beat of the music using their chosen percussion instrument. Unbeknown to participants, pairs were allocated to either the synchronous or the asynchronous condition, and half of the pairs of each condition were also allocated to the empathy manipulation group (Table 4.4), listening to the empathy manipulation message before proceeding to the task. The experimenter, who was present throughout the task, was not blinded to the conditions, as simple observation of children's performance could reveal their experimental condition. Nonetheless, they remained silent throughout the task, avoiding eye contact with the participants.

Table 4.4

Distribution of synchrony and empathy manipulation conditions across pairs.

Groups	Synchrony conditions	Empathy manipulation	Distribution
1	Synchronous (i.e. same tempo of background music)	Yes	19 pairs
2	Synchronous (i.e. same tempo of background music)	No	16 pairs
3	Asynchronous (i.e. different tempo of background music)	Yes	17 pairs
4	Asynchronous (i.e. different tempo of background music)	No	17 pairs

During Task 2, participants were instructed again to imagine performing in a music band and to play on the beat of the music while facing each other. Their strokes were not recorded this time to facilitate the use of a wider range of percussion instruments. Following the four trials of the task,

participants completed the social bonding questionnaire again (post-task) and were debriefed before returning to their classroom. The task lasted approximately 10 minutes. The sessions of six pairs were video-recorded for transparency purposes, and written consent was obtained from their parents/carers beforehand. A screenshot of a session can be found in Figure 4.3.

Data processing and analysis

Task 1

Onsets of the audio recordings were extracted in *Python* (version 3.7.7) using *Librosa* (version 0.8.1, McFee et al., 2015), relying on peak-picking in the onset strength envelope. A measure of synchrony between the extracted beats was calculated using the *onsetsync* R package (version 0.5.1, Eerola & Clayton, 2024). More precisely, we calculated absolute asynchrony between the participants' onsets within pairs that were no more than 100 milliseconds (ms) apart. This approach was chosen following Novembre et al.'s (2019) method of using absolute differences between participants' onsets. Utilising absolute values for asynchrony avoids situations where keeping the sign (non-absolute asynchrony) would average to 0 ms when participants randomly switch in positions in terms of leading or lagging. Additionally, we established the strength of the periodicity of tapping using autocorrelation of individuals' tapping, a variable reflecting their temporal regularity. This was utilised to understand how stable each child's tapping was during each trial of the task.

To assess participants' rhythmic abilities, we estimated their tapping accuracy during the baseline task when they tapped along with the metronome. Synchronisation accuracy was defined as the absolute asynchrony between the metronome and their tapping using the same procedure described above. For the part of the baseline task when the metronome had faded out, we calculated individual consistency of the continuation accuracy by taking the consistency of the tapped periods by calculating the coefficient of variation for the onset time differences between the successive taps.

In order to investigate the effects of trait empathy and the assignment of leadership roles on children's interpersonal synchrony, linear mixed-effects models (LME) were run using the package *lme4* (Bates et al., 2020) in RStudio (RStudio Team, 2020). The models utilised "absolute asynchrony" as the main dependent variable, indicating pairs' average asynchrony for each trial. Therefore, high values of this variable would indicate low levels of interpersonal synchrony. Trait empathy and its three

facets were treated as continuous variables comprising total scores of participants' ratings on CASES. Leadership assignment was considered a three-level factor, delineating trials where a participant was a leader, a follower or when no roles were assigned. We also examined the effects of individuals' temporal regularity, as well as their rhythmic accuracy and consistency as evaluated in the baseline task. Figure 4.3 presents a summary of all variables used in the models. All assumptions (i.e. normality of residuals, linearity between predictors and response variable and homoscedasticity) were satisfied, and the diagnostic tests conducted are reported in the Appendix.

To identify the most influential random effects, null models with no fixed effects were initially run, including random intercepts for schools, trials, pairs and participants and intercepts for pairs varying within schools and participants within pairs (Bousquet, 2021). Subsequently, the models were gradually simplified, removing random effects explaining close-to-zero variance. Where variance was not zero, each model was compared with a reduced one by assessing the Akaike Information Criterion (AIC), chi-square estimates, and associated *p*-values via the ANOVA function in RStudio. In cases where models did not demonstrate significant differences, the model with the smallest AIC value was selected, favouring a simpler structure.

A hypothesis-driven minimal approach was then applied to investigate the fixed effects of trait empathy and leadership on absolute asynchrony. Starting with trait empathy as a total score, we gradually added more predictors to the model, including main effects and interactions between leadership assignment and each empathic facet, aligning with the research questions. We further added individuals' temporal regularity, and their rhythmic accuracy and consistency into the models to investigate their potential main effects and interactions with empathy and leadership roles. Using the ANOVA function, each new model was compared with its preceding one, and predictors not significantly improving the fit of the model were removed (Schmidt et al., 2016). Significance was assessed based on *p*-values obtained from the *lmerTest* R package (Kuznetsova et al., 2017) using the Satterthwaite (1946) approximation. When model comparisons did not indicate a significant difference ($p>.05$), the simpler model with a lower AIC was chosen.

For exploratory purposes, we examined whether familiarity within pairs (also referred to as previous acquaintances), participants' gender and prior musical experiences, as well as pairs' gender

composition (female-female, male-make or mixed) had any confounding effects on children's interpersonal synchrony. These factors were tested considering their previously observed influence on synchrony and empathy (Timmers et al., 2020; Gaggioli et al., 2019; Fujiwara et al., 2019; Schulte-Rüther et al., 2008). The R packages *emmeans* (Lenth, 2021) and *ggplots2* (Wickham, 2016) were utilised to perform post-hoc comparisons (using Tukey's adjustment) and visualise the identified effects, respectively. A link to the code utilised for data analysis can be found in the Appendix.

Task 2

The linearity and homoscedasticity assumptions required for LME were not met for Task 2 due to the ordinal nature of the response variables. Therefore, cumulative mixed-effects models (CLMMs) were run instead via the *ordinal* package in RStudio (Christensen, 2018). To further satisfy the assumptions for these models, the social bonding and state empathy ratings were transformed into ordinal variables by creating four ranges (0 for scores <0.5; 1 for scores 0.5-1; 2 for scores 1-1.5; 3 for scores 1.5-2).

Two separate models were run, one for social bonding and one for state empathy. Both models investigated the effects of synchrony (synchrony or asynchrony), induced empathy (empathy manipulation applied or not), trait empathy (total score and separate empathic facets), time (pre- and post-task ratings) and their interactions on children's social bonding (average of closeness, perceived similarity and state empathy scores) and state empathy ratings, separately.

In order to identify the random effects of the two models, a similar approach to Task 1 was first followed. A hypothesis-driven minimal approach was then applied investigating the effects of the four predictors on social bonding and state empathy. For both models (social bonding and state empathy models), we started with structures containing only "time", assessing changes in the response variables post-task. We gradually added more predictors, keeping only those that significantly improved the fit of the models. Finally, the impact of familiarity within pairs, participants' gender, pairs' gender composition and prior musical experiences were also examined here, exploring their confounding effects on social bonding and state empathy.

Results

Task 1

The final model of pairs' absolute asynchrony indicated a significant interaction between individuals' trait empathy (total score) and their temporal regularity, as well as a significant main effect of pairs' gender composition (Table 4.5). The inclusion of leadership roles and individuals' rhythmic accuracy and consistency did not improve the fit of the model.

Table 4.5

The final best-fitting model of absolute asynchrony for Task 1 and its parameter estimates.

Model	Random effects	AIC	BIC
Pair's absolute asynchrony ~ Individuals' total empathy * Individuals' temporal regularity + Pairs' gender composition	(1 | Pair : Participant)	8567.75	8609.09

Fixed effects	*β*	*SE*	*df*	*t*	*p*	η_p^2	95% CI
(intercept)	**51.62**	**4.88**	**659.04**	**10.55**	**<.001*** **	**-**	**[42.03, 61.20]**
Female-Female pairs (F-F)	**-3.55**	**1.13**	**140.69**	**-3.13**	**<.01** **	**.09**	**[-5.77 -1.33]**
Male-Male pairs (M-M)	1.43	1.25	140.11	1.14	.255	.09	[-1.03, 3.89]
Individuals' total empathy	**-0.25**	**0.11**	**669.27**	**-2.23**	**.02***	**.007**	**[-0.48, -0.03]**
Individuals' temporal regularity	**-36.80**	**9.09**	**1286.52**	**-4.04**	**<.001*** **	**.01**	**[-54.63, -18.96]**
Empathy * Ind. temp. regul.	**0.52**	**0.21**	**1283.68**	**2.42**	**.01***	**.004**	**[0.10, 0.95]**

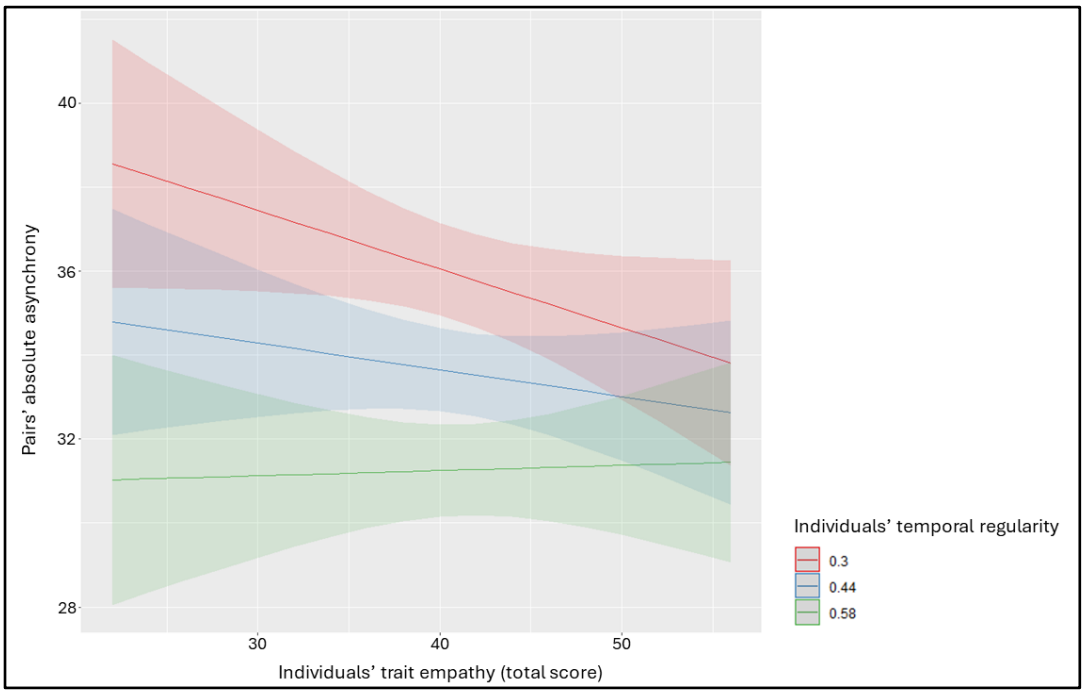
Note. The variance explained by the random effect was low; however, it was kept in the model as it was meaningful given the experimental design. For "pairs' gender composition", RStudio compared Female-Female and Male-Male pairs with mixed-gender pairs. AIC: Akaike Information Criterion. BIC: Bayesian Information Criterion. *β*: Coefficient estimate. *SE*: Standard Error. *df:* Degrees of freedom. *t*-values and *p*-values associated with *β*. η_p^2*:* Partial eta-squared measuring effect size: Small=.01; Medium=.06; Large=.14. CI: Confidence Intervals. Significance levels: *p*<.001***, *p*<.01**, *p*<.05*.

Focusing on the significant interaction between trait empathy and temporal regularity (Table 4.5), Figure 4.4 indicates that participants with higher total empathy improved their pairs' synchrony when their tapping was more irregular. Looking at empathy's effect across three levels of individuals' temporal regularity (Figure 4.4), children with high empathy were more synchronised than those with low empathy when their tapping was less stable. However, for those with strong internal periodicity (reflected in better temporal regularity), empathy's effects on pairs' absolute asynchrony are not

evident. In other words, increased empathy tended to improve pairs' synchrony more effectively when temporal regularity was low or moderate.

Figure 4.4

Predicted values of absolute asynchrony within pairs for Task 1.



Note. Pairs' absolute asynchrony is calculated in milliseconds (ms). The shaded areas represent 95% Confidence Intervals. Lower values of absolute asynchrony indicate better synchrony within pairs. Higher temporal regularity indicates more stable participants' tapping.

Furthermore, we sought to explore which empathic facet (cognitive, affective or somatic) contributed more to the observed interaction between empathy and temporal regularity; therefore, we ran separate models with each empathic manifestation and reported their parameter estimates in the Appendix. Only the model of cognitive empathy indicated a significant interaction between individuals' empathy and temporal regularity on absolute asynchrony (β=1.53, *SE*=0.50, *t*(1293.89)=3.06, *p*=.002), while both the cognitive and affective models demonstrated a main effect of empathy on pairs' absolute asynchrony (Cognitive empathy: β= -0.61, *SE*=0.26, *t*(705.24)= -2.29 *p*=.021; Affective empathy: β= -0.56, *SE*=0.28, *t*(687.66)= -1.96, *p*=.049). The negative estimates (β) of these effects suggest that higher levels of cognitive and affective empathy were associated with lower levels of absolute asynchrony,

thus better interpersonal synchrony for highly empathic children. Somatic empathy was not found to significantly influence absolute asynchrony here.

Turning now to the significant effect of pairs' gender composition, (Table 4.5), post-hoc analyses were conducted, comparing the three levels of this variable, i.e. a) mixed, b) female-female and c) male-male pairs. The comparisons revealed that female-female pairs synchronised significantly better than male or mixed-gender pairs (Table 4.6 and Figure 4.5). . We also explored the confounding effects of familiarity within pairs, participants' gender and prior musical experiences on pairs' absolute asynchrony; however, none of these variables improved the final model.

Table 4.6

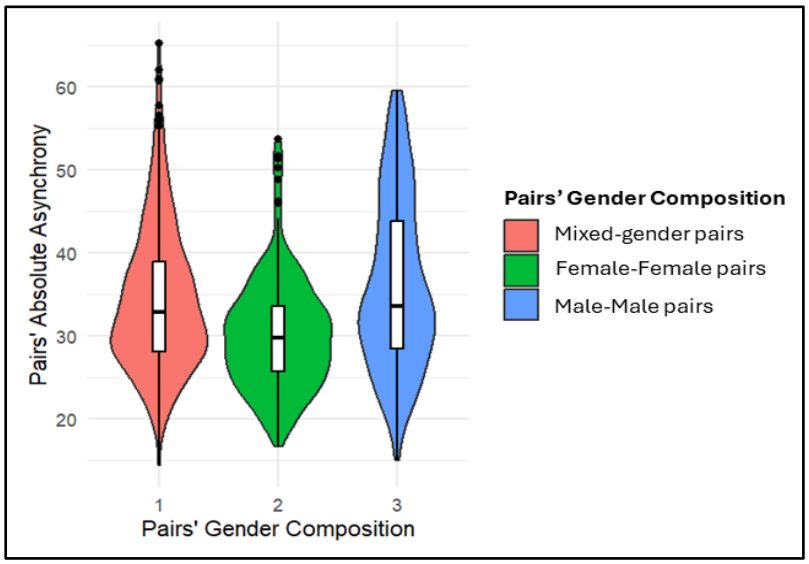
Pairwise comparisons between levels of pairs' gender composition in the model of absolute asynchrony

Pairwise Comparisons	*β*	*SE*	*df*	*t*	*p*
Mixed pairs - F-F pairs	**3.56**	**1.15**	**149**	**3.08**	**.006***
Mixed pairs - M-M pairs	-1.43	1.28	149	-1.12	.501
F-F pairs - M-M pairs	**-4.99**	**1.44**	**149**	**-3.47**	**.001****

Note. *β*: Coefficient estimate, *SE*: Standard Error; *df:* Degrees of freedom; *t*-values and *p*-values associated with *β*. CI: Confidence Intervals. The values in **bold** indicate a significant effect. Significance levels: *p*<.001***, *p*<.01**, *p*<.05*.

Figure 4.5

Distribution of pairs' absolute asynchrony across the three levels of pairs' gender composition.



Note. The width of each violin corresponds to the density of the data at different values of pairs' absolute asynchrony (in ms) The line in the middle of the boxplots represents the median. Lower pairs' absolute asynchrony indicates better synchrony.

Task 2

Table 4.7 presents the final CLMM models for social bonding and for state empathy. Starting with the social bonding model, only the main effects of time and affective empathy remained in the final model. The effects of synchrony and empathy manipulation did not improve the fit of the model and were, therefore, excluded. The effect of time indicated that all participants experienced higher social bonding following their musical interaction than before it (β= -1.98, *SE*= 0.35, *z*= -5.59, *p*< .001), regardless of the synchrony and empathy manipulation conditions assigned. Regarding affective empathy, those with higher affective empathy tended to report higher social bonding with their partners than those with lower affective empathy in both questionnaires, as illustrated in Figure 4.6 (β=0.29, *SE*= 0.10, *z*= 2.91, *p*=.003).

Table 4.7

The best fitting CLMM models of Task 2 for a) social bonding and b) state empathy ratings.

Dependent variable	Fixed effects	Random effects	AIC	BIC
a) Social bonding	Time + Affective empathy + Familiarity + Pairs' gender composition	(1| Pair) + (1| Participant)	553.43	600.49
b) State empathy	Time * Synchrony + Trait empathy (total score) + Familiarity	(1| Participant)	625.01	668.46

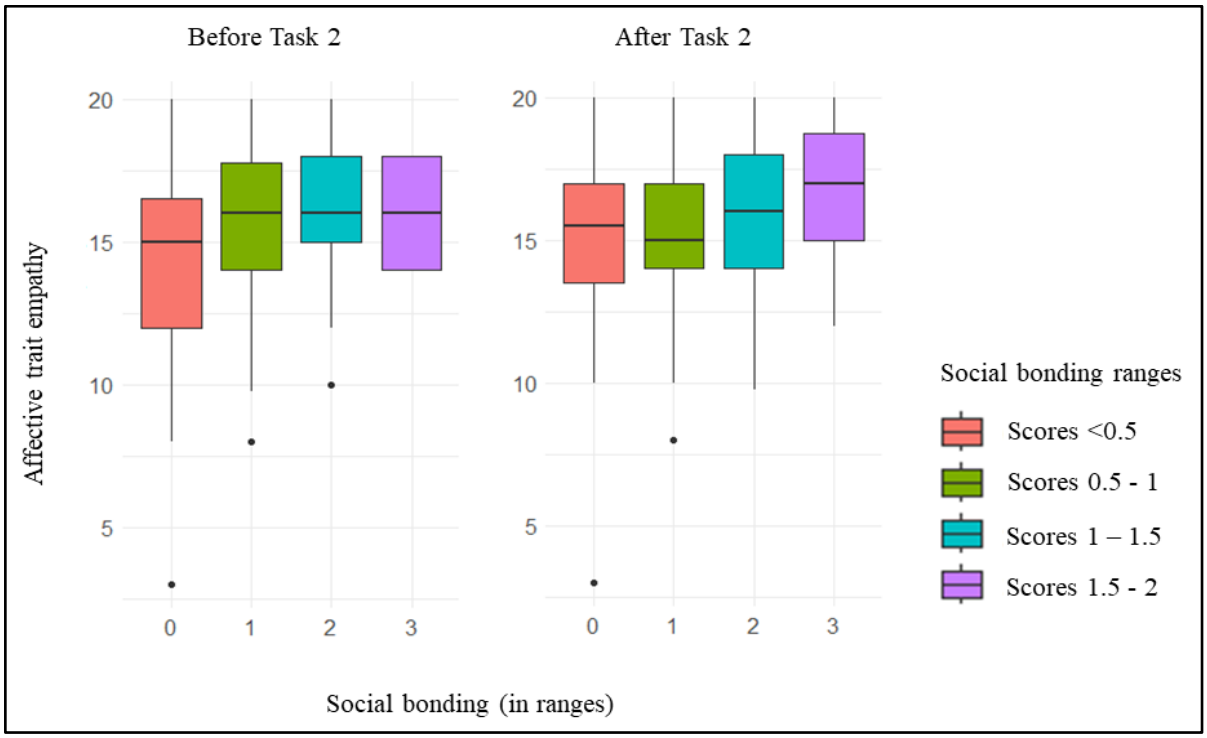
Note. The social bonding model allowed for random intercepts for pairs and participants. The state empathy model allowed for random intercepts for participants.

Furthermore, for exploratory purposes, we examined the potential confounding effects of previous acquaintance (familiarity) within pairs, the role of gender and its interaction with affective trait empathy, as well as participants' previous musical experience. Previous acquaintance improved the fit of the model, indicating that greater familiarity between participants was associated with higher social bonding ratings, regardless of the musical interaction, synchrony and empathy manipulation conditions. The coefficient estimate for the contrast between level 1 (*"Not knowing each other at all"*) and level 5 (*"Knowing each other very well / we are friends"*) was -7.80. (*SE*= 2.01, *z*= -3.84, *p*=.001), indicating significantly higher levels of social bonding for participants who knew each other very well. Additionally, we examined whether the pairs' gender composition presented any differences, a factor that improved the fit of the final social bonding model (Table 4.7). Indeed, female-female pairs tended

to report significantly higher social bonding than male-male or mixed pairs (Contrast between mixed and female-female pairs: β=-2.33, *SE*=0.73, *z*=-3.18, *p*=.004; contrast between female-female and male-male pairs: β=2.14, *SE*=0.86, *z*=2.47, *p*=.035).

Figure 4.6

The effects of affective trait empathy on social bonding before and after Task 2.



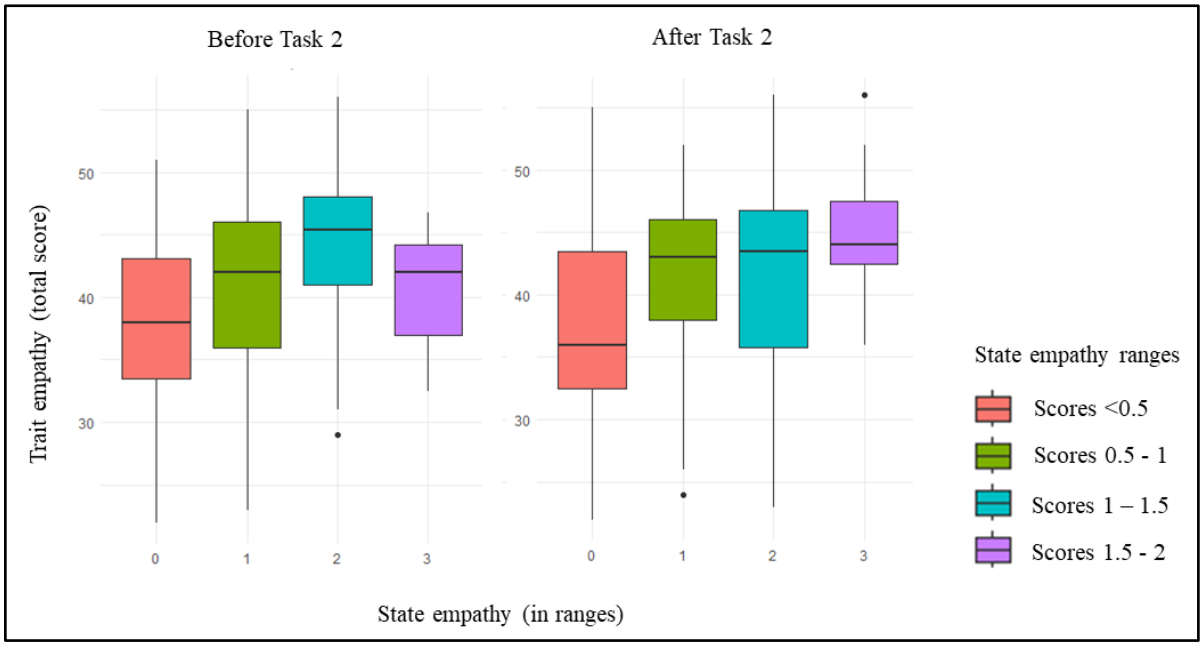
Note. The size of the boxes represents the interquartile range (IQR), the range containing the middle 50% of the data. The line in the middle of the boxes indicates the median of the distribution. The social bonding variable was transformed into an ordinal variable with four ranges, as indicated by the separate boxes.

Focusing now on the best-fitting model for state empathy (Table 4.7), a significant interaction between time and synchrony indicated that participants in the synchronous conditions reported higher state empathy ratings following Task 2 than before it (β= -1.78, *SE*= 0.40, *z*= -4.39, *p*< .001). This was not the case for participants in the asynchronous conditions, whose scores did not vary significantly between the pre- and post-task measurements (*p*=.837). In addition to these effects, trait empathy as a total score significantly improved the fit of the model, confirming, as expected, that participants with higher trait empathy tended to provide higher state empathy scores than those with lower empathy

(β=0.14, *SE*= 0.03, *z*= 3.65, *p*< .001). Figure 4.7 illustrates the effects of trait empathy on the pre- and post-task state empathy ratings. Induced empathy did not improve the fit of the model.

Figure 4.7

The effects of trait empathy (total score) on state empathy before and after Task 2.



Note. The size of the boxes represents the interquartile range (IQR), the range containing the middle 50% of the data. The line in the middle of the boxes indicates the median of the distribution. The social bonding variable was transformed into an ordinal variable with four ranges, as indicated by the separate boxes.

Finally, as in the social bonding model, we explored the effects of the confounding variables of interest and found that previous acquaintance improved the fit of the state empathy model, associating greater familiarity within pairs with increased state empathy. The coefficient estimate of state empathy for the contrast between level 1 (*"Not knowing each other at all"*) and level 5 (*"Knowing each other very well / we are friends"*) was -4.55. (*SE*= 1.59, *z*= -2.86, *p*=.03). The effects of participants' gender, pairs' gender composition and prior musical experiences were tested without improving the fit of the final model.

Discussion

This study investigated, via two tasks, three important aspects of the relationship between empathy and synchrony in children's musical interactions, providing empirical evidence for theoretical claims of the positive feedback loop model (Tzanaki, 2022). The first task explored the direction from empathy to synchrony, namely the role of trait empathy in facilitating children's capacity to synchronise with others. The reverse direction was subsequently examined by Task 2, exploring whether synchronising briefly with others can sufficiently encourage social bonding and state empathy in children and whether these effects are modulated by trait or induced empathy. For exploratory purposes, we also investigated the potentially confounding effects of familiarity between participants in each dyad, their gender, prior musical experiences, and the gender composition of each pair. This exploration was motivated by previous findings suggesting an impact of such factors on synchrony and empathy (e.g. Timmers et al., 2020; Gaggioli et al., 2019; Fujiwara et al., 2019; Schulte-Rüther et al., 2008).

Our results support the first hypothesis (Table 4.1), revealing that children with higher trait empathy synchronised better than those with lower empathy, improving their pairs' attained synchrony. However, this was prominent when individuals' tapping was less stable, suggesting that in trials where participants' tapping was more irregular, the pairs' synchrony benefited from participants with high empathy (Figure 4.4). This observation could be potentially attributed to empathy supporting the capacity to predict others' temporal behaviour, as previously suggested by Novembre et al. (2019). Specifically, we speculate that highly empathic children synchronised better than those with low empathy as they could anticipate their partners' actions more effectively when the latter's tapping was irregular. Conversely, for trials with more consistent tapping, synchrony was attained without requiring superior predictive skills and further contribution from individuals' empathy. Furthermore, looking at the contribution of each empathic facet and in addition to cognitive empathy (as in Novembre et al., 2019), we also found an association between higher affective empathy and enhanced interpersonal synchrony (see *"Parameter estimates for separate models of absolute asynchrony"* in the Appendix). Previous research has proposed that top-down empathic processes, such as consciously adopting others' perspectives, rely on an automatic emotional alignment with others (de Waal, 2008). Therefore, it is plausible that the musical interactions of Task 1, which encouraged children to imagine playing music

together in a band, facilitated emotional alignment within pairs (Cross et al., 2012), activating automatic affective sharing. This might have resulted in participants with higher cognitive and affective empathy utilising their predictive skills (Novembre et al., 2019) and the emotional alignment stemming from this shared experience to a greater extent, thereby synchronising better than those with lower empathy.

The model in Task 1 did not indicate an effect of somatic empathy or interaction between empathy and leadership roles on children's attained synchrony. Therefore, there is not enough evidence to confirm Hypotheses 2 and 3 and support our speculations above regarding empathy enhancing children's predictive skills, as found in adults (Novembre et al., 2019). The lack of evidence supporting the role of leadership could be due to the limited number of trials per role (in comparison to the original study) and the frequent role changes, which did not allow participants sufficient time to fully experience each role. Nonetheless, the exploratory analysis of confounding variables indicated some gender-related differences in attaining synchrony with others Specifically, dyads of female participants synchronised better than male and mixed-gender pairs. This is consistent with prior research indicating that females present more synchronous behaviour in social interactions than male participants (Fujiwara et al., 2019; Paolizzi et al., 2022). Pairs' gender composition was also a significant predictor in the social bonding model of Task 2 (Table 4.7), indicating that female pairs typically reported stronger bonding with their partners than male or mixed-gender pairs. These gender-related findings collectively reflect the social dynamics inherent in musical interactions, corroborating previously observed gender differences in the development of coordination and interpersonal skills (Pahlevanian & Ahmadizadeh, 2014; Hajovsky et al., 2022). Our results indicate that attaining synchrony in musical interactions and the subsequent experience of social bonding in younger populations are susceptible to social factors such as gender. Nonetheless, it is essential to approach this claim with caution. Pairs were randomly formed without controlling for gender, although the distribution of the same- and mixed-gender pairs was eventually balanced (Table 4.2). Turning now to Hypotheses 4-8 and the reverse direction of the empathy-synchrony relationship, our analysis showed that the synchrony and empathy manipulations did not differentiate children's social bonding ratings, as previously hypothesised (Hypotheses 4a and 7). Instead, all participants increased their social bonding ratings post-task, irrespective of the condition they were exposed to. Nonetheless, a significant interaction between time and synchrony in the state

empathy model indicated that the increase in state empathy ratings post-task was predominantly driven by participants in the synchronous condition. This observation aligns with Hypothesis 4b, suggesting that interpersonal synchrony in Task 2 prompted participants to report greater state empathy toward their partner, whereas the asynchronous condition did not exhibit a significant difference.

A potential explanation for synchrony manipulation not differentiating social bonding in Task 2 might lie in the modality via which asynchrony was perceived. As participants could solely perceive their partner's performance visually, this might not have been sufficient to create a substantial distinction between synchronous and asynchronous partners. Indeed, prior relevant studies (e.g. Rabinowitch & Knafo-Noam, 2015) exposed their child participants to synchrony conditions via auditory cues and individuals tend to be more sensitive to timing discrepancies via auditory than visual cues (Iversen et al., 2015). Therefore, the visually perceived asynchrony here might not have been adequate to diminish the positive effects of the shared musical task (Cross et al., 2012). Nonetheless, that was not the case for state empathy, and our observation aligns with outcomes from studies in adults, indicating that synchrony encourages mentalising and a sense of understanding (Baimel et al., 2018; Koehne et al., 2016). It is possible that the synchronous interactions here created a channel of communication (Wheatley et al., 2012), prompting participants to pay attention to partners' actions. This might have subsequently fostered mentalising and state empathy (Macrae et al., 2008; Baimel et al., 2018). Conversely, asynchronous interactions may have directed children's attention to their own performance, disrupting nonverbal communication and shared understanding.

The results above suggest that individuals from a young age engage in appraisal processes of their musical partners during music-making, consequently influencing the social outcomes of synchrony and musical engagement (Lamm et al., 2007; Cross et al., 2012). This is further reinforced by our finding that participants who interacted with familiar partners provided higher social bonding and state empathy scores than those with no previous acquaintances. Given that social familiarity encourages state empathy (Preston & de Waal, 2002), our findings indicate that children appraised their musical interactions, utilising synchrony and familiarity with a partner as social cues to direct state empathy.

Finally, empathy manipulation was not involved in the models of Task 2, rejecting Hypotheses 7 and 8, which proposed that the empathy message would enhance participants' experience of bonding

and state empathy. In order to maintain a short duration for the experiment and minimise participant fatigue, we did not implement measures to assess the efficacy of the empathy manipulation. Consequently, this absence from the Task 2 models may stem from either empathy not being sufficiently induced or children's focus being captured by the subsequent musical interactions, causing them to overlook the message. Prior research with adults (Miu & Baltes, 2012; O'Neil & Egermann, 2020) has indicated that adopting another's perspective during music listening can impact individuals' emotional responses to music. Therefore, further work is needed here to establish if that is also the case in children. While induced empathy did not appear to play a role, higher trait empathy was associated with stronger social bonding and state empathy ratings. This suggests that children with higher trait empathy experienced a stronger inclination to share their partners' emotional states during their musical interactions than those with lower empathy, subsequently leading to enhanced bonding and a higher tendency to empathise in a specific situation.. This aligns with research linking trait empathy with prosocial behaviour and the situational manifestations of empathy (Eisenberg et al., 2010; (de Vignemont & Singer, 2006). Nonetheless, this tendency was evident across all conditions, rejecting Hypotheses 5 and 6, which originally posited that these effects would be present only in the synchronous conditions.

Although some of the proposed hypotheses were not confirmed, our results have made important contributions to the positive feedback loop model (Tzanaki, 2022), shedding light on additional factors, such as familiarity and gender, that might influence the loop's functioning. Referring back to Figure 4.1, the study has confirmed that a) trait empathy contributes to children's ability to synchronise with others (Aspect 1), especially when partners' temporal regularity is low, and b) attained synchrony might act as a social cue for children to direct empathy in a given situation (Aspect 2). Our approach to manipulating empathy within pairs was not sufficient; thus, we could not observe if induced empathy influences the bonding effects of synchrony (Aspect 3). Nonetheless, the observed direct impact of trait empathy on the experience of social connection through music underscores the social dynamics of musical engagement with others (Cross et al., 2012). The study has also highlighted the susceptibility of the feedback loop to inter-individual or contextual factors that might facilitate or obstruct its positivity, as previously proposed by Tzanaki (2022). Indeed, the outcomes imply that the

characteristics of individuals with whom one interacts in a musical context - here, a familiar person or someone of the same gender perceived as more similar - can influence the functioning of the loop.

The present findings can guide future longitudinal investigations directly exploring the bidirectional relationship between empathy and synchrony in musical contexts. However, certain considerations should be noted following some limitations of this study. Firstly, we chose absolute asynchrony to assess interpersonal synchrony in order to align Novembre et al.'s methodology (2019) replicating here. However, this approach might present inaccuracies in cases where asynchronies are consistent but preserve a certain absolute value (e.g. when some are consistently ahead of others). Instead, future investigation could use the variance of asynchronies, i.e. the variance of differences in onset timing, for a more nuanced understanding of pairs' synchrony. Additionally, since tempo variations influence asynchronies (e.g. some might naturally accelerate as the trial progresses), dividing mean absolute asynchrony by the local or mean inter-onset intervals (IOI) could provide important insights. Furthermore, given the substantial lack of research into the effects of induced empathy in musical interactions in young populations, future studies could extend our methodology, employing additional paradigms, such as video clips, role-playing or longer narratives. Such approaches could provide additional insights into the role of empathy in experiencing bonding following interpersonal synchrony (Stupacher et al., 2022; Tzanaki et al., 2024), thus informing interventions utilising music to enhance social connections.

Finally, although tapping in Task 1 required imitation, previously associated with somatic empathy (Dimberg et al., 2000), the task did not incorporate strong somatic experiences (as in CASES; Raine & Chen, 2018) to enable somatic empathy to influence synchrony. Future investigations could explore alternative methods to evaluate this empathic facet or involve participants in interactions without direct visual contact, stimulating the imagination of partners' emotional and cognitive states. Given somatic empathy's underlying involvement in cognitive and affective empathy (Van der Graaff et al., 2016), this approach could further inform us about motor simulations supporting synchrony and how empathic capacities facilitate musical interactions with others.

Conclusion

The study informed important developmental aspects of the positive feedback loop model (Tzanaki, 2022), revealing that trait empathy supports children's ability to synchronise in musical interactions, in particular when partners' temporal performance is unstable. In addition to the role of cognitive empathy (Novembre et al., 2019), we found that affective empathy also supports interpersonal synchrony, reinforcing the emotional alignment stemming from musical interactions. Brief exposure to visually perceived asynchrony was not sufficient to outweigh the positive effects of musical interactions on children's social bonding, while short-term interpersonal synchrony provided social cues for children to empathise with their partners. Pairs' gender composition and familiarity were found to influence interpersonal synchrony and its social outcomes, highlighting the social dynamics of musical engagement. Future investigations could build upon the current outcomes to inform and test educational interventions leveraging a bidirectional feedback relationship to promote children's simultaneous musical and social development.

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Appendix

Demographics Questionnaire

The questionnaire below was distributed in Greek. Its English version is presented below.

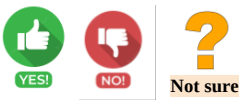
A bit about yourself

Can you please answer these questions about yourself?
If you need any help, please let the researcher know. Thank you :)

What's your name?

How old are you?

What year are you in?

Do you like listening to music? Circle your answer. 

If you like listening to music, what type of music do you like?

Do you like playing music? Circle your answer. 

If you like to play music, what instruments do you play?

Have you ever had any music lessons? Circle your answer. 

If yes, how long have you been learning music?

Thank you for your help. Please return this paper to the researcher :)

Child information and assent form

The following information sheet and assent form were given to the child participants. They were tailored to their age and comprehension level.

Invitation to join a research project on
"Synchronisation and empathy when children play music"

Hello, we are researchers from the University of Sheffield in the United Kingdom, and we are running a music study. We want to understand better how children play music together and how they feel about it. We would appreciate it if you would like to help us with this study.

If you agree to take part in this study, we would like to ask you some questions about yourself. These questions will be on a paper that we call a "questionnaire". It is up to you to decide if you want to answer the questions, and there is no right or wrong answer. A few weeks after that, we will invite you to take part in two music games with another child from your school. During these games, you will sing a song, listen to music and play with small musical instruments. At the end of these games, we will ask you some more questions about how you felt during the games.

We will ask your parent/carer if they agree that you participate in this study. And we will let you know when you are asked to answer questions for the research project and complete the musical games. If, at any point, you want to stop and not answer the questions or do the musical games, you can tell us, and that is fine. This is not a test, and it does not have any influence on your life at school.

Do you think this is something that you are happy to do? Circle your answer.

Yes / No

If you have any questions or concerns, you can ask your teacher or your parent/carer to get in touch with Persefoni Tzanaki, who is running the project, at ptzanaki1@sheffield.ac.uk. Questions can also be directed to Prof. Renee Timmers, Head of the Department of Music, at r.timmers@sheffield.ac.uk.

Thank you for your help! :)

Participant exclusion process

Some participants were excluded from data analysis for the following reasons:

- **Seven** pairs were excluded from both tasks because one or both children of the pair did not understand aspects of the tasks or were very distracted during the study, as the experimenter observed.
- **Three** children left multiple statements in the CASES questionnaire unanswered; therefore, their pairs were excluded from both tasks.
- Additionally, **three** children and their pairs were excluded from Task 2 as they left multiple questions unanswered in the social bonding questionnaires.

Task 2 music excerpt

Participants in Task 2 listened to the Greek song "Συννεφούλα" (Sinnefoula) by Dionysis Savvopoulos (Album: Fortigho, released in 1966).

Empathy manipulation message

Participants in the induced empathy conditions listened to the following message in Greek via their headphones before proceeding to the task. Please note that the words "toy" and "game" are the same in Greek and are considered appropriate for this age group.

"Before we start this activity, I want to tell you a little secret. Earlier today, the other child lost their favourite toy/game, and they couldn't find it. They looked everywhere, but they couldn't find it. Can you imagine how they might be feeling at the moment? Try to imagine how you would feel if you had lost your favourite toy/game."

Assumption tests

The final LME models of Task 1 were subjected to tests for the assumptions of a) normality of residuals, b) linearity, and b) homoscedasticity. These tests involved assessing Quantile-Quantile (Q-Q) plots depicting residuals, plots showing the relationship between residuals and fitted values, and Scale-Location (Spread-Location) plots examining homoscedasticity. The analyses were conducted via the R package *lattice* (Sarkar, 2008) in R Studio (RStudio Team, 2020). As for the final CLMM models of Task 2, these were subject to the assumptions of a) independence of observations and b) proportional odds, ensuring that the relationships between predictors and response variables are consistent across the ordinal categories (Christensen, 2018; Schmidt, 2012). For the first assumption, intraclass correlation coefficients were calculated, quantifying the proportion of total variance due to between-cluster variation. The second assumption was assessed on the same models without random effects (CLM) as the "nominal_test" and "scale test" used are not currently available for CLMM (Mangiafico, 2016). The

code utilised to conduct these tests can be found here: https://doi.org/10.15131/shef.data.25382545.v2. The file contains notes interpreting the results of the tests.

Code for data analysis

The code utilised to conduct the data analysis of the present study is available here: https://doi.org/10.15131/shef.data.25382545.v2.

Parameter estimates for separate models of absolute asynchrony

The table presents the separate models of absolute asynchrony that were run with each empathic facet as a predictor.

Model	Random effects	AIC	BIC
Pair's absolute asynchrony ~ Individuals' cognitive empathy * Individuals' temporal regularity + Pairs' gender composition	(1 | Pair : Participant)	8564.20	8605.54

Fixed effects	*β*	*SE*	*df*	*t*	*p*
(intercept)	**49.62**	**3.89**	**695.75**	**12.74**	**<.001*** **
Female-Female pairs (F-F)	**-3.62**	**1.13**	**140.54**	**-3.18**	**.001****
Male-Male pairs (M-M)	1.62	1.24	139.71	1.30	.195
Individuals' cognitive empathy	**-0.61**	**0.26**	**705.24**	**-2.29**	**.021***
Individuals' temporal regularity	**-36.87**	**7.28**	**1294.81**	**-5.06**	**<.001*** **
Cognitive Empathy * Ind. temp. regul.	**1.53**	**0.50**	**1293.89**	**3.06**	**.002****

Model	Random effects	AIC	BIC
Pairs' absolute asynchrony ~ Individuals' affective empathy * Individuals' temporal regularity + Pairs' gender composition	(1 | Pair : Participant)	8569.47	8610.81

Fixed effects	*β*	*SE*	*df*	*t*	*p*
(intercept)	**50.21**	**4.53**	**663.21**	**11.06**	**<.001*** **
Female-Female pairs (F-F)	**-3.58**	**1.11**	**140.87**	**-3.20**	**.001****
Male-Male pairs (M-M)	1.23	1.24	140.17	0.98	.324
Individuals' affective empathy	**-0.56**	**0.28**	**687.66**	**-1.96**	**.049***
Individuals' temporal regularity	**-25.65**	**8.58**	**1285.54**	**-2.99**	**.002****
Affective empathy * Ind. temp. regul.	0.68	0.54	1287.39	1.25	.211

Model	Random effects	AIC	BIC
Pairs' absolute asynchrony ~ + Individuals' somatic empathy * Individuals' temporal regularity + Pairs' gender composition	(1 | Pair : Participant)	8572.21	8613.54

Fixed effects	*β*	*SE*	*df*	*t*	*p*
(intercept)	**44.01**	**2.98**	**669.34**	**14.72**	**<.001*** **
Female-Female pairs (F-F)	**-3.62**	**1.14**	**140.66**	**-3.18**	**.001****
Male-Male pairs (M-M)	1.56	1.26	140.23	1.23	.218
Individuals' somatic empathy	-0.23	0.24	683.59	-0.94	.344
Individuals' temporal regularity	**-21.73**	**5.56**	**1294.90**	**-3.90**	**<.001*** **
Somatic empathy * Ind. temp. regul.	0.56	0.45	1290.52	1.24	.212

Note. For "pairs' gender composition", RStudio compared Female-Female and Male-Male pairs with mixed-gender pairs. AIC: Akaike Information Criterion. BIC: Bayesian Information Criterion. *β*: Estimate. *SE*: Standard Error. *df:* Degrees of freedom. *t*-values and *p*-values associated with *β*. The values in **bold** indicate a significant effect. Significance levels: $p<.001$***, $p<.01$**, $p<.05$*.

CHAPTER 5

Report: "The Greek CASES: Translation and validation of the Cognitive, Affective, and Somatic Empathy Scales for children" (Paper 4)

Forthcoming publication as:

Tzanaki, P. *The Greek CASES: Translation and validation of the Cognitive, Affective, and Somatic Empathy Scales for children.* [Manuscript in preparation]. Department of Music, The University of Sheffield.

Candidate's contribution:

The candidate performed the translation and validation processes and wrote the report.

Abstract

The Cognitive, Affective, and Somatic Empathy Scales for Children (CASES), initially developed by Raine and Chen (2018), serve as a self-reported instrument assessing three facets of trait empathy in children. An adaptation of CASES into Greek was undertaken to utilise in a music psychology study involving Greek-speaking primary school pupils (Tzanaki et al., 2024; in preparation). The present report outlines the translation and validation procedures employed to ensure the comprehensiveness and suitability of the Greek CASES. The results indicated acceptable levels of equivalence and test-retest reliability between the original and the translated scales. However, certain items presented poor agreement, requiring further work with a larger sample to fully confirm the validity of the Greek CASES. Details of the statistical tests conducted, as well as the strengths and limitations of this study, are discussed.

Keywords: empathy, CASES, self-reported measure, children, translation, validation, Greek

Introduction

Empathy is the ability to understand and share the emotional and mental states of others and is a crucial element of social interactions (Singer, 2009). Despite the absence of a precise definition and the ongoing debates regarding its underlying components, empathy is widely considered a multifaceted phenomenon (Blair, 2005), encompassing both cognitive and affective processes which develop at different stages in life (Stietz, 2019). Alongside this cognitive-affective dichotomy, Blair (2005) has argued that empathy also comprises somatic or motor facets, referring to the automatic bodily responses one experiences when observing others' emotions (Raine & Chen, 2018). Examples include spontaneous smiling when seeing someone laugh or flinching when seeing another person being hurt (Raine & Chen, 2018). This somatic facet aligns with neuroscientific evidence supporting that the internal motor simulation of others' affective states serves as the neural basis for empathy (Iacoboni, 2009). In other words, individuals' neurons "mirror" the facial expressions and actions of an empathic target, enabling the experience of the target's emotions as if the individuals themselves felt them.

In order to assess all three manifestations in children and incorporate the important aspect of somatic empathy, Raine and Chen (2018) developed a self-report instrument, the Cognitive, Affective, and Somatic Empathy Scales for Children (CASES). CASES is a 30-item assessment tool investigating positive and negative aspects of all three empathic facets. The scales have been validated in samples of children and adolescents aged 8 to 18 (Raine & Chen, 2018; Chen et al., 2021) and recently with adults (Raine et al., 2022) and contain statements depicting everyday life scenarios. Within each empathic facet, ten statements address positive and negative scenarios. The cognitive-related items refer to situations requiring perspective-taking (e.g., *"I can tell when someone is feeling guilty"*), while the affective ones gauge children's experience of others' emotional states (e.g., *"Hearing the cheer of a sports crowd gives me a thrill"*). Lastly, somatic statements investigate motor responses to events described (Chen et al., 2021), for example, *"Seeing someone enjoying a tasty dessert makes my mouth water"*. All statements are rated on a 3-point Likert scale with responses including "*Rarely*", "*Sometimes*", and "*Often*".

Currently, the questionnaire is only available in English (Raine & Chen, 2018) and Chinese (Liu et al., 2018) and has not been tested in populations speaking other languages. Considering the

significant impact of culture on emotional expressions and social behaviours (Liu et al., 2018), additional translations are required to enable the investigation of somatic empathy in other populations. Building on this imperative, CASES was translated into Greek, enabling its administration to Greek-speaking groups. This version was recently employed in a music psychology study (Tzanaki et al., 2024; in preparation) examining the relationship between empathy and interpersonal synchrony in Greek-speaking primary school children. By integrating statements assessing somatic empathy, CASES enabled the exploration of this empathic manifestation in children's musical interactions, an aspect not previously investigated in the realm of music psychology.

This report outlines and discusses the procedures undertaken to translate and validate the Greek CASES. These procedures aimed to provide a robust tool for capturing the three empathic facets in Greek-speaking children and adolescents, enabling further empirical research on the subject. The following sections detail the methodology utilised and discuss its outcomes.

Methods

The Department of Music Ethics Committee at the University of Sheffield (UK) approved the following methodology. Permission for translating and using CASES was granted by its first author (Prof. Adrian Raine) and the © 2018 Society of Clinical Child and Adolescent Psychology, Division 53, American Psychological Association.

Participants

Eight bilingual (speaking Greek and English) pupils (1 Female participant, Age: M =10.25 years, SD =1.38) participated in the pilot version of the aforementioned music psychology study that first employed the Greek CASES. Their data was used here to prepare for the validation process of the new questionnaire, as will be described in the following sections. Participants were recruited from the Greek School of Sheffield (UK). Parental/caregiver informed consent and assent from the child participants were obtained before the study commenced.

Furthermore, 67 bilingual adults, sourced via social media and the University of Sheffield's participant recruitment mailing lists, took part in the main validation process of the Greek CASES. Obtaining an adequate sample size of bilinguals within the age range of 8-18 years old (as in the original CASES) proved challenging due to time constraints; therefore, adults were recruited instead. Sixty

individuals completed both versions of the questionnaire, while four completed only the Greek CASES and three only the English version. Participants verbally confirmed their fluency in both languages upon recruitment, and informed consent was obtained prior to questionnaire completion. No additional demographic information was collected.

Translation procedure

The original 30 items of CASES were translated into Greek by the author of this report, a native Greek speaker with proficiency in English and a teaching background in Greek primary schools. The aim was a "conceptual rather than literal" translation (Chang et al., 1999, p.317), ensuring the Greek statements were culturally relevant to the target group (Greek-speaking primary school children). Subsequently, the Greek questionnaire was back-translated into English by an independent and native Greek researcher, and the author evaluated its similarity with the original scales. An additional round of forward and back translations was conducted with two independent bilingual researchers before reaching the final Greek version. Two primary school teachers and a parent from the Greek School of Sheffield reviewed the final statements of the Greek questionnaire. Through these discussions, two items were identified as unsuitable for the target group and were consequently modified (Table 5.1).

Questionnaire administration

The questionnaire was first administered to the eight children of the pilot study. All pupils completed both versions (English and Greek) on paper forms, with one week between administrations to reduce the likelihood of recalling responses given on the first occasion. This interval was adequate for participants' memory to fade without allowing for significant developmental changes that would affect the test-retest reliability estimate (Tsang et al., 2017). Five participants completed the English version first, whereas the remaining three started with the Greek CASES. The experimenter remained present during administration, offering guidance and documenting qualitative observations regarding questionnaire comprehension.

During the pilot study, some pupils encountered difficulty in understanding the translation of the response *"Rarely"* into Greek (*"Σπάνια"*). After consulting with the same reviewers as in the translation review process, the term was replaced with the response *"Ποτέ"* translating to *"Never"*. Although the selected word denotes a more definitive response than *"Rarely"*, it was deemed more

suitable and comprehensible for the intended group. This adjustment also maintains consistency with similar self-reported instruments for children in Greek (for example, Mellon & Moutavelis, 2007).

Data collection with adult participants followed, utilising the revised questionnaire responses. Participants completed both questionnaires online via Google Forms. Those responding to the recruitment announcements were asked to confirm their fluency in Greek and English before receiving separate links to the two forms, spaced one week apart to reduce the likelihood of recall. Thirty-two participants completed the Greek CASES first, whereas 28 commenced with the English version. Seven additional participants completed only one of the questionnaires, failing to respond to follow-up emails. The experimenter was not physically present during completion but remained available via email for any inquiries.

Validation procedure

A methodology akin to Chang et al. (1999) was employed to validate the Greek CASES, incorporating guidance from Tsang et al. (2017) and Chen et al. (2021). Only data from the adult participants were used in the validation analysis. Three statistical tests were employed to evaluate the equivalence between the Greek and English CASES. Firstly, Cronbach's alpha (α) reliability coefficients assessed internal consistency within each dimension (positive and negative) of each empathic subscale (cognitive, affective and somatic). Secondly, test-retest reliability was evaluated utilising intra-class correlations (ICC) to examine the similarity of subscales and total scores between the two versions. Finally, Weighted Kappa values were calculated to assess consistency across individuals' scores, i.e. the item-to-item agreement across their responses after factoring out chance (Tsang et al., 2017). All analyses were conducted on IBM SPSS Statistics (Version 28.0).

Results

Translation outcomes

The final translated version of CASES is available in the Appendix. Table 5.1 presents the two statements that were adapted following discussions with two primary school teachers and a parent (Statements 10 and 19 of the original scales; Raine & Chen, 2018). The table presents the original statements, their adapted versions in Greek, and their translations into English.

Table 5.1

Adapted CASES items (Statements 10 and 19)

Original items	Rationale for adaptation	Adapted items (Greek)	Adapted items (English)
Statement 10: I would feel angry if I saw a man hitting a defenceless woman	The concept of a "man" hitting a "woman".	Θα νευρίαζα αν έβλεπα κάποιον να χτυπάει έναν ανυπεράσπιστο άνθρωπο.	I would feel angry if I saw someone hitting a defenceless person.
Statement 19: Seeing a man pointing a gun at an unarmed person would make me feel frightened	The use of the word "gun".	Αν έβλεπα έναν καρχαρία να πλησιάζει έναν άνθρωπο στη θάλασσα, αυτό θα με τρόμαζε.	Seeing a shark approaching a person in the sea would make me feel frightened.

Validation outcomes

Starting with internal consistency, and given that the test concerns internal aspects of each version, data from participants who completed only one of the questionnaires were also included in the analysis. Table 5.2 presents the results for each version. Since the items within each calculation were fewer than ten, an acceptable Cronbach's alpha was considered any value greater than 0.5 (Pallant, 2013). The analysis revealed that the two affective subscales and total scores of each questionnaire presented adequate internal consistency, whereas the rest of the subscales demonstrated poor consistency in both versions. A closer examination of these inconsistencies involved examining Cronbach's alpha coefficients if one of the items of each subscale was deleted. Table 5.3 presents the results of this analysis for Cognitive Positive (CP), Cognitive Negative (CN), Somatic Positive (SP) and Somatic Negative (SN) subscales. An improvement to adequate internal consistency was observed for the CN subscale in its Greek version if item CN1 was deleted and for the SP subscale in the English questionnaire if item SP4 was removed.

Table 5.2

Internal consistency within subscales and total CASES scores

Subscale	Cronbach's alpha reliability coefficients	
	Greek version *(n=64)*	English version *(n=63)*
Cognitive Positive (CP)	**.31**	**.20**
Cognitive Negative (CN)	**.47**	**.48**

Affective Positive (AP)	.63	.57
Affective Negative (AN)	.57	.62
Somatic Positive (SP)	**.14**	**.39**
Somatic Negative (SN)	**.43**	**.37**
Total CASES score	.82	.82

Note. The values in **bold** indicate low internal consistency among the items of the subscale.

Table 5.3

Internal consistency of subscales with small Cronbach's alpha coefficient and the corrected internal consistency if the item was deleted.

Subscales		Cronbach's alpha reliability coefficients	
		Greek version *(n=64)*	English version *(n=63)*
Cognitive Positive (CP)	If CP1was deleted	.29	**.27**
	If CP2 was deleted	.30	.18
	If CP3 was deleted	.21	.19
	If CP4 was deleted	**.38**	-.04
	If CP5 was deleted	.12	.12
Cognitive Negative (CN)	If CN1was deleted	**.53**	.39
	If CN2 was deleted	.23	.45
	If CN3 was deleted	.43	.34
	If CN4 was deleted	.33	.44
	If CN5 was deleted	.47	**.47**
Somatic Positive (AP)	If SP1was deleted	**.26**	.35
	If SP2 was deleted	.05	.33
	If SP3 was deleted	.14	.36
	If SP4 was deleted	.18	**.50**
	If SP5 was deleted	-.09	.17
Somatic Negative (SN)	If SN1was deleted	.35	.40
	If SN2 was deleted	.41	.37
	If SN3 was deleted	.17	.08
	If SN4 was deleted	**.47**	**.43**
	If SN5 was deleted	.45	.24

Note. The values in **bold** indicate the maximum improvement in internal consistency detected if one of the subscale items was deleted.

Furthermore, in order to examine test-retest reliability, only data from participants who completed both questionnaires was included in this analysis. Table 5.4 presents the ICC results, interpreted based on Koo and Li's (2016) guidelines (see Appendix for the criteria). The total scores of each subscale were used in this analysis (a test using the mean scores provided the same results). All subscales demonstrated moderate reliability, while the total scores showed good reliability.

Table 5.4

Test-retest reliability assessment using total scores of each subscale

Subscale	Intra-class correlations (ICC) using total scores *(n=60)*	Interpretation
Cognitive Positive (CP)	.58	Moderate reliability
Cognitive Negative (CN)	.59	Moderate reliability
Affective Positive (AP)	.74	Moderate reliability
Affective Negative (AN)	.59	Moderate reliability
Somatic Positive (SP)	.65	Moderate reliability
Somatic Negative (SN)	.56	Moderate reliability
Total CASES scores	.79	Good reliability

Finally, the item-to-item agreement was assessed, again using only data from adults who completed both questionnaires. Table 5.5 presents the results, interpreted following guidance from Shrout and Fleiss (1979), as seen in Chang et al. (1999; see Appendix for the criteria). Eleven statements (items 3, 4, 9, 12, 15, 17, 18, 19, 23, 26, 27) demonstrated poor equivalence, having weighted kappas (Cohen, 1968) below .4. Notably, items 12 and 17 indicated very poor agreement, while items 3, 4, 9, 15, 18, 19, 23, 26 and 27 showed minimal or borderline acceptable agreement (McHugh, 2012). The remaining 19 items of the questionnaire demonstrated an acceptable level of agreement between their Greek and English versions (Chang et al.,1999).

Table 5.5

Weighted Kappa's for each item, assessing agreement between its Greek and English versions.

Subscale	Item	κ_w	*p*	Interpretation
Cognitive Positive (CP)	CP1 (Item no. 1)	0.53	<.001	Acceptable level of agreement
	CP2 (Item no. 17)	**0.08**	**.43**	**Poor equivalence or agreement**
	CP3 (Item no. 9)	**0.29**	**<.05**	**Poor equivalence or agreement**
	CP4 (Item no. 23)	**0.39**	**<.001**	**Poor equivalence or agreement**
	CP5 (Item no. 28)	0.47	<.001	Acceptable level of agreement
Cognitive Negative (CN)	CN1 (Item no. 6)	0.44	<.001	Acceptable level of agreement
	CN2 (Item no. 18)	**0.28**	**<.05**	**Poor equivalence or agreement**
	CN3 (Item no. 21)	0.61	<.001	Acceptable level of agreement
	CN4 (Item no. 26)	**0.38**	**<.05**	**Poor equivalence or agreement**
	CN5 (Item no. 12)	**-.01**	**.89**	**Poor equivalence or agreement**
Affective Positive (AP)	AP1 (Item no. 5)	0.56	<.001	Acceptable level of agreement
	AP2 (Item no. 25)	0.42	<.001	Acceptable level of agreement
	AP3 (Item no. 8)	0.59	<.001	Acceptable level of agreement
	AP4 (Item no. 13)	0.62	<.001	Acceptable level of agreement
	AP5 (Item no. 22)	0.45	<.001	Acceptable level of agreement
Affective Negative (AN)	AN1 (Item no. 2)	0.45	<.001	Acceptable level of agreement
	AN2 (Item no. 10)	0.45	<.001	Acceptable level of agreement
	AN3 (Item no. 16)	0.49	<.001	Acceptable level of agreement
	AN4 (Item no. 19)	**0.37**	**<.001**	**Poor equivalence or agreement**
	AN5 (Item no. 27)	**0.22**	**<.05**	**Poor equivalence or agreement**
Somatic Positive (SP)	**SP1 (Item no. 3)**	**0.31**	**<.05**	**Poor equivalence or agreement**
	SP2 (Item no. 11)	0.46	<.001	Acceptable level of agreement
	SP3 (Item no. 15)	**0.27**	**<.05**	**Poor equivalence or agreement**
	SP4 (Item no. 20)	0.61	<.001	Acceptable level of agreement
	SP5 (Item no. 30)	0.64	<.001	Acceptable level of agreement
Somatic Negative (SN)	**SN1 (Item no. 4)**	**0.36**	**<.05**	**Poor equivalence or agreement**
	SN2 (Item no. 7)	0.54	<.001	Acceptable level of agreement
	SN3 (Item no. 14)	0.42	<.001	Acceptable level of agreement

SN4 (Item no. 24)	0.54	<.001	Acceptable level of agreement
SN5 (Item no. 29)	0.43	<.001	Acceptable level of agreement

Note. The values in **bold** indicate the items presenting poor equivalence across versions.

Discussion

The purpose of the study was to translate the Cognitive, Affective and Somatic Empathy Scales for Children (Raine & Chen, 2018) into Greek and validate this new version. The assessments conducted showed, in general, acceptable agreement between the original and the Greek scales, establishing the latter as the first self-reported instrument capturing all three facets of trait empathy in Greek-speaking young populations. Nevertheless, further examination of certain items would be worthwhile to correct for their low internal consistency and poor equivalence.

Examining the validation outcomes, Cronbach's alpha coefficients indicated sufficient internal consistency within the affective subscales and total scores; however, the remaining subscales displayed low inconsistency for both versions of the questionnaire. This finding could be attributed to the small number of items per subscale, which tends to affect Cronbach's alpha (Pallant, 2013). Indeed, all subscales presented relatively low coefficients, whereas the total scores, which included 30 items, showcased high internal consistency. Nonetheless, the observation of low consistency in the cognitive and somatic subscales across the two versions might suggest that participants interpreted the items within those subscales differently, a trend that remained the same across the translated versions. This is further reinforced by the secondary analysis, which examined Cronbach's alpha when one of the items was removed. The analysis revealed that the only subscales whose internal consistency would improve were the Greek CN and the English SP, whereas the other subscales would remain largely inconsistent. Since this does not align with previous relevant measurements of the subscales (Raine & Chen, 2018; Liu et al., 2018), we attribute it to the sample used in the study. It is possible that participants' experiences depicted by these statements varied significantly, thereby influencing the subscale's homogeneity. For instance, items such as statement 4 (*"I know when my family members are pleased by how they talk"*) might have appeared ambiguous for the adult participants of the study. They may

generally understand when their family members are pleased, but they rely on other cues beyond how they talk, encouraging them to respond accordingly.

Regarding the test-retest reliability estimates, the ICC values indicated moderate and good agreement between the two versions, suggesting they captured similar aspects of participants' experiences exhibiting empathy. However, upon closer examination of the item-to-item agreement, eleven statements presented poor equivalence with their original ones, with two items presenting very low agreement and the remaining 9 showcasing minimal or borderline acceptable equivalence (Table 5.5). These results might arise once more from participants interpreting some ambiguous statements differently, potentially exacerbated by language differences. Despite the thorough forward and back translations, these items may still have been construed differently in each language. This effect might have further been amplified by the inclusion of the word "Never" as one of the responses in the Greek version. While this choice aimed to provide a more understandable response for younger participants, it might have elicited diverse responses among adult participants, who may perceive a significant distinction between "*Rarely*" and "*Never*." This discrepancy might have led the adult participants to select "*Rarely*" in English and "*Sometimes*" in the Greek questionnaire for the same statement, resulting in low equivalence across versions.

Given the good test-retest reliability between versions and the good internal consistency of their total scores, the Greek questionnaire was implemented in the music psychology study mentioned above (Tzanaki et al., 2024; in preparation) without further adaptations. Nonetheless, future investigations should address the issues highlighted in this analysis. Replicating the study with a larger sample size could demonstrate stronger similarity between versions, as smaller sample sizes tend to affect Cronbach's alpha coefficients (Bujang et al., 2018). Notably, previous studies replicating or validating CASES involved significantly larger sample sizes (N=428 in the original Raine & Chen, 2018; N=860 in the validation of the Chinese CASES; N=4676 in a cross-cultural replication by Chen et al., 2021). Another aspect to consider is the involvement of children rather than adult participants. Although the translated version demonstrated good test-retest reliability with the original CASES and reviewers evaluated its comprehensibility by primary school children, the inclusion of adults poses a limitation and further work is required to verify its suitability for the intended age group.

Future research could also investigate alternative terms to *"Never",* conveying similar frequency levels as *"Rarely"* while maintaining comprehension for younger Greek-speaking populations. The observed poor equivalence across certain items of the two versions also warrants further exploration by repeating the assessments with different samples or exploring alternative translations of the statements, ensuring a cohesive portrayal of the empathic facet across all items. Moreover, future research would benefit from collecting demographic information about participants to better understand the sample and interpret any inconsistencies observed. Lastly, validating participants' fluency in both languages using standardised methods would be beneficial, mitigating potential variabilities across versions stemming from misinterpretation or language-related challenges.

Conclusion

Despite certain limitations, this study represents the first step towards accessing an important self-reported tool for investigating the development of trait empathy in young Greek-speaking populations. It is highly recommended to replicate the above analysis with larger sample sizes and conduct a further examination of the translated versions of items exhibiting poor equivalence with the original ones. These actions can help refine a robust translated version of CASES, thereby providing a valuable tool for future cross-cultural investigations into empathy.

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Appendix

The Greek version of CASES

Subscale code	Statement
CP1	Καταλαβαίνω γιατί οι φίλοι μου είναι χαρούμενοι ακόμα και όταν δεν λένε γιατί.
CP2	Όταν κάποιος έχει καλή διάθεση, το καταλαβαίνω από το πρόσωπό του και το πως συμπεριφέρεται.
CP3	Μπορώ να καταλάβω πως νιώθουν οι ήρωες σε μία συναρπαστική ιστορία.
CP4	Καταλαβαίνω πότε η οικογένειά μου είναι χαρούμενη από το πως μιλάνε.
CP5	Μπορώ να βάλω τον εαυτό μου στη θέση κάποιου άλλου όταν μου περιγράφει τη χαρά του.
CN1	Μπορώ να καταλάβω όταν κάποιος νιώθει ένοχος.
CN2	Όταν κάποιος ντρέπεται, το καταλαβαίνω από το πρόσωπό του και το πως συμπεριφέρεται.
CN3	Καταλαβαίνω πότε κάποιος δεν είναι χαρούμενος ακόμα και πριν μου πει γιατί.
CN4	Όταν πειράζουν κάποιον φίλο μου, μπορώ να καταλάβω γιατί νιώθει άσχημα.
CN5	Όταν κάποιος είναι απογοητευμένος, μπορώ να το καταλάβω από το πως φαίνεται.
AP1	Με κάνει χαρούμενο/χαρούμενη να βλέπω κουταβάκια να παίζουν.
AP2	Ενθουσιάζομαι όταν ακούω τον κόσμο να πανηγυρίζει σε ένα γήπεδο.
AP3	Όταν βλέπω ανθρώπους σε μία ταινία να ζουν μία περιπέτεια, αυτό με ενθουσιάζει.
AP4	Νιώθω χαρούμενος/χαρούμενη όταν κάποιος μου λέει κάποια καλά νέα που έλαβε.
AP5	Με κάνει χαρούμενο/χαρούμενη να βλέπω παιδιά να τρέχουν και να διασκεδάζουν.
AN1	Αν δω κάποιον να κοροϊδεύει τον φίλο ή τη φίλη μου, αυτό με κάνει να νιώθω άβολα.
AN2	**Θα θύμωνα αν έβλεπα κάποιον να χτυπάει έναν ανυπεράσπιστο άνθρωπο.**
AN3	Αν έβλεπα λυπημένους ανθρώπους σε μία κηδεία, θα ένιωθα κι εγώ λυπημένος/λυπημένη.
AN4	**Αν έβλεπα έναν καρχαρία να πλησιάζει έναν άνθρωπο στη θάλασσα, αυτό θα με τρόμαζε.**
AN5	Θα ανησυχούσα αν έβλεπα ένα σκύλο να κυνηγάει ένα μικρό παιδί.
SP1	Όταν βλέπω άλλους να γελάνε, γελάω κι εγώ.
SP2	Όταν βλέπω μία ταινία περιπέτειας, η καρδιά μου χτυπάει πιο γρήγορα.
SP3	Όταν βλέπω κάποιον να απολαμβάνει ένα νόστιμο γλυκό, μου τρέχουν τα σάλια.
SP4	Όταν βλέπω χαρούμενους ανθρώπους, χαμογελάω.
SP5	Όταν βλέπω παιδιά να χαμογελάνε, χαμογελάω κι εγώ.
SN1	Θα ίδρωνα αν έβλεπα κάποιον να του βγάζουν τα δόντια.
SN2	Τινάζομαι όταν βλέπω κάποιον να τον χτυπάνε.
SN3	Θα δάκρυζα αν έβλεπα έναν φίλο μου να κλαίει.
SN4	Ανατριχιάζω όταν βλέπω κάποιον να κόβεται ή να αιμορραγεί.
SN5	Η καρδιά μου χτυπάει πιο γρήγορα όταν βλέπω κάτι τρομαχτικό στην τηλεόραση.

Note. The statements in **bold** were significantly adapted before their translation - see Table 5.1.

Interpretation of intra-class correlations (ICC; 2nd test)

The following criteria are detailed in Koo and Li (2016):

- ICC <.5 = Poor reliability
- ICC between .5 and .75 = Moderate reliability
- ICC between .75 and .9 = Good reliability
- ICC >.9 = Excellent reliability

Weighted Kappa criteria for interpretation of item-to-item agreement (3rd test)

The following criteria, originally derived from Shrout and Fleiss (1979) and detailed in Chang et al. (1999; p.318), were followed for the item-to-item assessment between the two versions of CASES: “Kappa below 0.4 represents poor equivalence or agreement, between 0.4 to 0.75 represents an acceptable level of agreement and larger than 0.75 shows a high level of agreement”.