Psychological Mechanisms of Empathy: Methods and Characteristics

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Date: 2019-03-26T00:00:00+00:00

Abstract

Due to the lack of a unified operational definition for "empathy", researchers often adopt inconsistent methodological approaches across different levels of analysis based on their individual interpretations in actual research practice. In recent years, empathy research methods based on multiple levels—including questionnaires, behavioral paradigms, and physiological signals—have made considerable progress, providing multifaceted information for investigating the mechanisms of different dimensions of empathy. However, existing empathy research methods each have their own advantages and disadvantages, and suffer from issues of comparability and ecological validity. Therefore, future empathy research should effectively integrate methods across multiple levels and develop experimental paradigms with greater ecological validity.

Full Text

Research on the Psychological Mechanisms of Empathy: Methods and Characteristics

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Abstract

Due to the lack of a unified definition of "empathy," researchers have adopted inconsistent methodologies across different research levels based on their respective understandings. In recent years, empathy research methods based on questionnaires, behavioral paradigms, and physiological signals have made substantial progress, providing multifaceted information for investigating the mechanisms of different empathy dimensions (e.g., emotional empathy, cognitive empathy). However, existing empathy research methods each have their own strengths and weaknesses, and suffer from issues of comparability and ecological validity. Therefore, future empathy research should effectively integrate multi-level methodologies and develop more ecologically valid experimental paradigms.

Keywords: empathy; emotional empathy; cognitive empathy; questionnaire; experimental paradigm
Classification: B841; B845

1 Introduction

The term "empathy" was first translated from German by German philosopher Edward Bradford Titchener in 1909, meaning "feeling into" (cited in Chen, 2017). To date, empathy research has a history of over a hundred years. Generally speaking, empathy refers to the sensitivity to perceive others' mental states, encompassing a series of psychological processes including being affected by another' s state, sharing in this state, assessing reasons for the state, and adopting the other' s point of view (de Waal & Preston, 2017). Based on the different psychological processes involved, empathy can be broadly divided into emotional empathy and cognitive empathy (Zaki & Ochsner, 2012). Emotional empathy refers to vicariously experiencing others'mental states, representing a more primitive and primary component of empathy that is a stimulus-driven, automatic process. Cognitive empathy refers to the process of explicitly understanding others' mental states and their causes, involving more advanced cognitive activities. Currently, researchers have investigated different dimensions of empathy from multiple levels using methods such as questionnaires, behavioral paradigms, and physiological signal recordings (e.g., electromyography, electroencephalography, magnetoencephalography, functional magnetic resonance imaging) (see Figure 1 [Figure 1: see original paper]).

Figure 1. Commonly used empathy research methods and indicators. To effectively integrate research across different levels and gain a deeper understanding of empathy and its mechanisms, this paper aims to systematically summarize recent empathy research across three levels: questionnaires, behavioral paradigms, and physiological signals. Specifically, this paper first introduces currently widely used and influential empathy scales, which embody different definitions of empathy and measure different dimensions of empathy. Second, it summarizes existing empathy behavioral paradigms and compares the characteristics of commonly used experimental materials and behavioral paradigms across different empathy dimensions. Third, it systematically introduces how to extract and analyze empathy-related physiological signals in empathy research using methods such as facial electromyography (EMG), electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance

imaging (fMRI). Finally, this paper comprehensively compares the advantages and disadvantages of various research methods, identifies current issues of comparability and ecological validity in empathy research, and proposes recommendations for improving empathy research methodologies in the future.

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2 Overview of Commonly Used Empathy Questionnaires

Currently, there is no unified definition of empathy. Different researchers may use the term "empathy" to refer to different dimensions of empathy, or may employ different terminology to describe similar empathy dimensions (Zaki & Ochsner, 2012). Consequently, based on different concepts and dimensions of empathy, dozens of empathy scales have been developed to date (commonly used empathy scales are shown in Table 1). These scales can be broadly categorized into three types: those focusing on measuring emotional empathy, those measuring cognitive empathy, or those measuring both emotional and cognitive empathy simultaneously. Standardized scales facilitate convenient and efficient assessment of individuals' empathy traits.

2.1 Scales for Measuring Emotional Empathy

Mehrabian and Epstein (1972) developed the first and most widely used scale focusing on emotional empathy—the Emotional Empathic Tendency Scale (EETS), also known as the Questionnaire Measure of Emotional Empathy (QMEE). This scale defines emotional empathy as "a reaction to the emotional experiences of others." Specifically, the scale was developed based on the assumption that individuals with higher emotional empathy levels show stronger reactivity to others' emotional feelings; that is, when noticing others' suffering, those with high emotional empathy are less likely to engage in aggressive behavior and more likely to exhibit helpful behavior. The scale' s 33 items cover seven factors: emotional contagion sensitivity, understanding strangers' emotions, extreme emotional reactions, tendency to be moved by positive emotions, tendency to be moved by negative emotions, sympathetic tendencies, and voluntary contact with unfortunate others. For example, "People around me have a great influence on my emotions" is a representative item for emotional contagion sensitivity, while "I would rather be a social worker than work in a vocational training center" represents the tendency for voluntary contact with unfortunate others. However, the scale' s authors later noted that, rather than measuring empathy per se, the scale largely reflects general emotional arousability (Mehrabian, Young, & Sato, 1988). Consequently, the author redefined emotional empathy as "the ability to vicariously feel others' emotions" and developed a new "Balanced Emotional Empathy Scale" (BEES) based on the EETS (Mehrabian, 1996). This scale includes items such as "Unpleasant movie endings still bother me hours later" and "I cannot feel much sadness for people who suffer because of themselves."

Other common emotional empathy scales include the Multidimensional Emotional Empathy Scale (MDEES) (Caruso & Mayer, 1998) and the Emotional Contagion Scale (ECS) (Doherty, 1997). These scales measure emotional empathy with subtle conceptual differences; for instance, the MDEES includes multiple dimensions such as emotional contagion, whereas the ECS focuses solely on the single dimension of emotional contagion.

2.2 Scales for Measuring Cognitive Empathy

The Hogan Empathy Scale (HES) (Hogan, 1969) is one of the most classic scales focusing on cognitive empathy. This scale defines empathy as "the intellectual or imaginative apprehension of another's condition or state of mind without actually experiencing that person's feelings." However, some researchers have pointed out that the scale has low reliability and validity, and recommend discontinuing its use as an empathy measurement tool (Froman & Peloquin, 2001). Other researchers argue that the HES measures social skills rather than cognitive empathy, as it includes items such as "being aware of making a good impression on others" (Baron-Cohen & Wheelwright, 2004).

Additionally, another commonly used cognitive empathy scale is the Jefferson Scale of Empathy (JSE) (Hojat et al., 2001). This scale focuses on the medical care field and has been translated into over 45 languages, being used in more than 70 countries. It defines empathy as "an uncritical understanding of patients' experiences, emotions, and feelings." The JSE has three versions with similar content but slightly different wording, designed for measuring empathy in physicians, medical students, and healthcare students in fields other than medicine (Hojat & Lanoue, 2014). Factor analysis results indicate that the JSE items involve three factors: perspective-taking, compassionate care, and standing in the patients' shoes (Hojat & Lanoue, 2014).

2.3 Scales for Measuring Both Emotional and Cognitive Empathy

Empathy is a multidimensional concept, and only by considering both its emotional and cognitive components can people's empathy abilities be comprehensively assessed (Davis, 1983). Therefore, more empathy scales have been designed to measure both emotional and cognitive empathy simultaneously.

The Interpersonal Reactivity Index (IRI) developed by Davis (1983) is the most frequently cited empathy scale to date. The IRI includes four subscales: Empathic Concern (EC), Personal Distress (PD), Perspective Taking (PT), and Fantasy (FS). Specifically, EC assesses concern for others' emotions, PD assesses negative feelings in response to others' suffering, PT assesses the tendency to spontaneously understand others' thoughts cognitively, and FS assesses emotional identification with characters in books, movies, or plays. Davis (1983) considered EC and PD to focus on the emotional empathy dimension, while PT and FS focus on the cognitive empathy dimension. However, some researchers have questioned whether FS and PD actually measure imagination and emotional self-control abilities, respectively, rather than empathy (Baron-Cohen &

Wheelwright, 2004). The Chinese version of the Interpersonal Reactivity Index (IRI-C) contains 22 items, with an internal consistency coefficient of 0.750, split-half reliability of 0.734, and test-retest reliability of 0.737 (Zhang et al., 2010).

Since then, numerous questionnaires capable of simultaneously measuring emotional and cognitive empathy have emerged, showing a developmental trend toward more precise definitions of empathy and clearer specification of applicable populations. The Empathy Quotient (EQ) developed by Baron-Cohen and Wheelwright (2004) defines empathy as "the drive or ability to attribute mental states to others/animals and to respond to these mental states with an appropriate emotion." This scale includes three dimensions: cognitive empathy, emotional reactivity, and social skills, though the social skills dimension measures behavioral conduct in specific situations and is unrelated to empathy (Lawrence, Shaw, Baker, Baron-Cohen, & David, 2004). In addition to being suitable for adults with normal intelligence, this scale is also frequently used in empathy research with autism populations (Minio-Paluello, Baron-Cohen, Avenanti, Walsh, & Aglioti, 2009).

In contrast, the Basic Empathy Scale (BES) developed by Jolliffe and Farrington (2006) defines empathy as "understanding and sharing the emotional state or condition of another." The advantages of this scale include: assessing both cognitive and emotional dimensions of empathy based on four basic emotions (happiness, anger, sadness, and fear); avoiding the confounding concept of "sympathy" in specific items; and preventing the common problem in previous scale development where the age range for scale development and application were inconsistent. The Chinese version of this scale has an internal consistency coefficient of 0.77, test-retest reliability of 0.70, and split-half reliability of 0.77 (Geng, Xia, & Qin, 2012).

The Questionnaire of Cognitive and Affective Empathy (QCAE) was the first empathy scale administered online via the internet. It not only distinguishes empathy from sympathy but also differentiates cognitive empathy from theory of mind, and emphasizes the distinction between self and other in emotional empathy (Reniers et al., 2011). To fill the gap in measuring empathy in children, some researchers adapted the well-known IRI scale into the Feeling and Thinking Scale (FTS) (Garton & Gringart, 2005).

Additionally, Mark et al. (2008) developed a parent-report scale for children' s empathy—the Griffith Empathy Measure (GEM). Its Chinese version has an internal consistency coefficient of 0.83 (Zhang et al., 2014). In addition to cognitive and emotional empathy, this questionnaire includes a dimension of "behavioral empathy," referring to explicit behavioral expressions in response to others' emotions (Zhang et al., 2014). This questionnaire has demonstrated good reliability and validity among various populations in China, including preschool children, school-age children, adolescents, college students, and even autism populations (Su, 2018).

Table 1. Commonly Used Empathy Scales

Scale Name	Chinese Name	Target Population/Dimensions	Citations
Interpersonal Reactivity Index (Davis, 1983)	中文版人际反应指针量表	Emotional empathy, Cognitive empathy	7322#
Autism Quotient (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001)	自闭症商数	Autism patients	2077*
Empathy Quotient (Baron-Cohen & Wheelwright, 2004)	中文版共情商数量表	-	-
Emotional Empathic Tendency Scale (Questionnaire Measure of Emotional Empathy) (Mehrabian & Epstein, 1972)	情绪共情问卷	-	-
Hogan Empathy Scale (Hogan, 1969)	霍根共情量表	Emotional empathy, Cognitive empathy	1358* 1062*

Scale Name	Chinese Name	Target Population/Dimensions	Citations
Child and Adolescent Temperament Scale (Caspi, Henry, McGee, Moffitt, & Silva, 1995)	儿童青少年气质量表	Children, adolescents	-
Basic Empathy Scale (Jolliffe & Farrington, 2006)	基本共情量表	Emotional empathy, Cognitive empathy	-
Jefferson Scale of Empathy (Hojat et al., 2001)	杰弗逊共情量表	Medical workers and students	-
Multifaceted Empathy Test (Dziobek et al., 2008)	多维共情测验	-	-
Emotional Contagion Scale (Doherty, 1997)	情绪感染量表	-	-
Penner Prosocial Personality Battery (Penner, Fritzsche, Craiger, & Freifeld, 1995)	佩纳亲社会人格量表	-	-

Scale Name	Chinese Name	Target Population/Dimensions	Citations
Toronto Empathy Measure (Spreng, McKinnon, Mar, & Levine, 2009)	多伦多共情量表	-	-
Scale of Ethnocultural Empathy (Wang et al., 2003)	民族文化共情量表	-	-
the Consultation and Relational Empathy Measure (Mercer, Maxwell, Heaney, & Watt, 2004)	咨询和关系共情量表	-	-
Balanced Emotional Empathy Scale (Mehrabian, 1996)	平衡情绪共情量表	Emotional empathy, Cognitive empathy (QMEE)	-
Questionnaire of Cognitive and Affective Empathy (Mercer et al., 2004; Reniers, Corcoran, Drake, Shryane, & Völlm, 2011)	认知和情绪共情问卷	Emotional empathy, Cognitive empathy	-
MDEES	-	-	-
PACES	-	-	-
EmQue	-	-	-

Scale Name	Chinese Name	Target Population/Dimensions	Citations
Griffith Empathy Measure (Dadds et al., 2008)	格里菲斯共情量表	Emotional empathy, Cognitive empathy	-
Multidimensional Emotional Empathy Scale (Caruso & Mayer, 1998)	多维度情绪共情量表	Adolescents, adults	-
Feeling and Thinking Scale (Garton & Gringart, 2005)	感觉和思维量表	-	-
Parent Affective and Cognitive Empathy Scale (Stern, Borelli, & Smiley, 2015)	父母情绪和认知共情量表	Emotional empathy, Cognitive empathy	-
Adolescent Measure of Empathy and Sympathy (Vossen, Piotrowski, & Valkenburg, 2015)	青少年共情和同情量表	Emotional empathy, Cognitive empathy, Sympathy	-
the Empathy Questionnaire (Rieffe, Ketelaar, & Wiefferink, 2010)	-	-	-

Scale Name	Chinese Name	Target Population/Dimensions	Citations
Empathy for Pain Scale (Giummarra et al., 2015)	疼痛共情量表	-	-
Emotion Specific Empathy Questionnaire (Olderbak, Sassenrath, Keller, & Wilhelm, 2014)	情绪特异性共情问卷	-	-
Emotional Empathy Scale (Ashraf, 2004)	情绪共情量表	Emotional empathy, Cognitive empathy	-

Note: Citation counts are from Web of Science () and Google Scholar (#, used when Web of Science data is unavailable), as of January 10, 2019; the "Dimensions Measured" column only represents categorization of scale dimensions from the perspective of emotional and cognitive empathy, and does not indicate the exact dimensions of the scales; "/" indicates that the scale treats empathy as a whole and cannot be categorized.*

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3 Classic Experimental Paradigms in Empathy Research

Empathy is not only viewed as a relatively stable trait or ability; some researchers also conceptualize empathy as a highly variable state influenced by cognitive and contextual factors such as cognitive load (Rameson, Morelli, & Lieberman, 2012) and emotion (Han et al., 2009). Based on this conceptualization, researchers typically design specific experimental paradigms to measure participants' empathy levels. The basic logic of commonly used behavioral paradigms in empathy research is as follows: present participants with stimulus materials that directly or indirectly reflect others' emotions, mental states, or situations, and then ask participants to rate either their own emotional or mental states evoked by the stimuli, or the emotions/mental states of others depicted in the stimuli.

Commonly used empathy experimental materials include static pictures, dynamic pictures, videos, symbols/cues, and narrative texts. These materials can be presented in different ways. Presenting stimuli from a first-person perspective directly evokes empathy and facilitates participants' ability to "feel as the other feels."Presenting stimuli from a third-person perspective, with instructions manipulating the relationship between participants and empathy targets (asking participants to imagine that the stimuli depict the experiences of strangers, friends, or romantic partners), facilitates participants' empathy for "others" from a bystander perspective and allows investigation of how interpersonal relationships or familiarity affect empathy (Cheng, Chen, Lin, Chou, & Decety, 2010). Manipulating perspective helps researchers compare the similarities and differences between self-representation and other-representation during empathy (Jackson, Brunet, Meltzoff, & Decety, 2006).

Following the classification of commonly used empathy questionnaires, these behavioral paradigms can also be broadly divided into three categories: those focusing on measuring emotional empathy, those measuring cognitive empathy, or those simultaneously measuring both emotional and cognitive empathy.

3.1 Emotional Empathy Behavioral Paradigms

Based on the definition of emotional empathy, commonly used experimental paradigms typically explore individuals' emotional empathy abilities from perspectives such as emotion induction and emotion recognition. Experimental designs minimize or even eliminate interference from advanced cognitive activities like reasoning, selecting simple and clear materials with obvious emotional cues. For example, in pain empathy paradigms, stimuli typically include static pictures with clearly harmful or threatening content (such as a finger being cut by a knife) (Jackson, Meltzoff, & Decety, 2005), painful facial expressions (Saarela et al., 2006), or even dynamic emotional videos (such as a person describing unfortunate circumstances) (Barraza & Zak, 2009), with participants asked to assess pain intensity, thereby directly evoking emotional arousal. Another example is the emotion recognition task, where participants are required to identify the emotion types expressed by different facial expressions. The emotion recognition ability measured by this paradigm is considered an important component of emotional empathy, and thus individual task performance can reflect their emotional empathy capacity (Shamay-Tsoory, Aharon-Peretz, & Perry, 2009).

Both direct emotion induction and subjective judgment in emotion recognition reflect the phenomenological aspects of emotional empathy, focusing on subjective feelings and judgments, but inevitably suffer from reporting biases. Implicit empathy paradigms address this issue by using the degree of interference from empathy-related materials on participants' performance in empathy-irrelevant tasks as an indirect measure of empathy. For example, in implicit pain empathy paradigms, although participants are presented with pictures of body parts in painful or non-painful conditions, the experimental requirement is not to judge or identify the pain information in the pictures, but rather to quickly and accurately judge other information, such as whether the presented hand (or foot) is a left or right hand (or foot) (Gu et al., 2010). The underlying assumption of this paradigm is that viewing pictures of others' injuries will evoke empathic responses in participants, such as empathic distress, which in turn interferes with their task performance by increasing reaction times and decreasing accuracy. The stronger a participant' s empathy ability, the more susceptible their judgments of pain-irrelevant information are to such interference (Coll et al., 2017).

3.2 Cognitive Empathy Behavioral Paradigms

Experimental paradigms measuring cognitive empathy focus on examining participants' reasoning abilities regarding empathy-related events or situations, as well as other advanced cognitive processes related to empathy. Therefore, cognitive empathy tasks often employ complex stimulus materials requiring certain levels of inference, such as texts describing car accidents or videos of threatening situations (Kanske, Böckler, Trautwein, & Singer, 2015).

Some researchers view cognitive empathy as a sub-dimension of theory of mind —affective theory of mind—referring to individuals' understanding of others' emotions (Walter, 2012), and use affective theory of mind tasks to measure cognitive empathy. For example, one study required participants to watch the eye gaze and facial expressions of a cartoon character named "Yoni" and judge Yoni' s feelings toward other people or objects. Since this involves certain reasoning processes, participants' performance on the task can be used as an indicator of cognitive empathy (Shamay-Tsoory & Aharon-Peretz, 2007).

Another commonly used cognitive empathy research paradigm is the second-order false belief task in comic strip form, which focuses on examining individuals' understanding of multi-person situations and their ability to infer beliefs about third parties' thoughts (Shamay-Tsoory et al., 2009). Simple line drawings lack direct cues about emotional states—that is, they do not provide close-up facial expressions like those of "Yoni" —and participants must understand the multi-person situation in the drawings and infer characters' mental states, using task performance level as an indicator of cognitive empathy (Schnell, Bluschke, Konradt, & Walter, 2011). The difficulty of such tasks can be easily adjusted, making them widely applicable in empathy research with children (Jones, Happé, Gilbert, Burnett, & Viding, 2010).

However, some researchers consider empathy and theory of mind to be independent concepts and have designed the EmpaToM paradigm to differentiate between them (Kanske et al., 2015). In this study, participants first watched autobiographical narrative videos with negative or neutral emotional valence, and then completed both emotion-understanding questions (such as rating their own emotions and sympathy for characters in the videos) and false-belief questions (such as questions requiring logical reasoning based on video content). Ultimately, responses to emotion-understanding questions were used to measure empathy levels, while responses to false-belief questions measured theory of mind levels. Compared with low-realism experimental materials such as texts and cartoons used in previous paradigms, the autobiographical narrative videos in the EmpaToM paradigm are more realistic and have higher ecological validity.

3.3 Behavioral Paradigms Simultaneously Measuring Cognitive and Emotional Empathy

In addition to separate emotional and cognitive empathy tasks, researchers have developed experimental paradigms that can simultaneously assess both cognitive and emotional empathy. For example, participants are first presented with three comic strips describing a continuous scene, and then asked to make a forced choice between two options, each being a different scene picture. The choice question for the cognitive empathy task is "What will the protagonist do next?" , which engages participants' understanding of the protagonist' s intentions, whereas the choice question for the emotional empathy task is "What would make the protagonist feel better?" , prompting participants to experience the protagonist' s emotional feelings (Völlm et al., 2006).

Furthermore, in some pain empathy studies using picture-rating tasks, participants' ratings of others' pain intensity are considered inferences about others' physical pain sensations and are therefore treated as indicators of cognitive empathy, while ratings of others' pain unpleasantness are considered to involve vicarious emotional experiences and are thus treated as indicators of emotional empathy (Lamm, Nusbaum, Meltzoff, & Decety, 2007).

Some researchers have also attempted to separate emotional and cognitive empathy by manipulating the presence or absence of emotional cues in experimental paradigms. Empathy for individuals in negative scenes (such as interpersonal aggression situations) is considered perception of others' emotional states and classified as emotional empathy, whereas empathy for individuals in neutral scenes (such as daily non-emotional activities) is interpreted as requiring inference about others' experiences and intentions, and is therefore classified as cognitive empathy (Nummenmaa, Hirvonen, Parkkola, & Hietanen, 2008).

In summary, current research attempts to separate emotional and cognitive empathy based on respective definitions of empathy, and no unified separation paradigm exists yet. However, the core principle of classification is relatively consistent: direct emotional sharing belongs to emotional empathy, while processes involving reasoning belong to cognitive empathy.

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4 Neuroscientific Research Methods for Empathy

While behavioral paradigms can collect participants' subjective ratings, supplementary electrophysiological techniques (such as EMG, EEG, MEG) and brain functional imaging techniques (such as fMRI) can further provide objective measures of participants' empathy-related physiological and brain activity levels. The application of these technologies in empathy research has greatly advanced researchers' understanding of the neural processing underlying empathy phenomena.

4.1 Facial Electromyography (EMG)

Motor mimicry is a core component of empathy (de Waal & Preston, 2017). Studies on both humans (Dimberg, Thunberg, & Elmehed, 2000) and primates (Mancini, Ferrari, & Palagi, 2013) have found that observers exhibit rapid facial mimicry toward empathy targets. Researchers can quantify facial mimicry by measuring the electrical potentials generated during skeletal muscle contraction during facial imitation (i.e., facial electromyography) (Neumann & Westbury, 2011). Facial expressions that can reflect empathy primarily involve the activity of facial muscles such as the corrugator supercilii, zygomaticus major, levator labii superioris, and orbicularis oculi (Neumann, Chan, Boyle, Wang, & Westbury, 2015).

Beyond facial expression mimicry, individuals' response sensitivity to others' facial expressions and the intensity of facial response potentials can also effectively reflect their emotional empathy abilities. Individuals with high emotional empathy scores show greater corrugator supercilii activity in response to angry faces and greater zygomaticus major activity in response to happy faces, whereas individuals with low emotional empathy scores show no significant differences in responses to these two types of facial stimuli (Dimberg, Andréasson, & Thunberg, 2011; Dimberg & Thunberg, 2012). Additionally, when participants view stimulus materials depicting others or animals in negative situations, the amplitude of their corrugator supercilii potentials shows significant positive correlations with both subjective empathy ratings and BEES scores (Westbury & Neumann, 2008).

Although EMG has high temporal precision and can detect facial reactions below visual threshold, EMG signals may be contaminated by muscle responses to empathy-irrelevant visual stimuli, and therefore cannot serve as an objective indicator reflecting only motor mimicry. Additionally, attaching electrodes to participants' faces may increase their attention to facial expressions, thereby exaggerating facial reactions (Neumann et al., 2015). Most importantly, since muscle activity is not an empathy-specific response and studies often record only certain specific facial muscles, EMG results typically need to be interpreted in conjunction with other empathy indicators to address relevant questions in empathy research.

4.2 Electroencephalography and Magnetoencephalography

EEG signals are also commonly used as an objective indicator for assessing participants' empathy levels in empathy behavioral paradigms (Cheng, Chen,

& Decety, 2014). Taking pain empathy as an example, a pioneering 2008 event-related potential (ERP) study on pain empathy found that, compared with neutral stimuli, pain stimuli elicited a larger ERP component (i.e., N1/N2) in frontal regions at approximately 140 ms after presentation, and a larger ERP component (i.e., P3/LPP) in central-parietal regions at around 380 ms (Fan & Han, 2008).

Since then, numerous studies have further supported this conclusion, demonstrating that both early automatic N1 and N2 components and later P3 and LPP components are related to empathy. For instance, early and late ERP components evoked by pain empathy paradigms not only show significant positive correlations with participants' trait empathy scores (Fabi & Leuthold, 2017; Vaes, Meconi, Sessa, & Olechowski, 2016), but also positively correlate with their subjective ratings of others' pain intensity and unpleasantness (Cheng, Hung, & Decety, 2012; Meng et al., 2012).

Moreover, when the experimental task is unrelated to pain empathy processing, the amplitude differences in both early and late ERP components between painful and neutral pictures decrease (Cui, Zhu, & Luo, 2017; Fan & Han, 2008); when the experimental task emphasizes empathy processing, the amplitude differences between the two conditions increase (Ikezawa, Corbera, & Wexler, 2013). These ERPs are even influenced by the type of empathy target, with smaller ERPs produced when participants empathize with cartoons (Fan & Han, 2008), robots (Suzuki, Galli, Ikeda, Itakura, & Kitazaki, 2015), or individuals of other races (Fabi & Leuthold, 2017), compared with same-race individuals.

However, which specific processes of empathy are reflected by early versus late ERP components remains controversial. Since these two types of components are modulated by stimulus characteristics (such as authenticity) and cognitive evaluation (such as attention), respectively, previous researchers generally believed that N1 and N2 components reflect emotional sharing, while P3 and LPP reflect cognitive evaluation of others' pain (Decety, Yang, & Cheng, 2010; Fan & Han, 2008; Li & Han, 2010). However, a recent meta-analysis based on 40 pain empathy ERP studies indicated that pain empathy can reliably elicit larger P3 and LPP in central-parietal regions, but does not necessarily elicit early N1 and N2 components (Coll, 2018). The authors further suggested that this may be because early N1 and N2 components reflect perceptual processing of stimuli and do not involve genuine empathic responses.

Moreover, since various types of emotional stimuli can elicit these early and late ERP components (Schupp, Junghöfer, Weike, & Hamm, 2003), these components are likely not empathy-specific but rather reflect general perceptual and aversive processing (Coll, 2018).

Beyond ERPs, specific EEG rhythms are also related to empathy levels. For example, viewing others' pain induces enhanced suppression of mu/alpha rhythm (8-13 Hz) (Perry, Bentin, Bartal, Lamm, & Decety, 2010; Yang, Decety, Lee, Chen, & Cheng, 2009). This mu/alpha rhythm suppression originates from activation in early empathy-processing brain regions such as the sensorimotor cortex and primary somatosensory cortex, and thus can reflect early processing of pain empathy (Cheng et al., 2014). Additionally, since prefrontal activation is related to emotional experience and expression but not to emotional perception (Davidson, 2004), individual prefrontal alpha asymmetry activity during empathy tasks is often considered a good indicator for measuring participants' emotional empathy (Gutsell & Inzlicht, 2012). Further research has found that the degree of right prefrontal alpha asymmetry in participants at baseline (i.e., before stimulus presentation) can predict their empathic concern ratings during tasks, suggesting that this brain activity can reflect participants' sensitivity to others' suffering (Tullett, Harmon-Jones, & Inzlicht, 2012).

Empathy involves multiple processing stages, and a single EEG rhythm, while potentially related to empathy, is insufficient to fully explain the brain mechanisms of empathy. To further investigate these mechanisms, researchers have utilized the high spatial and temporal resolution advantages of MEG to explore dynamic associations of oscillatory signals across multiple brain regions and frequency bands. Even with similar pain empathy scores, the brain mechanisms of empathy differ across age groups: from children to adults, empathy-related brain activity shifts from single alpha rhythm to efficient interconnections among multiple rhythms including alpha, beta (14-30 Hz), and gamma (30-100 Hz), and expands from neural responses in sensorimotor brain regions to activity in emotional empathy brain networks (Levy, Goldstein, Pratt, & Feldman, 2018).

4.3 Functional Magnetic Resonance Imaging

fMRI technology has high spatial resolution and can more intuitively and finely characterize brain structure and function. By analyzing the relationship between individual brain structural images (such as gray matter volume in specific brain regions) and empathy traits, researchers have found that IRI empathic concern scores negatively correlate with gray matter volume in the precuneus, inferior frontal gyrus (IFG), and anterior cingulate cortex (ACC); personal distress scores negatively correlate with gray matter volume in the somatosensory cortex but positively correlate with gray matter volume in the insula; perspective-taking scores positively correlate with gray matter volume in the ACC; and fantasy scores positively correlate with gray matter volume in the right dorsolateral prefrontal cortex (DLPFC) (Banissy, Kanai, Walsh, & Rees, 2012).

Functional imaging studies of empathy have found that emotional empathy tasks involve greater activation of emotion- and movement-related brain regions, such as the insula, ACC, thalamus, amygdala, fusiform gyrus, somatosensory and motor cortices, and ventromedial prefrontal cortex (VMPFC). Cognitive empathy tasks involve greater activation of brain regions related to executive function, working memory, and visuospatial processing, such as the DLPFC, VMPFC, superior temporal cortex, temporo-parietal junction, and superior and inferior parietal lobules (de Waal & Preston, 2017).

Leveraging fMRI' s high spatial resolution, researchers have been able to identify differences in brain activity elicited by different empathy paradigms. For example, emotion-oriented and cognition-oriented theory of mind tasks produce subtle differences in prefrontal activation: emotion-oriented tasks activate more medial parts of the prefrontal cortex, namely the orbitofrontal cortex and/or VMPFC, while cognition-oriented tasks activate more lateral parts of the prefrontal cortex, namely the DLPFC (Lamm et al., 2007; Nummenmaa et al., 2008).

Different pain empathy experimental paradigms also activate not entirely identical brain regions: viewing pictures of body parts in painful situations involves to a greater extent brain regions related to action understanding, such as the inferior parietal/ventral premotor cortices; viewing abstract visual information representing others' emotional states involves to a greater extent regions related to inferring and representing self and others' mental states, such as the precuneus, VMPFC, superior temporal cortex, and temporo-parietal junction (Lamm, Decety, & Singer, 2011).

Furthermore, fMRI facilitates investigation of empathy characteristics in brain-damaged patients. Studies have shown that damage to the somatosensory cortex causes deficits in emotional empathy but not cognitive empathy, whereas damage to the VMPFC leads to abnormalities in cognitive empathy rather than emotional empathy (Shamay-Tsoory et al., 2009), providing further evidence for the neural separation of emotional and cognitive empathy.

It should be noted that fMRI measures brain activity correlated with a certain psychological-cognitive process, and reverse inference may be problematic (Hu & Iannetti, 2016), meaning that it cannot prove these brain regions are empathy-specific. Additionally, a single voxel in fMRI results encompasses thousands of neurons, and functionally different neuronal activities can produce similar fMRI activation maps, so overlapping activated brain regions do not necessarily represent identical neural processing (Rütgen, Seidel, Silani, et al., 2015).

For example, meta-analytic results show that "seeing" others experience pain consistently activates the bilateral anterior insular cortex and medial/anterior cingulate cortex, which overlap with brain regions involved in processing the emotional-motivational dimension of pain (Lamm et al., 2011). However, common brain region activation cannot prove that empathy is achieved by "engaging in the same neural activity as others." Some researchers have attempted to overcome this issue through experimental design. For instance, pharmacological or psychological analgesic methods can simultaneously reduce both individuals' own pain and pain empathy, with covariation effects manifested not only in subjective ratings but also in activation of the anterior insula and aMCC (Rütgen, Seidel, Riečanský, & Lamm, 2015), and these effects can be blocked by opioid antagonists (Rütgen, Seidel, Silani, et al., 2015), indirectly demonstrating that both personal pain and pain empathy involve the same neural processing.

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5 Discussion

5.1 Advantages and Disadvantages of Various Empathy Research Methods

An individual' s empathy ability determines the upper limit of empathy levels they can produce in actual situations (Keysers & Gazzola, 2014). The core purpose of existing empathy research methods is to assess individuals' empathy levels as accurately as possible, thereby approximating their true empathy abilities.

Among empathy research methods, questionnaires are the most abundant and interpretable measurement approach and are convenient to administer. Although questionnaires can adequately reflect participants' subjective evaluations of their own empathy, their accuracy is susceptible to social desirability, response biases, and factors such as participants' expressive and awareness abilities. Moreover, the wide variety of empathy scales and the lack of systematic guidelines for scale selection increase the difficulty for researchers to choose appropriate measurement tools. For example, the IRI scale is currently the most commonly used self-report empathy scale, and many researchers prioritize its use for measuring empathy, but this scale is also a primary cause of the conceptual confusion between empathy and sympathy (Vossen et al., 2015). How researchers understand empathy and its dimensions, as well as the context and population in which empathy is measured, all influence scale selection.

Regarding empathy experimental paradigms, researchers can more directly explore participants' subjective ratings and behavioral performance in specific empathy situations. However, empathy task performance is also more susceptible to influences from material quality, presentation perspective, attentional bias, and other factors. Researchers need to design experiments that can elicit participants' "genuine" empathy as much as possible, for example, by using multi-person experiments (Rütgen, Seidel, Silani, et al., 2015) or simulated donation tasks (Cameron, Spring, & Todd, 2017).

Neuroscientific techniques combined with empathy experimental paradigms serve as important supplements to subjective measures, better avoiding the influence of the aforementioned interfering factors and providing objective indicators such as facial action mimicry, EEG signals, and even brain structure and activation, which facilitate researchers' in-depth understanding of the cognitive neural mechanisms of empathy. However, there is currently no recognized "specific" physiological indicator of empathy, meaning that physiological signals accompanying empathy tasks need to be cross-validated with questionnaire and subjective rating results to be meaningful. Additionally, some studies have collected participants' autonomic nervous system responses during empathy tasks, such as skin conductance, heart rate, respiration, and hormonal changes like oxytocin and cortisol. These methods can provide rich and effective information for the embodied manifestations of empathy but are not central to the definition of empathy, and thus are not detailed in this paper.

Empathy research methods at different levels each have their strengths, and linking results across multiple levels often provides better support for research conclusions than single-level evidence. Therefore, researchers should flexibly employ both subjective behavioral indicators and objective neuroscientific methods according to their experimental purposes. For example, EEG' s high temporal resolution is more suitable for exploring the temporal processing sequence of empathy, from initial perceptual processing to emotional arousal and then to advanced processing such as reasoning; fMRI' s high spatial resolution is more advantageous for researchers to explore the brain regions and networks corresponding to different functions of empathy, such as emotion regulation, self-other distinction, and reward.

5.2 Comparability Issues in Empathy Research

Currently, up to 43 different definitions of empathy are employed across studies (Cuff, Brown, Taylor, & Howat, 2016). Due to this lack of unified definition, different researchers may adopt different research designs and interpret results differently at the levels of subjective reports, behavioral ratings, and even objective physiological and brain mechanisms. For example, using multiple questionnaires to measure emotional empathy in two groups of participants may yield different assessment results (Peretti et al., 2018); ratings of pain intensity may be interpreted by one researcher as an indicator of emotional empathy and by another as a manifestation of cognitive empathy (Lamm et al., 2007); and even for the same pain empathy, subtle differences in paradigm design are sufficient to elicit different brain activities (Coll, 2018).

The separation of emotional and cognitive empathy also faces comparability issues. Although many studies clearly show that emotional and cognitive empathy involve different neural mechanisms, these studies mostly rely on different stimulus types and experimental tasks, making it difficult to interpret the specific significance of differences in their neural mechanisms (Zaki & Ochsner, 2012). Moreover, the conceptually fuzzy association between emotional and cognitive empathy makes dimensional separation difficult to achieve.

Diverse explorations are beneficial to some extent for macro-level understanding of empathy and its mechanisms, but they also weaken the comparability of different research findings and hinder the integration and development of empathy research. Therefore, when comparing results across studies, researchers need to pay special attention to the definitions of empathy and the measurement tools and research methods employed, and comparing similar types of studies can better avoid drawing erroneous conclusions. Meanwhile, as calls for a unified, standardized definition of empathy increase and understanding of the psychological processes and neural mechanisms of cognitive and emotional empathy becomes more refined, mutual corroboration among empathy research findings will be greatly strengthened.

5.3 Ecological Validity Issues in Empathy Research

Most existing empathy research employs highly simplified cues that differ from real-life situations to some extent. For example, emotional empathy tasks typically present participants with decontextualized pictures containing simple cues, such as a superficial expression or action, and ask participants to "empathize." This type of empathy is largely influenced by extraneous variables such as participants' engagement or imagination. Participants' subjective ratings of stimulus materials may merely involve repetitive evaluation without truly "putting themselves in others' shoes." Additionally, materials that are not "vivid" enough may prevent individuals with inherently high empathy abilities from demonstrating their true capacity. Therefore, researchers should adopt more naturalistic and ecologically valid materials and paradigms in future studies, such as introducing confederates or using virtual reality (VR) technologies.

Furthermore, previous research has mostly focused on exploring the processing and mechanisms of a particular sub-dimension of empathy, while less attention has been paid to investigating dynamic, holistic, and mutually influential empathy and its mechanisms. Different empathy components interact with each other, representing more than simple additive processing stages. Future research should focus on studying the formation process and principles of interactive "macro-level" empathy in social contexts.

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Note: Figure translations are in progress. See original paper for figures.