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The role of heart rate in children's empathic experience

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Introduction

When children are born into the world, first stirrings of empathy are observable very quickly. At the beginning of the 19th century the German psychologist Charlotte Bühler together with the Austrian psychologist Hildegard Hetzer observed the phenomenon, that 84% of infants in their first year of life start to cry when another infant in their immediate vicinity cries (Bühler & Hetzer, 1928). Decades later this phenomenon, called contagious crying, was investigated and proved with modern experimental methods in newborns aged 70 hours or even 34 hours (Simner, 1971; Sagi & Hofmann, 1976). Martin & Clark (1982) replicated the findings and showed that calm infants start to cry and crying infants continue to cry when exposed to the crying of another neonate. Interestingly, crying infants stop to cry when they hear their own crying and calm children show no response to their own crying or to the crying of a chimpanzee or an older child.

Although contagious crying is an interesting phenomenon and serves as evidence that precursors of empathy are already available at birth, it cannot be said that newborns experience empathy in the narrow sense. Empathy seems to develop as children grow up, but opinions of scientists regarding the exact time frame are divided. Some researchers found evidence that infants experience empathy between three months and one year of life (Liddle et al., 2015; Davidov et al., 2013, 2021). Other researchers found evidence for an emerge of empathy during the second year of life (Vaish & Warneken, 2011; Decety & Holvoet, 2021; Paulus et al., 2024). Ruffman et al. (2025) reviewed current studies and concluded that "empathy develops along with self-recognition around about 18-24 months of age" (p. 186). But recent evidence from neuroscience casts doubts on this finding, emphasizing the involvement of different components in the experience of empathy which partly seem to develop much later. For instance, Decety (2010) in his neuroscientific model stresses the fact, that among others emotion understanding is a necessary component to experience empathy in the narrow sense. This ability draws on the prefrontal cortex (especially the ventromedial and medial part) and executive functions and "begins to be really mature around the age of 2-3 years" (p. 259). Another frequently emphasized component is a self-other distinction, an ability which is in the scientific literature sometimes divided up into an affective and a cognitive self-other distinction. The cognitive self-other distinction is necessary to attribute a certain mental status to others and therefor a prerequisite of the theory of mind (Steinbes, 2016). Cognitive self-other distinction is associated with the maturity of the white matter of the right temporoparietal junction (rTPJ) as well as the density of alpha waves in the dorsal medial prefrontal cortex and the rTPJ (Grosse Wiesmann et al., 2017; Sabbagh et al., 2009). Commonly a false-belief test is used to assess the theory of mind and the cognitive self-other-distinction in children and Wellmann et al. (2001) showed that children pass this test above chance level with about four years. Affective self-other distinction on the other hand is associated with the activity of right supramarginal gyrus and the connectivity with right primary and secondary somatosensory cortices, bilateral visual cortex and left dorsolateral prefrontal cortex (Silani et al., 2013; Steinbeis et al., 2015) The right supramarginal gyrus is located on the parietal lobule and has been shown in neuroimaging studies to mature throughout childhood until the end of adolescence (Giedd et al., 1999; Gogtay et al., 2004; Natu et al., 2019). This is in line with studies regarding the emotional egocentricity bias, which has been observed to be higher in children compared to young adults or in adolescents and older adults compared to middle-aged adults (Hayashi & Nishikawa, 2019; Hoffmann et al., 2015, Steinbeis et al., 2015; Riva et al., 2016). Obviously, evidence from neuroscience suggests that children seem to experience empathy in the narrow sense not before about four years.

Since development of children is a complex, individual process, it is despite neuroscientific evidence difficult to pinpoint a specific timepoint or a time frame for the onset of the experience of empathy. This might be one reason for the varying results mentioned before. Another reason is, typical for scientific research, the differences in methodology and quality of the studies. But especially in the field of empathy research, we must not forget a third important reason. Empathy is a very complex construct and there is a lot of variety regarding the operational definitions and conceptualisation of empathy which leads to a lot of ambiguity in further consequence.

Yet the scientific study of experience of empathy in children is a very encouraging research field. But since there are so many difficulties regarding the conceptualisation and operational definitions it is necessary to tackle these controversies at the very beginning to understand what empathy as the underlying research object is.

What is empathy?

From an etymological point of view, the term empathy is an artificial word which has its origin in the Greek word "empatheia" and consists of the word "em" (meaning in this context "(with)in") and a form of "pathos" (meaning "feeling", "suffering" or "passion") and can therefore be understood as "feeling into" (Körner, 1998; Singer & Klimecki, 2014; Breyer, 2020). It was coined by the English psychologist Edward Bradford Titchener in 1909, who conceptualized empathy as an affective-kinaesthetic process-an internal act or more precisely as an act of inner imitation (Wispé, 1986). He defined empathy as follows: "Not only do I see gravity and modesty and pride and courtesy and stateliness, but I feel or act them in the mind's muscle. That is, I suppose, a simple case of empathy, if we may coin that term as a rendering of Einfühlung" (Titchener, 1909, p. 21).

Although Stotland et al. (1978) regard that philosophers had discussed about empathy and related constructs since "the beginnings of philosophical thought" (p. 11), both this first conceptual definition of empathy and the etymological background mentioned at the very beginning reveal the philosophical debate of "Einfühlung" as the true origin of the notion of empathy. "Einfühlung" was used by German philosophers such as Johann Gottfried Herder and Hermann Lotze in the 18th century to describe the act of feeling into or empathically understanding phenomena that were foreign or unfamiliar, such as nature, art or other cultures (Körner, 1998; Scholtz 2011). Vischer (1873) and Lipps (1903) discussed "Einfühlung" in a more psychological context, with Lipps' theory being especially interesting in this context using "the notion of Einfühlung to explain not only how people experience inanimate objects, but also how they understand the mental states of other people." (Montag et al., 2008, p. 1261). Interestingly, Lipps stressed a cognitive view of Einfühlung, whereby Titchener, who coined empathy as a rendering of Einfühlung, emphasized a more affective conceptualisation.

Since the time of Lipps and Titchener, empathy has been studied intensively and today "the concept of empathy provides a broad umbrella under which many kinds of researchers can pursue the origins, processes, and outcomes of humane social emotions, attitudes, and behaviour" (Hall & Schwartz, 2019, p. 225). On the one hand, this has led to an uncountable number of articles and a broad body of evidence but, on the other hand, has also given rise to a lot of variety and ambiguity, for instance regarding the operational definition. Decety & Jackson (2004) mediated on some definitions but concluded "There are many other definitions of empathy, almost as many as there are researchers in this field" (p. 73). This conclusion is supported by a review from Cuff et al. (2016), who listed 43 different definitions of empathy. Leaving aside the fact that the list is far away from completeness, a passing view on the definitions is enough to realize, that there are not only huge differences but even conflicts between the definitions. This has to do with the fact that there is an incredible variety of conceptualisations in the field of empathy research (Duan & Hill, 1996, Hall & Schwartz, 2019). A dip into the past reveals the reason for this variety. As mentioned before, even the founding fathers of modern empathy research had a different view on empathy and history repeated itself. During the 19th and 20th century, empathy theorists shifted from a cognitive-centred conceptualisation in the 1950s, back to a more emotional-oriented conceptualisation in the 1960s to a narrowing of this emotional view in the late 1970s centring upon other-focused feelings (Batson et al., 1987). These shifts have given rise to a lot of movements within psychological empathy research, each with an own notion, conceptualisation and definition of empathy.

Some scientists investigate empathy from a social-psychological point of view. Most of them have conceptualized empathy as a vicarious, emotional reaction but they focused their research not on the emergence or unfolding of this emotion by itself but on the results of this reaction in terms of different kinds of motivation with empathic concern (EC, sometimes also called sympathy) on the one hand and personal distress (PD) on the other hand. Both outcomes relate to different kinds of feelings and different motivational consequences in the context of prosocial behaviour. This is a research approach which originates in the work of philosophers from the 18th century like Adam Smith or Herbert Spencer who had distinguished cognitive and emotional aspects of compassion in the context of moral and prosocial behaviour (Davis, 1983; Jordan et al., 2016; Martingano, 2022). During the emerging of the altruism-egoism-debate, this kind of research enjoyed a new lease of life with, for instance, Batson et al. (1981, 1987) and Batson (1991), who proposed the empathy-altruism-hypothesis. They argued that EC and PD are two distinct affective responses to another's suffering which lead to different kinds of motivation: EC generates altruistic motivation aimed to help other people in stressful situations, while PD generates egoistic motivation aimed to reduce one's own aversive arousal when escape is easy. If escape is difficult, PD might also generate helping behaviour. In contrast, Cialdini et al. (1973, 1987) proposed a negative-state relief model and argued, that helping behaviour is solely motivated by the desire to reduce own's own aversive emotional state which is elicited by seeing other people in distress. The sharp distinction between EC and PD has been criticized in several ways. Eisenberg & Eggum (2009) also investigated EC and PD as affective-motivational consequences but admitted that empathy could also result in both. Maibom (2019) came to the same conclusion and stressed the fact that both reactions tend to co-occur and may be observed in parallel during an empathic experience.

Other scientists draw on classical psychological science to conceptualize empathy. They urge to conceptualize empathy as a trait in terms of a multidimensional concept. A prominent representative of this approach is the American psychologist Mark H. Davis, who was among the first to translate theoretical conceptualisations into an empirically testable multidimensional model, arguing that there "is a growing belief among empathy theorists and researchers that our understanding of empathy can improve only with the explicit recognition that there are both affective and cognitive components to the empathic response" (Davis, 1983, p.113). Therefore, he explicitly conceptualised, operationalised and psychometrically validated empathy as multidimensional construct in terms of the interpersonal reactivity index (IRI) (Davis, 1983). This 28 item questionnaire measures four discriminable dimensions of empathy, of which Perspective Taking (PT) and Fantasy (FA) assess different cognitive aspects and EC and PD measure different emotional aspects. PT is conceptualized as the ability to adopt the mental state of others, which enables human to mentally understand how the other feels. This is often viewed as cognitive empathy in the narrow sense. FA is the ability to imagine the state of fictitious characters, like the mental state of a movie character. EC is understood as other-oriented feelings like concern for the situation of the other and PD at the contrary is assumed as self-oriented feelings like anxiety. Both conceptualisations recall the previous mentioned view on empathy proposed by scientists like Batson, but instead of understanding EC and PD as kind of motivation they are here understood as distinct facets of trait empathy. Although the IRI is widely in use, this kind of conceptualisation has been criticized, for instance regarding the psychometric properties of the PD subscale of the German version of the IRI (Koller & Lamm, 2014). In addition, it must be said, that there is no consensus regarding this four-factor structure. For instance, Reniers et al. (2011) published the Questionnaire of Cognitive and Affective Empathy and revealed a five-factor structure of empathy based on factor analyses. The good news is that despite the controversies regarding number and conceptualisation of (sub)factors, there is a broad consensus that empathy is a multidimensional construct. This is supported by a review from Hall & Schwartz (2019), who analysed 393 empathy studies published between 2001 and 2013 and 96 studies published in 2017. They found out that not only the number of authors, who cited a multidimensional construct of empathy increased from 33% between 2001 and 2013 to 52% in 2017, but that in 2017, 76% of the conceptual definitions assumed a multidimensional concept. In addition, they reported a very frequent distinction made between cognitive and affective empathy as two related yet distinct factors.

The American psychologist Martin Hoffman was among the empathy researchers who focused more on the developmental aspect of empathy and proposed a stage model of empathy. He defined empathy as a process to “make a person have feelings that are more congruent with another’s situation than with his own situation” (Hoffman, 2000, p. 30). Hoffman neither defined empathy as a solely emotional reaction but stressed the importance of understanding the other’s state nor was empathy a stable trait over life. He proposed a model consisting of four consecutive steps, with global empathy as a first step evident in newborns. He referred to contagious crying as an example, which he explained based on mimicry and conditioning. As this is an automatic, undifferentiated reaction without any self-other distinction it is just a precursor of empathy. Between about six months of life and the end of the first year of life, infants reach the next level of empathy which Hoffman called egocentric empathic distress. On this level, they feel distress but are unaware of the origin. They start to develop a sense for the self but are far away from a functioning self-other differentiation. During early months in the second year of life, they reach the next step called quasi-egocentric empathy. Children can distinguish empathic distress from actual distress and are willing to help but still do not fully understand the state of others. They offer the kind of help they would hope to receive in a similar situation. In the middle of the second year, children reach the stage veridical empathic distress which is accompanied with passing the mirror test. Later in the second year they understand the inner state of others and have a better self-other distinction. Hoffman emphasized that children now have all necessary components to experience empathy, but still empathy is not fully developed, rather it develops throughout life. He points out several important milestones during early childhood (e.g. feelings can be elicited by the actions of others), preschool years (e.g. two people feel different in the same situation), middle childhood (e.g. better understanding of the correlation between own’s and other’s feelings), later childhood (e.g. an event can cause different types of emotions like happy and disappointment), adolescence and adulthood.

In recent years, a neuroscientific perspective has gained centre state in empathy research. In their influential paper, Decety & Jackson (2004) defined empathy as the “subjective experience of similarity between the feelings express by self and others without losing sight of whose feelings belong to whom” (p. 71). From a neuroscientific point of view empathy is often conceptualized as affective sharing which emerges from the interplay of several components (Decety & Jackson, 2004; Decety & Lamm 2006; Decety, 2010). Neuroscientists stress biological mechanism necessary for empathy, like the mirror neuron system (Rizzolatti & Craighero, 2004). They also aim to reveal activation patterns of brain areas which are associated with the experience of empathy. For instance, Fan et al. (2011) conducted a meta-analysis of 50 functional magnetic resonance imaging (fMRI) studies and found out that during tasks designed to investigate either more cognitive-elicited empathy or emotional-induced empathy particular patterns of activation are observable. Of course, to a certain degree the activated areas overlap, but the right anterior insula (AI) extending to right inferior frontal gyrus, the ventral part of anterior midcingulate cortex extending to right dorsal anterior cingulate cortex, the midbrain and the right dorsal medial thalamus are more frequently activated during emotional-induced empathy. In contrast, the dorsal part of the left anterior midcingulate cortex, left orbitofrontal cortex and left dorsal medial thalamus are more frequently activated in tasks which require perspective taking. Although neuroscience has a strong focus on the brain and the nervous system, scientists aim to integrate evidence from other research fields like social psychology or developmental psychology what makes their models integrative.

In summary, it must be said, that empathy is undoubtedly a complex phenomenon, and it seems not to be useful to cherish the illusion to find a conceptualisation which is broadly accepted in science. The upside is that there might be some themes which run like a golden thread trough the different conceptualisations. Hakansson Eklund & Summer Meranius (2021) reviewed 52 articles of empathy and came to the encouraging conclusion, that four themes are prominent in most conceptualisations, assuming that "in empathy empathizer understands, feels, and shares another person's world with self-other differentiation (p. 300). This is strongly reminiscent of the conceptualisation of empathy in the field of neuroscience and since neuroscience provides integrative models I will go for a definition widely used in this research area to answer the question underlying this first section. De Vignemont & Singer (2006) said that "there is empathy if: (i) one is in an affective state; (ii) this state is isomorphic to another person's affective state; (iii) this state is elicited by the observation or imagination of another person's affective state; (iv) one knows that the other person is the source of one's own affective state.“ (p. 435). With this definition in mind, it is interesting, what human in general make experiencing empathy.

The experience of empathy

Some neuroscientific models of empathy are based on the Perception-Action-Model, a process-oriented model of empathy alleged with evidence from behavioural, physiology and functional neuroanatomy data (Preston & de Waal, 2002; Preston, 2009). In this model, the experience of empathy starts with paying attention to a certain stimulus (= an object, like a person in distress). According to the model, the given attention depends on two important factors: The more salient a stimulus is (e.g. a person is crying) and the more a response is required (e.g. because of interdependence or interrelationship with the person in distress) the more attention will be paid to the stimulus. Hence attention can be controlled and shifted for which the activity of the cerebellum and the frontal lobe is necessary. Attention leads to the perception of the state of others which can be directly perceived (e.g. watching another person in distress) or imagined (e.g. a hypothetical situation). The imagined state of another person is hypothesised to evolve a less strong experience of empathy subsequently, and from a neuroscientific point of view the amygdala might not be engaged but the dorsolateral prefrontal cortex. The perception automatically activates representations, which are defined as "parallel distributed patterns of activation that reliably fire in response to a given stimulus" (Preston & de Waal, 2002, p. 5). These patterns include central processes (e.g. activation of brain areas) as well as peripheral processes (e.g. autonomic arousal) which leads to the experience of emotion dependent on "the degree of emotion in the object, degree of attention to the object and, thus, degree of activation of the representation (Preston, 2009, p. 434-435). If this experienced emotion based on representations is similar to the emotion of the other, the model refers to this as shared emotional experience which is understood as empathy. Despite the already mentioned influencing factors, own life history, similarity of experiences and the relationship to the other person also determine the intensity of empathy (Preston, 2009). The experience of empathy leads to two types of responses. One type is the response with the object (e.g. matching the emotion which leads to a physiological reaction linked to the emotion of the other) and the other type is the response to the object (e.g. instrumental reaction like concern).

Although this model explains the experience of empathy, it falls short regarding the previous mentioned conceptualisation of empathy. It is obvious that affective resonance gained centre stage, and it is hypothesized to be sufficient for the experience of empathy, while other important components, like self-other differentiation are neglected. But as I mentioned before, this work blazed the way for further models which extended our understanding.

Decety & Lamm (2006) published such a model of empathy. In contrast to Preston and de Waal they did not assume a linear model but described empathy in terms of a dynamic system with bottom-up and top-down information processes and particular components of empathy. At first, Decety & Lamm (2006) defined empathy as "the ability to experience and understand what others feel without confusion between oneself and others" (p. 1146). According to the model, the experience of empathy starts with the perception or the imagination of the emotion of somebody else which initiates a bottom-up information processing. This leads to a perception-action coupling, a phenomenon apparent in emotion contagion, which is "the tendency to automatically mimic and synchronize movements, expressions, postures, and vocalizations with those of another person and, consequently, to converge emotionally" (Hatfield et al., 1992, p. 153-154). On a neuroanatomy level, the human mirror system, which is a cortical network spanned over the inferior parietal lobule, the ventral premotor cortex and the caudal part of the inferior frontal gyrus, plays a very important role providing an automatic perception-action mechanism. (Fabbri-Destro & Rizzolatti, 2008). Besides, evidence from fMRI studies show, that similar neural circuits are activated during first-hand experience of emotions and vicarious emotions. For instance, no matter if disgust is experienced or observed in others facial expression, the AI is activated equally (Carr et al., 2003). Another example is the activation of rostral anterior midcingulate cortex, AI, brainstem and cerebellum independent of whether pain is experienced or expected to be experienced from a loved one in the same room (Singer et al., 2004). This perception-action coupling is an initial step to perceive and understand other's emotions and leads automatically to shared representations. Interestingly, a comparable process with common activated neural circuits which lead to shared representations is also observable during PT. For instance, in an fMRI study it was evident, that the parietal operculum, anterior cingulate cortex and AI were activated during imagining of self-experienced pain or others-experienced pain (Jackson et al., 2006). Whether shared representations are activated through bottom-up emotion sharing or through PT, they involve a vicarious affect and from now on some mechanisms come into play to direct the emotion into an empathic reaction. Decety and Lamm understand sympathy (which is like EC) and PD as empathic reactions, which is, as mentioned before, different to the initial idea proposed by Davis. They suggest that the experience of empathy in terms of shared representations "can lead to sympathy (concern for another based on the apprehension or comprehension of the other's emotional state or condition), or even personal distress (i.e., an aversive, self-focused emotional reaction to the apprehension or comprehension of another's emotional state or condition)" (Decety & Lamm, 2009, p. 199). One important mechanism to direct the experience of empathy to EC is a sufficient self-other awareness, which serves as ability to keep apart own emotions from shared emotions. Another mechanism is agency which is thought to enable human to navigate between these emotions. The rTPJ seems to play a key role in both self-other-awareness and agency (Blakemore & Frith, 2003, Jackson & Decety, 2004, Decety & Lamm, 2007). Both components are necessary to avoid a complete overlap between self and other representation, which would not lead to EC and an other-oriented reaction but to PD and therefore to emotions like upset or stress and self-oriented reactions to reduce the PD (Batson et al., 1987). Another mechanism which has influence on the avoidance of PD is emotion regulation, which is an aspect of top-down information processing and is enabled through executive function resources. A sufficient emotion regulation helps to find the most appropriate response out of many possible responses based on reducing or promoting own emotions in a particular situation. Attentional control is one effective strategy of emotion regulation as the degree of activation of brain areas like the amygdala or a region in the medial prefrontal cortex has been shown to be depended on the focus or the degree of paid attention of the observer (Williams et al., 2005, Wiech et al., 2005). Cognitive changes or emotion reappraisals are some other useful strategies.

The point is, that it is important to understand that based on the previously mentioned conceptualisation, definition and the two considered models, the experience of empathy includes a vicarious emotion. This is in line also with other influential models of empathy (Hoffman, 2000; Decety & Jackson, 2004; Eisenberg & Eggum, 2009). There is evidence from emotion psychology that reactions from different systems to the experience of an emotion are observable, for instance a psychological reaction in terms of a subjective experience, a physiological reaction in terms of activity from both the peripheral/autonomic and central nervous system (CNS) and a behavioural reaction (Mauss & Robinson, 2009). Usually, these reactions have been studied during experiencing first-hand emotions but also the experience of vicarious emotions in the context of empathy elicits reactions from the autonomic nervous system (ANS), the hypothalamic-pituitary-adrenals axis and the endocrine system (Carter et al., 2009). Based on the findings regarding the shared neural circuits it is discussed that physiological reactions to first-hand emotions resemble those to vicarious emotions (Singer & Lamm, 2009).

The reaction of the autonomic nervous system during empathy

Langley (1921) divided the ANS up into the sympathetic nervous system (SNS), parasympathetic nervous system (PNS) and enteric nervous system and this classification is accepted until to today. Both the SNS and the PNS innervate, except of a few exceptions, most organ systems including the heart. Berntson et al. (2007) showed that the parasympathetic pathway originates in the nucleus ambiguous and the dorsal moto nucleus of the vagus nerve and innervates the heart through several peripheral ganglia at the heart. The sympathetic pathway originates in lower central motor neurons and runs via prevertebral peripheral ganglia to the heart. Usually, the activity of the two nervous systems has opposing effects on the heart, with the systematic system having an activating and the parasympathetic system having a calming effect. It should be noted that both nervous systems work together as antagonists to regulate the heart rate (HR), conduction and myocardial contractility to maintain homeostasis, with the PNS having a more intense influence on the HR and the SNS on the cardiac contractility.

The polyvagal theory provides a theoretical framework regarding the expected reactivity of the ANS (Porges, 1995; 2001; 2007). Carter et al. (2009) applied this theory on the experience of empathy, arguing that human permanently and unconsciously evaluate their environment, a process they called neuroception. Depending on the result, particular neural circuits get activated. If the result is positive and the environment is perceived as safe, the ventral vagal complex gets activated. This leads to a regulation of autonomic responses and therefore to a decrease and slowing of the HR, inhibition of the SNS and downregulation the stress response as well as regulation of the muscles of the face and head. The ventral vagal complex is viewed as very important for social functioning and is associated with the experience of empathy. In other words, based on the polyvagal theory, empathy can only be experienced if the environment is safe and the phylogenetic newest neural circuit gets activated and people are enabled to regulate their ANS. If the environment is assessed as threatening, the SNS gets activated and a mobilization (like a flee or fight reaction) gets enabled. If the situation is still threatening and is not manageable through the reaction of the sympathetic-adrenal system, the third and phylogenetic oldest circuit in terms of the dorsal vagal complex gets activated which would lead to an immobilization.

Based on this theory, PNS activity is expected to correlate with the experience of empathy which should be accompanied with a regulation of the autonomic responses (e.g.

HR). Hence it comes as no surprise that a lot of research has focused of the functioning of the vagus nerve system. The activity of the vagus nerve system "can be assessed using measures of high-frequency heart rate variability (HRV)" (Miller, 2018, p. 51). HRV can be measured in several ways (for a review see Shaffer & Ginsberg, 2017). In some studies, HRV is reported using a global index. A very interesting component of HRV is the respiratory sinus arrhythmia (RSA), which is defined as "rhythmic changes in the parasympathetic (vagal) cardioinhibitory influence that increases during expiration, resulting in a decrease in HR, and decreases during inspiration, leading to an increase in HR" (Menuet et al., 2025, p. 979). RSA reflects the influence of respiration on the HRV and has been viewed as a reliable index for vagal tone and as a mediator between activity of PNS and variation in HR (Berntson et al, 1997; Appelhans & Luecken, 2006; Porges, 2007). Alternatively, dynamic measures like heart rate acceleration (HRA) and heart rate deceleration (HRD) are sometimes reported (Himichi & Ohtsubo, 2020). High HRV has been interpreted as greater parasympathetic influence and has already been linked to attentional control, emotion regulation or PT (Beauchaine, 2001, 2015; Porges, 2007; Jauniaux et al., 2020). Since these abilities are necessary for empathy, HRV has also been viewed as an physiological correlate of empathy. In earlier studies with children, a positive correlation between high HRV or HR deceleration respectively and EC have been reported (Eisenberg et al., 1988, 1989, Fabes et al., 1993; Zahn-Waxler et al., 1995). This is in line with recent research in adults which revealed a positive correlation between both baseline HRV and empathy-induced HRV and empathy (Spehar et al., 2018; Lischke et al., 2018; Sassenrath et al., 2021). Interestingly, the latest study findings suggest an u-shaped relationship between HRV and empathy in children (Tully et al., 2015; Miller et al., 2017) and in adults (Kogan et al., 2014; Himichi & Ohtsubo, 2020). It must be said that in these studies empathy was operationalized in terms of EC and PD and high HRV was associated with EC and low HRV was associated with PD.

While the role of HRV seems to be clear, the role of HR during the experience of empathy is vaguer because other than HRV it is influenced by both PNS and SNS. Interestingly, Liew et al. (2003) reported a significant correlation between HR acceleration in children (computed with as an HR slope based on beats per minute (BPM)) and regulation. This would make a correlation between HR and empathy possible. But this was not found in recent studies in adults (Deuter et al., 2018; Sampaio et al., 2019). Decety & Meyer (2008) hypothesized that a higher resting HR could be associated with empathy but referred to controverse research findings. This reflects the current situation perfectly with some researchers found higher HR in children associated with PD (e.g. Eisenberg & Fabes, 1990), others found higher HR associated with empathy (e.g. Zahn-Waxler et al., 1995) and a recent study with adults found lower mean HR associated with empathizing with others (Himichi & Ohtsubo, 2020). Interestingly a significant negative correlation between skin conductance responses (SCR) and empathy has been found in some studies with adults showing that an autonomic arousal seems to reduce empathy (Mathersul et al, 2013; Deuter et al., 2018). Of course, SCR is not influenced from PNS activity and therefore the best and most stable marker for arousal, but since HR is also used in stress research as a marker of autonomic arousal I assume, that it might be a question of computing the right HR index to find a possible correlation.

Until today, the role of the parasympathetic activity during an empathy-inducing situation has been investigated frequently and comprehensive and HRV pattern correlate with empathy by itself. The reverse is true for HR. On the one hand, there is no expected, stable correlation between HR pattern and empathy. This is not surprising, since HR does reflect PNS or ANS activity and is influenced by multiple factors like movement, breathing or excitement. But even HR might not correlate with empathy by itself, there could be based on the previous discussed models and theories specific HR patterns in an empathic-inducing situation, but little research has been done with children today.

Research Question and Hypothesis

Hastings et al. (2014) noted, that "most of what is known about emotions and the integration of CNS, HPA, hypothalamic-pituitary-gonadal axis, ANS and skeletomotor activity is based on research with adults" (p. 19). Since emotion is a very important component in empathy, I aim to overcome this shortage in research and address my first two hypotheses to the research question of what this connection between emotion and activation of the ANS looks like in children. From a theoretical perspective, it should be noted, that children in this study reported their experienced emotion following a situation designed to elicit empathy. Therefore, I expect that children, who experienced empathy, will report vicarious emotions. Children, who did not experience empathy will report their first-hand emotions. As discussed by Singer & Lamm (2009) and theorized in the Perception-Action-Model, vicarious emotions tend to elicit similar physiological reactions as first-hand emotions and therefore I will not distinguish between them.

Hypothesis 1: Response coherence

Several famous emotion theorists proposed a response coherence, regardless the type of the experienced emotion (e.g. Ekman 1972, 1992; Lazarus, 1991; Levenson, 1994). Mauss et al. (2005) defined this phenomenon as "the coordination, or association, of a person's experiential, behavioral, and physiological responses as the emotion unfolds over time" (p. 175). Empirical evidence regarding response coherence in emotion psychology is rare and mixed (Reisenzein, 2000; Mauss et al., 2005; Evers et al., 2014).

Based on the proposed theory of response coherence, there should be a positive correlation between two systems, and I aim to test this assumption for the responses of the psychological system in terms of reported intensity of experienced emotion and physiological response in terms of Peak HR. Subsequently, I will conduct an explorative analysis. Children are expected to report different types of emotions, and I will investigate whether response coherence in terms of the correlation between the two mentioned systems differs between these emotions.

H1: There is a positive correlation between reported emotional intensity (psychological arousal) and Peak HR (physiological arousal).

Hypothesis 2: Differences in change of HR between emotions

Kreibig (2010) showed based on a review of 134 studies, that the experience of emotions is accompanied by specific HR changes. For instance, HR increases as emotions like anger, anxiety, happiness or joy unfolds but decreasing when human experience sadness without crying. Empirical evidence regarding pride is mixed. Since children in this study are expected to report the experience of different emotions, I hypothesize, that change of HR will vary depending on emotions.

H2: There is a difference in change of HR between emotional categories.

However, the main research question of my master thesis regards the role of HR in children's empathic experience, which is still unclear with conflicting evidence. Thereby I also aim to overcome some limitations from earlier studies.

Anastassiou-Hadjicharalambous & Warden (2007) stressed the fact, that stimuli must be intense and realistic to elicit an empathic experience. In previous studies, graphics, stories, pictures and videos had been mostly used to induce empathy and these stimuli were quite sufficient. In this study an empathy-inducing situation was created using virtual reality (VR). Not only that VR studies are still rare in scientific research, but it also enables researchers to create an environment as realistic as possible. Further on, in previous studies, written materials like questionnaires and scales had been used to assess children's current emotion. This approach suffers from several biases but also involves the danger of lack of understanding due to language competence or misinterpretation. In this study, a symbolic scale designed with smileys was used to assess the current emotion of the children to avoid mistakes in their assessment. Another limitation of previous studies was the way to assess empathy. In some studies questionnaires like IRI were used to assess trait empathy but empathy tends to be highly modulated by intrapersonal factors like prior experiences, coping abilities, or current mood (Decety & Lamm, 2006). In this study, children's situational empathy was basically assessed as the convergence between the own valence of emotion and the attributed valence of emotion to the other. Thereby the limitation of a sharp distinction between EC and PD, which has been done in previous studies despite the mentioned critic, has been overcome. This leads me to two further hypotheses.

Hypothesis 3: Differences in HR dynamics

Bradley & Lang (2000) and Bradley et al. (2012) showed a typical HR response pattern following an emotion-inducing stimulus, starting with HRD (in this case not a measurement of HRV but simply the slowing of HR) as a sign of an orienting reaction for about two seconds, followed by HRA and HRD subsequently. Decades before, Eisenberg et al. (1989) proposed a comparable HR response pattern for empathy research, arguing, that HRA and HRD (again only the differences in averaged BPM) are associated with different types of information processing. While HRD in general is associated with an other-oriented focus, HRA is related to a focus on the own state. Since the previous discussed models assume the recognition and the processing of others states as a starting point to activate shared representations, an other-oriented focus with the corresponding HRD could be associated with the experience of empathy.

H3: HR dynamics differ between children, wo experienced empathy and children who did not.

Hypothesis 4: Differences in mean HR

The last hypothesis relates to the differences in mean HR when experiencing empathy. Recent research has often focused on resting HR and evidence regarding mean HR during an empathic experience is not only rare but also mixed (Decety & Meyer, 2008). Therefore, I aim to investigate this difference to find out, whether empathy is associated with higher or lower HR.

H4: Children, who experienced empathy differ in mean HR to children, wo did not.

Method

Design

I will do a quantitative, non-experimental secondary data analysis without any blinding from the pre-test data collected in the study "COMET4Kids". This study was an intervention study, designed as a quasi-experimental pre-post control-group design. The sample consisted of 12 fourth-grade classes of four different schools with necessarily two in Vienna and two in Lower Austria. In Lower Austria, the schools were recruited with the support of the Education Authority in terms of recommendations regarding both participation and allocation to experimental or control group from school quality managers. Since principals in Vienna have more authority and self-determination, the schools were contacted directly and the principals decided whether to participate or not. Therefore, a convenience sample was drawn. The classes had no exclusion criteria and only had to be fourth-grade classes. The 12 classes were not randomly allocated to a treatment or a non-treatment group, because the teachers had to know whether they had to deliver trainings for the children throughout the school year or not. To avoid biases, a matching of the schools regarding school type, location and demographic and social aspects was conducted. At the beginning of the school year 2024/2025, a pre-test measurement took place in every class. Subsequently, the classes in the treatment group received a mental health literacy training once a week for one hour throughout the school year. The training was delivered by the teachers who received a special training in advance. At the end of the school year, there was a post-test measurement to investigate the effects of the training. with a follow-up session three months afterwards.

Since the post-test was identically equal to the pre-test, I will use data from the pre-test only to avoid influence of learning or motivational effects. For my analyses, I will conduct correlational and group comparison analysis. Due to the small number of schools and classes I won't be able to use a multilevel model because of the insufficient computing of slop parameters (Maas & Hox, 2005). Because of this reason I will have to consider the clustered, nested, hierarchical data structure in the interpretation of the results and in the limitations.

Sample

According to the 2023/2024 report "Bildung in Zahlen", published by Statistik Austria, there are 19 primary school children per class on average in Lower Austria and 21,8 on average in Vienna (Statistik Austria, 2024). Since five classes from Lower Austria and seven classes from Vienna participated, a total number of about 248 children is expectable. Blom-Hoffman et al. (2009) reported an average participation rate of 65.5% based on 93 studies in school-based prevention and intervention literature, where active consent was necessary. Based on these theoretical assumptions, a total sample size of 162 participating children is theoretically expected.

Basic descriptive analysis of the data provided a comprehensive overview of the sample characteristics. In total, 194 children took part in the pre-test. I excluded data of six children because their HR were not recorded correctly or were even not recorded at all. For ten additional children, the VR program malfunctioned and froze during a phase. One child was excluded due to problems of understanding, and one child was excluded because of reported pain during the VR measurement. Final sample size (N = 176) consisted of 85 girls and 91 boys, ranged from 8 to 11 years (M = 9,28, SD = 0,54), who attended schools in Lower Austria (N = 90) and Vienna (N = 86).

Principals had to agree to the participation of the school. Subsequently, class teachers of the fourth-grade classes were asked for their consent. In the classes of teachers willing to participate, consent of the parents was obtained (Opt-in) and finally the children were asked for their consent too. Schools received money for participation and training for the teachers.

Instruments

VR Recording

VR data were recorded using the “Meta Quest 3” VR headset. After the measurement, a log-file for each participating child was created and could be downloaded at the end. This log file contained exact timestamps to identify the various phases of the measurement. I will go into detail later, but for now it is important to know that there were seven phases in total, whereby the first three phases were conceptualized as a mild stress test with a break phase as a fourth phase subsequently and three following phases, an anticipation phase, a empathy phase and a recovery phase, conceptualized as an empathy measurement. During the empathy measurement, the children had to rate the category and intensity of the own experienced emotion after the empathy phase and the recovery phase. The type of experienced emotion was measured by means of a symbolic scale consisting of six different smileys which represented the following emotions: happy, proud, sad, angry, anxious, neutral (Figure 1). Subsequently a four-point Likert-Scale was used to assess the scaling of the intensity of the experienced emotion (Figure 2). Additionally, only after the empathy phase the child had to rate the type and intensity of the attributed emotion to the non-playing character (NPC) called Charlie using the same type of scales.

Figure 1

Symbolic Scale for the Measurement of the Emotional Category

Figure 2

Four-Point Likert Scale for the Measurement of the Emotional Intensity

HR Recording

HR data were recorded during the whole experiment using a POLAR Verity Sense device. This device is an optical photoplethysmography sensor which measures the pulse oximetry signal to estimate HR. Although it stores pulse-to-pulse intervals internally, it only exports timestamps and BPM by default. Since only default information was extracted, I could only use HR data in terms of BPM and was not able to compute HRV data.

Interviews

After VR recording, children were asked three open questions, and the answers were recorded on a check list. The first question relates to the mild stress test, and the last two questions relate to the empathy measurement.

1) How did you feel in VR? How did you feel during your own test?
2) How did you feel when watching Charlie doing his/her test? Why did you feel in this way?
3) What do you think Charlie felt during the test? Follow up question: Why do you think Charlie felt that way?

Procedure

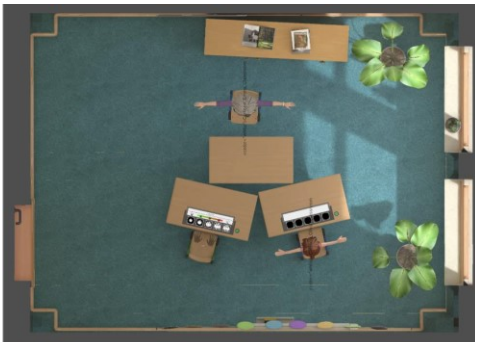
Pre-Test measures were collected at the start of the school year 2024/2025, in September and October precisely. The fourth graders were picked up in their classroom by two student experimenters and were taken to a separate room in pairs. The student experimenters explained the experiment, introduced the POLAR device and the VR headset and assured that nothing will hurt, and that every child could stop the experiment at any time if they want to. They asked for the consent and placed the POLAR device on the upper arm to record the HR and put on the VR headset. The experiment consisted of seven phases.

1) **Habituation phase (45 seconds)**

The child found themselves alone in a virtual classroom, sitting at a school desk (Figure 3). The HR was measured and was used as a baseline measure for the mild stress test. After the habituation phase, a teacher entered the classroom and a non-playing character (NPC) in form of another child of the same gender named Charlie appeared at the desk next to child. The teacher explained a task that the child had to perform first, followed by the NPC. The task was to quickly press the buttons that appeared on the table in front of the child in the correct order from one to five, even though the position of the buttons kept changing after a button was pressed. The child did a trial run subsequently. After the trial run, the child had to rate emotional category and intensity.

Figure 3

VR Classroom



2) **Anticipation Phase (45 seconds)**

The child could prepare themselves for the task. After the anticipation phase, emotional category and intensity were assessed a second time.

3) **Stress Phase (60 seconds)**

The child conducted the test and tried to do the task as quick and accurate as possible. The teacher encouraged the child two times to be quicker. After the test, emotional category and intensity were assessed a third time.

4) **Break Phase (60 seconds)**

This phase was used as a recovery phase of the stress test. The teacher told the child to calm down and to rest. A fourth assessment of emotional category and intensity was conducted at the end of the phase.

5) **Anticipation Phase (60 seconds)**

In this phase, the NPC was allowed to prepare for the same test. The child had only to wait until the start of the NPC's test.

6) **Empathy Phase (120 seconds)**

The NPC conduced the test but unfortunately struggled frequently. After the phase, the child had to evaluate both the own emotional category and intensity and the emotional category and intensity attributed to the NPC.

7) **Recovery Phase (45 seconds)**

There was no activity required from the child during this phase and the NPC was instructed to calm down and rest after the task. At the end a last assessment of the own emotional category and intensity during this phase was conducted.

During the measurement, the student experimenter observed the child and noted problems with the headset, movements or verbal comments during each phase. After the measurement, a short interview as explained above took place, and the student experimenters recorded the answers on a protocol in form of a checklist.

Variables

To test my hypotheses and to answer my research question, I needed to define six variables, which I describe in this section. I explain the underlying constructs, how they were conceptualized and operationalized and how they were measured.

Emotional intensity is conceptualised as the subjective psychological arousal evoked during the empathic phase. It was measured using the four-point Likert scale following the empathy phase. The variable is on an ordinal scale, with higher values indicating a greater psychological arousal.

Emotional category is defined as the type of emotion the children experienced during the empathy phase. This variable was recorded in two ways, using the symbolic scale following the empathy phase what resulted in quantitative data and asking a question regarding the experienced emotion in the interview, what resulted in qualitative data. For this variable the quantitative data was used making it a nominal-scale variable.

Empathy is defined based on the neuroscientific conceptualisation as affective sharing between two people. Affective sharing is understood as a match between the reported valence of the experienced and attributed emotion. This was measured by integrating multiple data through the following process.

1. **Interview data regarding the source of the experienced emotion was coded**

As proposed by De Vignemont & Singer (2006), the isomorphic state must be elicited by the observation of the other's state. Therefore, the source of an experienced emotion is an important requirement for empathy. While VR data did not reveal the source of an experienced emotion, the children were asked in the interview not only for the experienced emotion during the empathy phase but also for the reason. This information is very important since the children could have felt an emotion for different reasons. For instance, one child might have felt sad, because it had viewed the situation as competitive and was sad because the NPC showed a better performance in the test. Another child may have also felt sad but because it felt bad for the NPC to make so many mistakes. In both cases, an isomorphic state occurred, but only the second child is thought to experience empathy. Therefore, two raters coded the answers of the children in the interview regarding their experienced emotions with "allocentric", "egocentric" and "unclear". Inter-rater reliability was assessed on a random subset of responses (N = 34) and was found to be excellent (κ = .86, 95% *CI* = [.71, 1.00]. Only cases, in which a reported emotion was at least partly allocentric, could subsequently be assessed as empathic.

2. **VR and Interview data were coded regarding the valence of the emotion**

Both experienced and attributed emotion in the VR following the empathy phase and in the subsequent interview were coded regarding the valence. Quantitative VR data were coded in the following way. Happy and proud were treated as positive emotions, sad, angry and anxious as negative emotions and neutral as a third category. Qualitative data were coded from the same, independent raters regarding the apparent valence. If the valence was not clear, it was coded as unclear.

3. **Matching the valence of emotions**

The valence of the emotions derived from the VR data were compared and a match was coded as 1 (e.g. the child experienced a negative emotion, and a negative emotion was also attributed to the NPC), while a mismatch was coded as 0. The same procedure was applied to the interview data. If the emotion of the child or the attributed emotion to the NPC was unclear, a mismatch was automatically assumed. The quantitative and qualitative data were not mixed, since the rating in the VR was a standardized measurement and reflected a direct, situational, non-reflective spontaneous assessment, whereby the qualitative data were more a more reflective, complex and differentiated.

4. **Definition of empathy**

Empathy is a dichotomous variable and is assumed when a child meets the following three criteria.

- The child reported a specific emotion in the interview (positive or negative).
- This reported emotion was at least party allocentric.
- There was a match between the experienced and the attributed emotion, regardless of whether this match was in VR or based on the answers in the interview.

Peak HR was considered as a sign of physiological arousal. To avoid distortion caused by measurement artifacts, I did not simply use the highest value during a certain phase, but rather determined the five-second interval with the highest mean heart rate and treated this value as Peak HR. This makes Peak HR a metric-scaled variable, with higher values indicating a higher arousal.

HR Dynamics was conceptualised as the increase or decrease of HR. It was measured as a difference score between the average HR during the anticipation phase, which was treated as a baseline, and the average HR during 12 consecutive time intervals during the empathy phase. This makes HR Dynamics a metric-scaled variable reflecting HRA with values above zero and HRD with values below zero.

Statistical Analysis

I used Python (Version 3.13) to extract the data from the log files (VR data) and text files (HR data) and to merge them. Afterwards I used Microsoft Excel (Version 6.107.2) to process the data and to prepare it for statistical analysis. This analysis was conducted in JASP (Version 0.19.1).

Results

Hypothesis 1: Response coherence

To investigate the positive relationship between the emotional intensity, which was understood as a marker for psychological response and Peak HR, which is a sign for physiological response a correlation analysis was conducted. For a better comparison and to account for induvial differences in HR, a difference score between average HR during empathy phase and Peak HR was computed. Since the Shapiro-Wilk-Test used for testing multivariate normality was significant ($p < .001$) and the scaling of the own emotion was on a four-point Likert scale and therefore, strictly speaking, not interval-scaled but ordinal-scaled, two main assumptions of computing Pearsons's r were violated (Chen & Popovich, 2002). Hence, I computed Sperman's rho (r_s), a non-parametric test statistic as an alternative to Person's r in case of violation of assumptions (Rovetta, 2020).

Data from one child were excluded from the analysis because the z-scores of the Peak HR exceeded three and were therefore classified as outlier. Data from 31 additional children were excluded because they did not experience an emotion but reported a neutral state. Due to the small group size for the main analysis and the unequal group sizes for the subsequent explorative analysis, bootstrapping with 5.000 replicates was used to calculate 95% confidence intervals (CI) for the correlation coefficients. As illustrated in Figure 4, a significant, positive correlation between the psychological response and physiological response was observed, $r_s(144) = .21$, $p = .005$, 95% $CI = [.05, .37]$. Descriptive data are found in Table 1.

An explorative analysis revealed variability in response coherence among different types of emotions. Significant, positive correlations between psychological arousal and physiological arousal were found when children reported the experience of happiness ($r_s(73) = .256$, $p = .015$, 95% $CI = [.036, .460]$) or anxiety ($r_s(13) = .781$, $p < .001$, 95% $CI = [.329, .959]$. Correlations coefficients in the other types of emotions cannot be interpreted with certainty as the confidence interval included zero (see Table 2).

Figure 4

Correlation between Psychological and Physiological Response

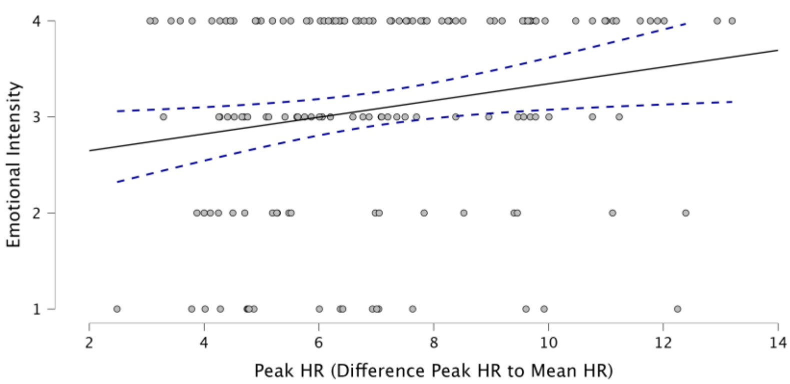


Table 1

Spearman Rank Correlation for Response Coherence

Variable	**1**	**2**	***M***	***SD***
1. Peak HR (Physiological Arousal)	-		7.07	2.45
2. Psychological Arousal (Emotional Intensity)	.214**	-	3.09	1.07

*Note: * p < .05, ** p < .01, *** p <.001*

Table 2

Variability of Coherence Among Emotional Categories

Type of Emotion	*N*	r_s	95% *CI*	*p*
Happy	73	.256	[.036, .460]	.015*
Proud	40	.119	[-.230, .454]	.232
Sad	12	-.289	[-.803, .382]	.819
Angry	6	-.247	[-1.000, .826]	.681
Anxiety	13	.781	[.329, .959]	< .001***

Note: r_s *= Spearman's rank correlation.* ***CI*** *= Confidence interval. 95% Confidence intervals based on 5.000 bootstrap samples. * p < .05, ** p < .01, *** p <.001*

Hypothesis 2: Differences in change of HR between emotions

To test the second hypothesis, that a change of HR, which was computed as a difference score between mean HR during anticipation phase and mean HR during empathy phase, is different between experienced emotions, a one-way ANOVA was conducted. Data of three children were excluded because the z-scores exceeded three and were therefore treated as outliers. In addition, data from 29 children were excluded because they did not report a specific emotion but rated their experiencing as neutral. Prior to the analysis, the assumptions of ANOVA were tested. Normal distribution was assessed via visual inspection of Q-Q plots and no substantial deviations from normality were apparent. Levene's test for equality of variances was not significant (p = .514) confirming the homogeneity of variances. Due to the unequal group sizes, bootstrapping with 5.000 replicates was used to calculate robust standard errors and 95% CI for the estimated marginal means.

A one-way ANOVA revealed no significant effect of emotion type on HR change, $F(4, 138) = 1.22$, $p = .305$, $\eta^2_p = .034$ (see Figure 5). Descriptively, the average HR during the empathy phase decreased compared to the anticipation phase when children experienced happiness, anger and anxiety, whereas increased when they felt proud or sad (see Table 3).

Figure 5

Sample Means of Changes of HR between Different Emotions

Note: Sample means of HR are reported. Error bars represent standard errors of the sample.

Table 3

Descriptive Statistics for HR Changes by Emotional Category

Type of Emotion	*N*	*M*	95% *CI*	*SE*
Happy	71	-0.190	[-0.931, 0.597]	0.385
Proud	40	0.183	[-0.713, 1.164]	0.475
Sad	12	0.116	[-2.604, 2.411]	1.256
Angry	7	-2.738	[-5.970, -0.295]	-0.295
Anxiety	13	-0.171	[-2.208, 1.332]	0.897

Note: Estimated marginal means and 95% CI based on 5.000 bootstrap samples.

Hypothesis 3: Empathy-related differences in HR dynamics

A 2x12 mixed ANOVA was conducted to test the effect of group (empathy) and time (12 consecutive time windows) on HR dynamics. Group was treated as a between-subjects factor and time as a repeated measures (within-subjects) factor. The assumptions were evaluated. Normal distribution was assessed via visual inspection of Q-Q plots and no substantial deviations from normality were apparent. Levene's test for equality of variances confirmed the homogeneity of variances across groups ($p > .05$). Mauchly's test indicated a violation of the assumption of sphericity, $\chi^2(65) = 909.41$, $p < .001$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates ($\varepsilon = 0.40$).

Data from 57 children were excluded because based on their answers in the interview regarding the experienced own emotions, the source of the emotion could not be determined with certainty, and it remained unclear whether the experienced emotion was egocentric or allocentric.

The results of the mixed ANOVA are summarized in Table 4. The analysis of between-subject effects showed that there was no significant main effect of Empathy on HR dynamics, $F(1,117) = 0.180$, p = .672, $\eta^2_p = .002$. Regarding the within-subject-effects, there was a significant main effect of Time, $F(4.37, 510.67) = 5.21$, $p < .001$, $\eta^2_p = .043$. The interaction between Time and Empathy was not significant, $F(4.37, 510.67) = 1.10$, $p = .357$, $\eta^2_p = .009$, showing that the physiological response patterns across the 12 intervals did not differ between children, who experienced empathy and children who did not (Figure 6). Decreased HR was found in children, who experienced empathy in more time intervals and the decrease by itself was stronger.

Table 4

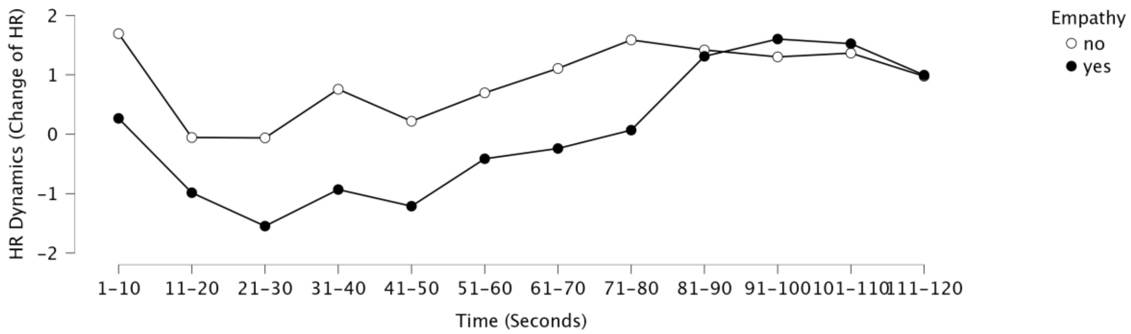
Summary of Repeated Measures ANOVA for HR Dynamics

	df	*F*	*p*	η^2_p
Within-Subjects				
Time	4.37	5.21	< .001***	.043
Time x Empathy	4.37	1.10	.357	.009
Residuals	510.67			
Between-Subjects				
Empathy	1	0.18	.672	.002
Residuals	117			

Note: η^2_p *= partial eta squared. * p < .05 ** p < .01 *** p <.001*

Figure 6

HR Dynamics Compared Between Groups



Note: Groups are defined for children, who experienced empathy and children who did not

Hypothesis 4: Differences in mean HR

An ANCOVA was used to test the last hypothesis, whether the two groups (empathy) differ in their mean HR during the empathy task. The mean HR during the anticipation phase was treated as a baseline measurement and as a covariate in the model.

Similar to the testing of the third hypothesis, data from 57 children were excluded, since it was not possible to determine with certainty the valence or the source of the emotion that unfolded. Z-scores of difference scores were computed to identify possible outliers, but all values ranged within three standard deviations above or below the mean. Normal distribution was assessed via visual inspection of Q-Q plots and no substantial deviations from normality were apparent. Levene's test for equality of variances confirmed the homogeneity of variances across the two groups (p = .733). Due to the unequal group sizes, bootstrapping with 5.000 replicates was used to calculate robust marginal means, standard errors and 95% confidence intervals.

Descriptive statistics for the difference in mean HR between the groups are presented in Table 5. A one-way ANCOCA revealed a significant effect of the baseline heart rate on the mean HR during the task, $F(1, 116) = 1037.25$, $p < .001$, $\eta^2_p = .899$. After controlling for these baseline differences, the effect of Empathy was not significant but showed a small effect size, $F(1,116) = 1.568$, $p = .213$, $\eta^2_p = .013$. As shown in Table 6, a bootstrapped post hoc comparison showed a negative, but not significant difference in mean HR (*M* = -0.790, 95% *CI* [-2.156, 0.368]).

Table 5

ANCOVA Results for Overall Mean HR with Baseline HR as Covariate

	df	*F*	*p*	η^2_p
Baseline HR	1	11790.80	< .001	.899
Empathy	1	1.568	.213	.013
Residuals	116			

Table 6

Comparison of Overall Mean HR Adjusted for Baseline

Empathy group	**N**	***M***	***SD***
yes	45	90.26	11.07
No	74	89.20	10.28

Note: (a) Estimated marginal means and standard errors adjusted for baseline HR (b) Figure of the adjusted group means. Error bars represent the 95% CI.

Discussion

General Discussion

In my master thesis I investigated the role of HR during in the experience of empathy in children. Thereby I drew on the definition and conceptualisation of empathy in neuroscience, where empathy is essentially defined as shared affect, with vicarious emotions playing a major role. The emotional aspect of empathy led me to my first two hypotheses.

First, I applied the theory of response coherence to the experience of empathy. Response coherence, as initially thought, suggests a coordinated and synchronous reactivity among different systems like the psychological or physiological system as an emotion unfolds. Therefore, I correlated the psychological response – specifically the subjective assessment of emotional intensity evolved from an empathic inducing situation, with the psychological response, measured as a peak in HR. The correlation was significant, p = .005), with an effect size (r_s = .21) being classified as medium according to the recommendation by Gignac & Szodorai (2016). On closer examination of the data a more nuanced picture becomes apparent. A significant, positive correlation was found only in two of the five reported emotions, specifically happiness ($r_s(73)$ = .256, p = 0.015, 95% CI = [.036, .460]) and anxiety ($r_s(13)$ = .781, p < .001, 95% CI = [.329, .959]. This finding does not support the assumptions of earlier emotion psychologists, who had an evolutionary view of the role of emotions and proposed response coherence for every kind of emotion (Ekman, 1992, Levenson, 1994). On the other hand, they also seem to be in contradiction to modern theories like the dual-process perspective, suggesting response coherence only within a system (automatic or reflective) but not across them (Evers et al., 2014). In this model, the physiological response is understood as part of the automatic system and the psychological response in terms of self-reported experience is part of the reflective system and coherence should not be found at all, no matter which emotion is experienced. Yet a significant, positive correlation was found when happiness and anxiety unfolded. It is possible, that the type of emotion determines the degree of coherence. This would be in line with other studies, where response coherence had been found in certain emotions. However, the results here are also mixed. For instance, Mauss et al. (2005) found response coherence in sadness, what is not supported with the results from this study. Then again, Mauss et al. (2004) found that physiological activation and subjective experience of anxiety might be less coupled, what showed the strongest correlation in this study. It is more likely that response coherence it not a question of the type of emotion that unfolds but that the experience of an emotion is much more dynamic and individual. This is in line with the Component Process Model proposed by Klaus Scherer (2009), which provides a good framework to explain the results. According to the model, several appraisals of an emotional stimuli are the starting point for the unfolding of am emotion. The appraisal of a stimuli as important and relevant leads to the activation of several subcomponents, which tend to synchronize. But this synchronization is the result of a dynamic, individual process and depends on several important factors like result of personal, cognitive appraisals, situation or context. It is theorized that even when the subcomponents synchronize, they mostly do it only to some extent. This leads to the assumption that response coherence is probabilistic, not deterministic, a conclusion which explains the ambiguity of recent empirical evidence and to some degree the variability in the data of this study.

Second, I investigated the differences in HR change between different types of emotions. Based on evidence from meta-analysis, a clear pattern of HR changes was expected with happiness, anger and anxiety causing an increase in HR compared to a baseline and sadness without crying a decrease. Results from this study show no significant difference in change of HR among the different types of emotions, $F(4, 138) = 1.22$, $p = .305$, $\eta^2_p = .034$. The bootstrapped 95% CI showed a significant change of HR only for the experience of anger, but unlike what previous studies have found, the change was in a negative direction in the sense of a decrease of HR. Due to the wide CI, no trend can be found for the remaining emotions and thus no definitive conclusion can be drawn regarding the change of HR. This in line with a finding from Anastassiou-Hadjicharalambous & Warden (2007), that convergence between physiological and verbal measures regarding emotions in typically developing children between eight and ten years was only on chance level, because "there may be dissimilarity between what children at this age experience affectively and how they interpret and report such experiences" (p. 247). It should also be noted that the anticipation phase, which served as a baseline measure, might not reflect a real baseline which would have a crucial influence on the results. I will go into further details when I get to the limitations. Besides, some children had viewed the situation designed to elicit empathy as competitive which would also have an impact on the HR during the anticipation phase. In addition, interview data showed that children experienced multiple emotions at the same time, but children were forced to select only one. This co-occurrence of emotion has been studied intensively during the last years and could be also a reason why it is difficult to find specific patterns of HR changes (Larsen & McGraw, 2011; Watson & Stanton, 2017).

My third hypothesis highlighted HR dynamics during the empathic experience. Whether or not children experienced empathy, the first 10 seconds were expected to follow the HR response pattern for processing of emotional stimuli reflected in an initial HRD and a subsequent HRA (Bradley & Lang, 2000; Bradley et al., 2012). Hence, the first time interval was not expected to be useful to distinguish HR dynamics between these two groups of children. For my analysis, the time intervals after this initial interval were particularly interesting, since children, who experienced empathy were thought to have a longer and more intensive HRD due to the other-oriented focus (Eisenberg et al., 1994). Although mixed ANOVA did not reveal a significant effect of the experience of empathy on HR dynamics, $F(4.37, 510.67) = 1.10$, $p = .357$, $\eta^2_p = .009$, descriptive statistics showed, that children, who experienced empathy, tended to have an HRD during six consecutive time intervals starting with the second time window right after the proposed orienting response. In contrast, children, who did not experience empathy tended to have a slight decrease of HR only during the second and third time interval. In addition, a comparison of mean values of HR change has shown that children, who experienced empathy might not only had a longer, but also a more intense decrease of HR, which would be in line with previous research (Eisenberg & Fabes, 1990; Zahn-Waxler et al., 1995). Interestingly, HR seemed to accelerate in the children, who did not experience empathy, during the fourth time interval. This might be a sign of an internal shift of attention away from the NPC to the self, which is reflected in HRA (Eisenberg et al., 1994). HR of children, who experienced empathy, seemed to slightly accelerate in the eighth time interval and to enhanced acceleration especially during the ninth time interval. Since the empathy phase had a duration of 120 seconds, this tendentious HRA could also be a sign of habituation or maybe empathic over-arousal. It must also be considered that the children did the test on their own before and they might experience excitement, whether the NPC will have a better result which would lead to HRA. Despite all assumptions, it must be said, that the two groups did not significantly differ during a single time interval. A reason for this might be the unequal group sizes with 45 children, who experienced empathy and 74 children, who did not respectively. Another reason might be the operationalisation of empathy, which, despite all efforts, was only an estimation, since empathy was not directly measured and as will be shown later in the limitations the data quality was not ideal.

The last hypothesis focused on the average HR during an empathic experience. As mentioned before, empirical evidence is mixed (Decety & Meyer, 2008). An ANCOVA showed no significant difference in mean HR between children, who experienced empathy and children, who did not, $F(1,116) = 1.568$, $p = .213$, $\eta^2_p = .013$. Essentially, most of the variance was explained with baseline HR ($\eta^2_p = .899$). Although descriptive findings showed a tendinous higher heart rate for children, who experienced empathy, the bootstrapped CI included zero, which makes a statistically robust statement about the difference impossible. The trend, that empathic children have a higher HR during empathic situations is in line with a few studies (e.g. Zahn-Waxler et al., 1995), but as mentioned earlier, most studies focused on the correlation between resting HR and conduct disorder.

Limitation

Data collection led to clustered, nested and hierarchical data which would have made a multilevel modelling necessary. As mentioned earlier, statistical power would have been too low because of the sample size. Besides, the study took place in provided, separate rooms in the school and was conducted from different student experimenters. Although the study followed a protocol, the objectivity of the data is limited since around a dozen of student experimenters were involved in data collection and it is not possible that all of them provide exact the same instructions to the children, they recorded events and the behaviour of the children differently and conducted the interview in a varying quality.

Regarding HR recording, it must be said, that the children were very excited from the very beginning. First, most of them had never participated in a scientific study before and they were curious about what was ahead. Second, they were picked up by student experimenters they had never met before and taken to a separate room. Third, most of them had no experience with VR. Recognizing these situational aspects as a starting point, HR values must be interpreted with caution in general. Another point is that, as shown in the procedure, the participating children had to do the same test as the NPC in advance during the mild stress test. Although there was a recovery phase of 45 seconds after the test, it cannot be ruled out that the performance during the own test and the consequent arousal influenced the HR during the anticipation phase, which served as a baseline measurement in this study. Besides, according to the interview data, a lot of children viewed the situation, in which the NPC did the test as competitive, which is also thought to influence the HR. At the end is must be recognized that most of children moved during the measurement which had also an impact on the HR.

The usage of a symbolic scale with smileys to assess the experienced emotion overcomes a lot of limitations like differences in verbal competences. Nevertheless, some characteristics of scales have an influence on children's rating of own and attributed emotions and therefore on the validity of the measurement. First, although the children were introduced to the scale prior to the measurement and were asked whether they understand the meaning of the emoticons, it cannot be ruled out that the children interpreted the emotions differently. Second, the scale was limited to five different emotions and a sixth, neutral state. This might led children to select an emotion which did not really represent the experienced state. For example, interview data from one child showed, that the child felt an emotion that they could not select on the scale, so the child selected "neutral". Third, the empathy phase had a duration of 120 seconds and was constituted of periods, where the NPC failed or succeeded respectively. These periods might evoke different emotions and as mentioned above it is likely, that children experienced multiple or mixed emotions. Since the children were forced to select only one emotion, it is possible, that they used the Peak-End-Rule, what is a heuristic, that the most intense or the last period of a recent experience have an influence on the rating of the previous experience (Alaybek et al., 2022). Based on this heuristic, the selected emotion tends to reflect the unfolded emotion during an intense but maybe very short time or the emotion during the end of the phase, but it does not reflect the complex experience during the phase.

The valence of emotion was also assessed during the interview after the measurement. Interview data confirmed some of the mentioned limitations, like the experience of multiple emotions. Hence interview data would have provided an excellent way to overcome these limitations but unfortunately the quality of the interview data varied, and some protocols were not useless. Besides, Strayer & Robert (1997) argued, that still-developing language skills and ability for introspection might be a limitation for verbal measurements of emotion.

The intensity of emotion was measured using a four-point Likert-Scale. The main limitation of this type of scale is the limited gradation, which would be necessary for such a dynamic, complex phenomenon like emotions.

The main limitation of this study was the conceptualisation of empathy. Although it was based on the neuroscientific understanding of empathy, there was no concrete measurement of empathy but only an assumption based on quantitative and qualitative data. Therefore, a valid measurement of the true source of an emotion (only accessible through interview data) and the valence of the emotion (accessible through qualitative and quantitative data) was a prerequisite. Unfortunately, data from 57 children had to be excluded because of missing, invalid or incomplete data. This led to a reduced sample size and therefore to a reduced power of the study.

Implications for further research

Empathy research has a colourful past and during the last years stimuli like photos, graphics or videos have been used to induce empathy. Further research should investigate empathy in more realistic environments and VR is a particularly noteworthy option. Despite this fact, empathy should not only be investigated in terms of trait empathy but also during specific situations. HR was viewed as an important marker of vicarious affective arousal (Anastassiou-Hadjicharalambous & Warden, 2007). Further research should not only focus on resting HR or HRV but also on the HR dynamics during an empathic experience. Results from this study were mostly not significant, but HR tendentious seemed to decrease during the experience of empathy and main HR seemed to be higher in empathic children. Further research might bring more light into the darkness.

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List of Abbreviations

AI	Anterior insula
ANS	Autonomic nervous system
BPM	Beats per minute
CNS	Central nervous system
EC	Empathic Concern
FA	Fantasy
HR	Heart rate
HRA	Heart rate acceleration
HRD	Heart rate deceleration
HRV	Heart rate variability
IRI	Interpersonal reactivity index
NPC	Non-playing character
PD	Personal distress
PNS	Parasympathetic nervous system

PT	Perspective taking
RSA	Respiratory sinus arrhythmia
rTPJ	Right temporoparietal junction
SCR	Skin conductance responses
SNS	Sympathetic nervous system
VR	Virtual Reality

Appendix

English Abstract

Among all the competing definitions of empathy, there is an integrative conceptualisation in neuroscience, understanding empathy as affective sharing, which involves self-other distinction. Whereby HRV reflects PNS activity and has been shown as a valid physiological marker of empathy, empirical findings regarding the role of HR are rare and mixed. In this study, I conducted a quantitative, non-experimental secondary data analysis without any blinding from the pre-test data collected in the study "COMET4Kids" to investigate first the correlation between emotional experiencing and HR and second the role of HR during empathic experience. Data from 176 Austrian fourth graders were included and a significant, positive correlation between HR and the experience of happiness ($r_s(73) = .256$, $p = .015$, 95% $CI = [.036, .460]$) and anxiety ($r_s(13) = .781$, $p < .001$, 95% $CI = [.329, .959]$) has been revealed. Regarding the change of HR, no significant difference between emotions was found, but with a significant decrease of HR when experiencing anger (M = -2.738, SE = -0.295, 95% CI = [-5.970, -0.295]). Regarding the role of HR, children, who experienced empathy had a tendentious longer and more intense HRD and a higher mean HR, but the effects were not significant. Further research should also use VR to explore HR response patterns in realistic scenarios to bring more light into the darkness.

German Abstract

Unter der Vielzahl an konkurrierenden Definitionen von Empathie, hat sich in den Neurowissenschaften eine integrative Konzeptualisierung herauskristallisiert, die Empathie als Teilen eines Affekts versteht, wobei zwischen dem eigenen und dem fremden Zustand unterschieden wird. Da HRV vorrangig durch die Aktivität des PNS beeinflusst wird, hat sich dieser Wert als valider physiologischer Marker für Empathie herausgestellt. Gleichzeitig sind die Erkenntnisse zur Rolle der HR widersprüchlich und vergleichsweise gering. In dieser Studie habe ich eine quantitative, nicht-experimentelle Sekundärdatenanalyse ohne jegliche Verblindung von den Pre-Test-Daten der Studie „COMET4KIDS“ durchgeführt. Dabei habe ich zunächst die Korrelation zwischen emotionalem Erleben und HR untersucht und dann die Rolle der HR im empathischen Erleben. Ich habe dabei Daten von 176 österreichischen Viertklässlern verwendet und dabei eine signifikante, positive Korrelation zwischen der HR und dem Empfinden von Glück ($r_s(73) = .256$, $p = .015$, 95% CI = [.036, .460]) und Angst ($r_s(13) = .781$, $p < .001$, 95% CI = [.329, .959]) gefunden. Hinsichtlich der Veränderung der HR konnte kein signifikanter Unterschied zwischen den Emotionen nachgewiesen werden, jedoch eine signifikante Abnahme der HR beim Empfinden von Wut (M = -2.738, SE = -0.295, 95% CI = [-5.970, -0.295]). Was die Rolle der HR im empathischen Erleben betrifft, haben empathische Kinder deutlich längere und intensivere Phasen von HRD und auch im Mittel eine höhere HR aufgewiesen, jedoch war keiner der Effekte signifikant. Zukünftig könnten Forscher ebenfalls VR nutzen, um in realistischen Szenarien HR Muster zu untersuchen, um somit noch mehr Licht in die Sache zu bringen.