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문학석사 학위논문

Sex Differences in the Voluntary
Control of Pain Empathy:
An EEG Study.

고통 공감의 의지적 조절과 그 성차:
EEG 연구

2021년 8월

서울대학교 대학원
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최수연

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이 논문을 문학석사 학위논문으로 제출함

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Abstract

Contrary to the long-held belief that empathy is automatic and reflexive, recent evidence has begun to emphasize the role of top-down processes in empathic experience. That is, empathy is increasingly conceived as motivational in nature. The present study aims to investigate whether the effect of motivation for empathy is modulated by biological sex. 24 subjects (14 men, 10 women) viewed pictures of painful situations either passively or actively trying to up- or down-regulate empathy. As an index of empathic resonance with the target's pain, I measured the EEG mu suppression. The results showed that men, as expected, exhibited the strongest mu suppression during up-regulation. For women, however, the strongest mu suppression occurred while trying to down-regulate pain empathy. One possible interpretation of such results for women is that their active inhibiting efforts "backfired", paradoxically leading to the greatest level of vicarious pain. In conclusion, women appear to experience greater difficulty voluntarily modulating pain empathy. Empathy for men, on the other hand, appears to be more motivational and flexible in nature. These findings contribute a line of neural evidence to the Primary Caretaker Hypothesis, which posits that empathy may have evolved from offspring care, a role predominantly associated by female primates. Theoretical and practical implications are discussed.

Keyword : Empathy, Pain, Motivation, Sex Differences, EEG, Mu Rhythm
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Table of Contents

Abstract.....	i
Table of Contents.....	iii
List of Tables.....	v
List of Figures.....	vi
1 . Introduction.....	1
2 . Literature Review.....	7
2.1. The Nature of Empathy.....	7
2.1.1. Empathy and Its Neurobiological Basis.....	7
2.1.2. Pain Empathy and Its Neurobiological Basis.....	10
2.2. Theories of Empathy.....	12
2.2.1. Automaticity as a Theme in the Empathy Literature.....	12
2.2.2. Motivation as a Theme in the Empathy Literature.....	15
2.2.3. Sex-related Effects in Motivated Empathy.....	19
2.3. Research Objectives and Hypotheses.....	23
3 . Methodology.....	24
3.1. Electroencephalogram (EEG).....	24
3.2. Time-Frequency Analysis.....	25
3.3. Mu Rhythm.....	26
3.4. Alpha Rhythm.....	29
3.5. Overview of the Study.....	30
4 . Expeirement.....	31
4.1. Participants.....	31
4.2. General Procedures.....	32
4.3. Picture Stimuli.....	35
4.4. EEG Data Acquisition	37
4.5. EEG Data Pre-processing and Time-Frequency Analysis.....	38
4.6. Statistical Analysis.....	40
5 . Results.....	41
5.1. Behavioral Results	41

5.2. EEG Results.....	42
5.3. Correlation of MuSuppressions and Self-report Measures of Pain Empathy.....	46
6. Discussion.....	47
6.1. Summary and Interpretation of the Results.....	47
6.2. Theoretical Contributions and Practical Implications.....	54
6.3. Limitations and Future Directions.....	55
7. Overall Conclusions.....	56
References.....	58
Appendix.....	74
Abstract in Korean.....	78

List of Tables

Table 1. The Descriptive Statistics (Mean Values and Standard Deviations) of Pain Intensity for the Final Set of Pictures.....	36
Table 2. Behavioral Measures of Empathy (on a Scale of 1-5) and Pain Sensitivity (on a Scale of 1-10) in the Male and Female Subgroups.....	42
Table 3. Suppression Indices in the Central Regions and Their Pairwise Comparisons.....	45
Table 4. Suppression Indices in the Occipital Regions and Their Pairwise Comparisons.....	45

List of Figures

Figure 1. An Example of Facial Mimicry in Infants (A) and Juvenile Gelada Baboons (B).....	14
Figure 2. Simulation of Mu Suppression in the 8-13-Hz Frequency Band...29	
Figure 3. Sequence of Events in One Trial in the Empathy Modulation Paradigm.....	35
Figure 4. An Example of Painful Pictures ((A) Hand, (B) Foot) Used in the Study.....	37
Figure 5. Mu Sppression Indices for the Increase, Decrease, and Watch Conditions for Men (red) and Women (blue) in Central (left) and Occipital (right) Regions.....	43
Figure 6. Raw Time-Frequency Spectra for the Increase, Decrease, Watch Conditions for Men and Women in the Central Brain Regions.....	46
Figure 7. Correlations Between the Mu Suppressions of Pain Empathy and the Subjective Ratings of the Pain Sensitivity Scale in Male (left) and Female (right) Subgroups.....	47

1. Introduction

Empathy refers to a cognitive phenomenon of sharing others' affective states (Decety, & Lamm, 2006). We experience empathy when we tear up while watching a bereaved person's cry on television, or when we wince and writhe while watching someone undergoing a painful medical procedure. In other words, through empathy we "penetrate the world of the other" using our own bodily resources (Gallese, 2003, p. 174).

Sharing others' emotions is essential in social functioning. Empathy promotes prosocial behavior and strengthens relationships (Zaki, & Cikara, 2015). Failures in experiencing empathy have been associated with various deleterious consequences including cases of neglect, discrimination, and physical/psychological aggression (Cikara, 2015; Zaki, & Cikara, 2015). Given its far-reaching social benefits, empathy has attracted much scholarly attention across various academic fields. Specifically, advances in knowledge on the nature of empathy have been made in disciplines such as developmental/social psychology, ethology, and neuroscience.

In many of these disciplines, empathy has been regarded as an automatic and reflexive phenomenon (e.g., Hatfield, Forbes, & Rapson, 2013; Lipps, 1903; Smith, 1790/2002). In Adam Smith's early description of empathy, it was stated that "when we see a stroke aimed and just ready to fall on the leg or arm of another person, we *naturally* shrink back our own leg or our own arm" (Smith, 1790/2002, p. 4; emphasis added).

Automaticity, since then, has been a dominating theme in the empathy literature for more than two centuries (Zaki, 2014).

This focus on automaticity, however, has severely limited opportunities to investigate the role of top-down processes (e.g., an observer's choice) in empathic experience. Despite the lack of attention in academia, there is ample evidence in reality, which suggests that empathy often comes under voluntary control. For instance, when confronted with socially distant others in pain, empathy is quickly suppressed in otherwise empathic individuals (Cheng, Chen, Lin, Chou, & Decety, 2010; Cikara, & Van Bavel, 2014). In addition to social distance, empathy has been shown to be modulated by other contextual factors such as *a priori* attitudes towards the target in pain (Decety, Echols, & Correll, 2009). These observations question the view that empathy is a pure bottom-up reflex.

Recently, there have been long overdue attempts in academia to frame empathy as a phenomenon, modulated by motivation (e.g., Groat, & Shane, 2019; Zaki, 2014). From this perspective, people have at least some degree of voluntary control to determine the degree to which their emotions resonate with those of the other. That is, motivated models of empathy posit that empathy, which appears to be automatic is, in fact, a *choice*. The present study aims to advance knowledge on the role of higher-level cognition in empathy.

Specifically, the present paper seeks to explore potential sex

differences in the role of motivation in experiencing empathy. This research interest originates from the assumption that empathy is rooted in women's role of childrearing (Babchuk, Hames, & Thompson, 1985; Christov-Moore, Simpson, Coudé Grigaityte, Iacoboni, & Ferrari, 2014). Specifically, female primates who have shown considerate and sensitive attitudes toward others' mental states could have been naturally selected due to their significant evolutionary advantages related to offspring care and reproduction. It can, thus, be claimed that women might have evolved to share others' emotions more automatically and universally, regardless of the situation, than men (Christov-Moore et al., 2014). For men who were mainly involved in hunting, empathy might have been a less advantageous response.

A body of empirical research has attested to the female advantage in empathy. According to a series of behavioral studies, women, compared to men, showed greater mimicry while observing facial expressions (Dimberg, & Lundqvist, 1990; Lundqvist, 1995), were more accurate and faster in their attempt to recognize facial expressions (Babchuk et al., 1985; Hampson, Vanandars, & Mullin, 2006; Thayer, & Johnson, 2000), and were more inequality-averse in resource-sharing tasks (Andreoni, & Vesterlund, 2001). In addition, such findings have been replicated in studies, conducted with infants (Sagi, & Hoffman, 1976), animals (Langford, 2006) as well as adult volunteers, measuring their brain responses (Cheng, Lee, Yang, Lin, Hung, & Decety, 2008; Yang, Decety, Lee, Chen, & Cheng, 2009).

Looking at the other side of the coin, this female advantage in empathy means that men have demonstrated less empathy than women across studies, conducted with a variety of populations and methodologies. Importantly, though, male empathy increased in cases of interacting with certain social targets such as familiar or favorably-perceived others (e.g., Singer, Seymour, Odoherly, Stephan, Dolan, & Frith 2006). In other words, men appear to have evolved to share others' emotions more selectively. This makes evolutionary sense, considering that empathy could have been more advantageous for male hunters when it depended on situational contexts, choice and motivation.

In sum, the existing literature implies that there is a greater likelihood of aspects of higher-level cognition, such as motivation, being involved in male empathy. Currently, however, no controlled experiments to investigate such a possibility have been conducted yet. In this sense, the existing literature is limited such that it provides only superficial descriptions of sex differences in empathic tendencies, while the nature of such differences remains yet to be understood. By employing an active empathy regulation paradigm, the present study aims to directly test the possibility that *not only do men have more control over the external emotional expressions, but they may also have more control over the internal experience of empathy itself* (Brehm et al., 1984; Christov-Moore et al., 2014).

This research will contribute to the literature in three important ways. First, I advance the literature on motivated empathy by contributing another line of empirical evidence. Recently, a burgeoning literature across various disciplines has demonstrated that motivation pervades information processing of nearly all stages. That is, information processing as early occurring as low-level perception (i.e., what people see or hear at the most fundamental level) can be shaped, biased, and distorted by aspects of higher-level cognition, such as motivation and goals (Hughes, & Zaki, 2015). In a similar vein, an increasing number of studies have focused on the importance of motivation in sharing another's emotions, which often feels automatic. The current study will present yet another opportunity to expand empirical knowledge on motivated cognition in general, and motivated empathy in particular.

Second, I advance the literature on motivated empathy by examining potential sex differences for the first time. Christov-Moore and colleagues (2014) stated that revealing sex-related effects in empathy may be a process of identifying the nature of empathy, such as its origin and evolutionary history. Understanding this nature can ultimately provide clues for solving problems, associated with empathic failures, which are emerging as global issues in this era. The literature, as such, has been littered with calls for more research on sex differences in empathy (e.g., Christov-Moore et al., 2014). The current study aims to serve as one attempt to respond to

these calls. Its findings are expected to contribute important insights to inform and develop potential treatments for empathy disorders (e.g., psychopathy, autism), which are more prevalent among men than women (Baron-Cohen, 2002).

Third, I advance the literature on motivated empathy by approaching the phenomenon at a neurobiological level using electroencephalogram (EEG) for the first time. Empathy is a social virtue—members of society tend to practice it and have been observed to artificially increase it under experimental conditions. Such a tendency has been frequently observed in behavioral research where artificial manipulation of reactions is possible (Klein, & Hodges, 2001). Measurements of sensitive constructs such as empathy, therefore, may be more accurate when the scale taps into implicit cognitions or brain responses (Koopman, Howe, Johnson, Tan, & Chang, 2013). The current study adopts a neurological approach to measure empathic reactions while minimizing social desirability responses of the study subject.

Thus far, only a handful of studies have explored the role of motivation in empathy by measuring brain reactions (e.g., Arbuckle, & Shane, 2016; Jimenez, Abdelgabar, Angelis, McKay, Keysers, & Gazzola., 2020; Meffert, Gazzola, Boer, Bartels, & Keysers 2013; Shane, & Groat, 2018). The extant literature is further limited in that i) all of the previous studies examined the phenomenon of interest through functional magnetic

resonance imaging (fMRI) only, and ii) potential sex-related effects were never explored. By conducting an EEG experiment, the present study aims to provide a line of converging evidence for the importance of motivation in empathy while, for the first time, shedding light on the sex differences in the phenomenon.

In the next chapter, I first review the general phenomenon of empathy with a focus on its neurobiological basis. Next, I examine the theories of empathy and how they have changed over time—early theories are discussed first, stressing its automatic nature, which will be followed by recent ones emphasizing motivation. I then discuss a possibility of sex-related effects in motivated empathy and provide the rationale for such a study. Lastly, I describe the methodology employed in the study as well as the overview of this project, which clarifies the research questions and hypotheses.

2. Literature Review

2.1. The Nature of Empathy

2.1.1. Empathy and Its Neurobiological Basis

Empathy refers to a cognitive phenomenon of sharing and vicariously experiencing others' affective states (Decety, & Lamm, 2006). With the rapid advances in neuroscientific technology in the 1990s, scholars' interest to unveil the mystery of the neural basis of empathy has skyrocketed. From the neurological perspective, empathy occurs when the brain regions

involved in a specific emotion are vicariously activated in an observer, who witnesses others' emotional experiences (Decety, 2011). For instance, experiencing pain first-hand and sharing the noxious painful experience of another often activate the same regions in the bilateral anterior insula (AI), left anterior cingulate cortex (ACC) as well as the somatosensory, frontal and parietal areas (Legrain, Iannetti, Plaghki, & Mouraux, 2011). Likewise, feeling disgust oneself and sharing the unpleasant experience by observing disgusted faces often activate the same regions in the anterior cingulate cortex and the anterior insula (Wicker, Keysers, Plailly, Royet, Gallese, & Rizzolatti, 2003). In short, through the neuroscientific lens, empathy is understood as neural simulation or resonance that occurs in the observer during an emotional encounter.

It has been reported that in some cases, the vicarious emotional experiences in the observer are triggered by vicarious activations of motor regions, specific to that given emotion (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Jabbi, & Keysers, 2008). To further elaborate on this neural circuit, an understanding of the critical features of the central motor regions should be preceded.

The central motor regions are believed to be an integral part of the mirror neuron system ^①(Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). A mirror neuron is a nerve cell that fires not only when an animal performs an act him/herself but also when he/she observes the same act performed by another (Rizzolatti, & Craighero, 2004). Hence, the neuron mirrors the action of another, as if the observer were him/herself acting. As such, in the brain of a person witnessing another's emotional experience (e.g., sadness), behavior associated with that emotion (e.g., a sad facial expression) could be emulated first through the mirror neurons in the observer. This vicarious activation of emotional behavior (e.g., a sad facial expression) could then be mapped onto a specific emotion corresponding to that behavior (e.g., sadness) (Carr et al., 2003; Jabbi et al., 2008).

Indeed, it has been shown in fMRI research that the two brain regions, associated with behavioral and emotional simulation respectively are functionally and causally linked through the anterior insular (AI) (Carr

^① A mirror neuron is a nerve cell that fires not only when an animal conducts an act, but also when he/she observes the same act conducted by others (Rizzolatti, & Craighero, 2004). Mirror neurons were first discovered in the macaque monkey through invasive single-cell recordings (Rizzolatti et al., 1996). There have been numerous attempts to identify the human homologues of mirror neurons using noninvasive brain imaging methods including fMRI. Meta-analyses of fMRI studies showed that the identified regions—the ventral premotor cortex, the inferior parietal lobe, and the inferior frontal gyrus—exhibit mirroring properties, entertaining the possibility of a mirror neuron system—as opposed to mirror neurons—in humans. Interestingly, the mirror system in humans is activated not only during an observation of bodily movements but also of movements involving mouths and faces (i.e., emotional facial expressions). Furthermore, the human mirror system becomes active through multiple sensory channels, including auditory and tactile domains (Christov-Moore et al., 2014). Accordingly, a burgeoning number of studies on the human mirror system are focusing on its functional significance for complex social and communicative abilities. For example, it has been claimed that the involvement of a perception-action model extends beyond the motor domain onto higher-cognitive function, namely empathy (Carr et al., 2003). While it is still controversial whether the mirror system serves as the neural basis of empathy, it is generally accepted that empathy has its evolutionarily roots in experience sharing/behavioral mimicry demonstrated by non-human primates (Zaki, 2014).

et al., 2003; Jabbi et al., 2008). While this motor involvement/mediation may not be a prerequisite for giving rise to empathy (Decety, 2011), such a neural mechanism appears to make one reasonable and intuitive route, considering that important signals for the initial detection of others' emotions are often behavioral (e.g., facial expression, bodily movement) (Jabbi et al., 2008).

2.1.2. Pain Empathy and Its Neurobiological Basis

Thus far, a considerable number of attempts to identify the neural basis of empathy have focused on the emotion of pain, given that there is extensive knowledge on the neural basis of first-hand experience of pain (compared to other emotions).

Neural networks implicated in pain (i.e., also known as the pain matrix) include insular and cingulate areas, as well as somatosensory, frontal and parietal areas (Legrain et al., 2011). These regions are anatomically connected, while subserving different aspects of pain (Decety, 2011). Specifically, the affective-motivational components of pain (i.e., the subjective unpleasantness or discomfort) are represented in the limbic system (e.g., anterior cingulate cortex (ACC) and anterior insula (AI)), while the sensory-discriminative dimensions of pain (i.e., the bodily location, intensity and duration of the aversive stimulus) are represented in the primary (S1) and secondary (S2) sensory cortices (Decety, 2011). It has been repeatedly documented that the pain matrix (in part or in its entirety)

can be vicariously instigated in the observer at a mere perception of pain (i.e., in the absence of first-hand experience) (Akitsuki, & Decety, 2009; Botvinick, Jha, Bylsma, Fabian, Solomon, & Prkachin et al., 2005; Cheng et al., 2008; Decety, & Michalska, 2010; Decety, Michalska, & Akitsuki., 2008; Jackson, Rainville, & Decety, 2005). Accordingly, measurements of limbic as well as somatosensory activation in the observer have served as reliable indices of pain empathy in numerous neuroscience studies using fMRI (Lamm, Batson, & Decety, 2007), EEG (Bufalari, Aprile, Avenanti, Di Russo, & Aglioti, 2007; Hoenen, Lübke, & Pause., 2015; Yang et al., 2009), and magnetoencephalography (MEG) (Cheng, Yang, Lin, Lee, & Decety, 2008).

In keeping with many prior studies in the literature, I adopt ‘pain’ in the current study as the focal emotion in examining empathy. Accordingly, a review of the relevant literature for the remainder of the study will be focused on, but not limited to pain. Specifically, I will discuss theories of empathy in generic terms, as the theories may be applied indiscriminately to a variety of emotions, regardless of the specific type. For a discussion of empirical evidence, however, I will primarily present research which focuses on pain. Such an organization is part of an effort to make the hypotheses of the current work firmly grounded in both theories and empirical evidence.

2.2. Theories of Empathy

2.2.1. Automaticity as a Theme in Empathy Literature

Empathy refers to the cognitive process that enables a person to vicariously feel the emotions of another. It has thus far been regarded largely as an automatic phenomenon, awareness in academia and popular belief notwithstanding (Zaki, 2014). In other words, it has long been considered that people cannot control their empathic experience, because this “so-called” temperament or ability (e.g., the empathy quotient (EQ), Baron-Cohen, & Wheelwright, 2004) is as natural as a simple reflex. The beginning of this line of thinking can be traced back to Adam Smith’s philosophical description of *fellow feeling* in the late 18th century. Smith stated that “when we see a stroke aimed and just ready to fall on the leg or arm of another person, we *naturally* retract our own leg or arm” (Smith, 1790/2002, p. 4; emphasis added). Over the course of the next two centuries, this idea has been consolidated by scholars such as Robert Vischer (1873) and Theodor Lipps (1903). They coined and developed the term *Einfühlung*, which was later translated to empathy by Titchener (1909). *Einfühlung* refers to the phenomenon in which a person is immersed in arts or others’ affective states. Vischer described *Einfühlung* as an “*unconscious* displacement of one’s bodily form—and thereby also of the soul—into the form” of art objects (Vischer, 1873, p. vii; emphasis added). Lipps, likewise, described *Einfühlung* as follows: “Observers share and comprehend targets’

affective states, *immediately and simultaneously*, with perception” (Lipps, 1903, p. 713; emphasis added)

Such a view is still strong and prominent in academia. Contemporary researchers believe that the developmental precursors of empathy can be found in early infancy (Alexander, & Wilcox, 2012), while the evolutionary precursors can be found in other social animals (Preston, & De Waal, 2002) both in the form of behavioral mimicry. Thus far, an impressive number of documents in various academic fields have provided evidence of automaticity of empathy and its developmental/evolutionary precursors. For example, developmental psychologists have emphasized the *innateness* of facial mimicry in infants, which refers to the newborn’s behavior of mimicking the mother’s facial expressions (Figure 1(A)) (e.g., Bernieri, Reznick, & Rosenthal, 1988). In the fields of evolutionary psychology and animal ecology, researchers have stressed empathy’s *primitiveness* through examples such as contagious yawning in apes (Figure 1(B)) (e.g., Palagi, Leone, Mancini, & Ferrari, 2009). Moreover, several brain and cognitive science studies have reported the existence of mirror neurons, which get *reflexively* activated in a person when he/she senses the motion of another (e.g., Iacoboni, Molnar-Szakacs, Gallese, Buccino, Mazziotta, & Rizzolatti, 2005; Rizzolatti, Fadiga, Matelli, Bettinardi, Paulesu, Perani, & Fazio, 1996). Taken together, empathy has been regarded as a process that is difficult to be adjusted through the intervention of

higher-level cognition; accordingly, its subconscious, automatic, and universal properties, regardless of the situation, have been highlighted. It has also been suggested that empathy has acquired its primitive properties because someone with empathy has an evolutionary advantage for managing his/her social life. With this perspective dominating academia, researchers have shown little interest in investigating the possibility of voluntary control of empathy (Zaki, 2014).

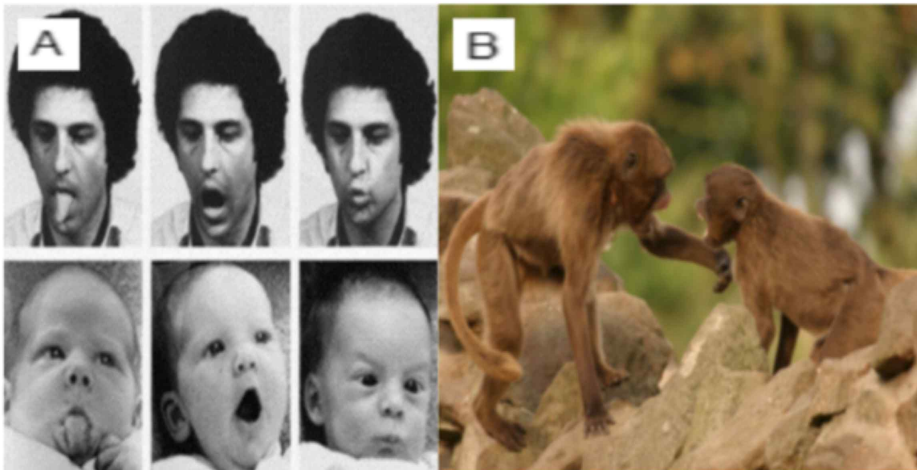


Figure 1. An example of facial mimicry in infants (A) (Meltzoff, & Moore, 1989) and juvenile gelada baboons (B) (Christov-Moore et al., 2014).

However, the importance of the observer's choice and motivation should not be underestimated in empathic experience. That is, there exist times when someone otherwise completely empathetic does not automatically share others' emotions. For example, athletes are unlikely to

share their injured opponents' pain—in fact, they may feel joy in such situations as they would likely relate such injuries to a win or loss. Likewise, a doctor might not feel a severely injured patient's pain, although his/her pain empathy is likely to be intact outside the surgical room. For both athletes and doctors, it is this temporary sense of disconnection on duty that helps them to perform their job more effectively.

The present study aims to advance knowledge on this context-dependency of empathy. Across many academic domains in recent years, research has increasingly converged on the idea that even a process traditionally regarded as the most fundamental (e.g., low-level perception for objective information gathering) can be shaped, biased and distorted by aspects of higher-level cognition, such as motivation and goals (Hughes, & Zaki, 2015). In a similar vein, evidence is emerging, which acknowledges the role of top-down influences in sharing others' emotion. In the next chapter, I specifically discuss this novel lens of motivation through which to examine empathy.

2.2.2. Motivation as a Theme in Empathy Literature

Recently, there have been long overdue attempts in academia to frame empathy as a phenomenon, modulated by motivation (e.g., Groat, & Shane, 2019; Zaki, 2014). Zaki's motivated account of empathy (2014), among others, has garnered a lion's share of academic attention. According to this theory, empathy is often motivational and highly context-dependent.

People use various strategies to adjust empathy according to their situational needs, and such motivation affecting empathy ultimately varies depending on evolutionary goals such as survival and reproduction. For example, people are motivated to boost empathy for their children to the maximum possible extent, and to suppress it when it comes to their enemies because empathy for enemies can result in unwanted physical and psychological cost.

Zaki also presented specific strategies, frequently used in modulating empathy and classified them into three broad categories. For the convenience of explanation, the discussion here will be limited to a situation in which individuals are motivated to *reduce* empathy. The first strategy to reduce empathy is to physically avoid a situation that might induce empathy *per se* (i.e., physical avoidance). For example, upon detecting a beggar far ahead, a person may physically avoid the potentially empathy-evoking situation by choosing to take a different path and prevent empathy altogether. The second strategy is to psychologically divert attention from another's emotions (i.e., cognitive avoidance). For example, the U.S. soldiers at the Abu Ghraib prison could probably avoid empathy in the face of the ruthless insults by denying the fact that the Iraqi prisoners could experience complex, uniquely human emotions such as humiliation and shame. The third strategy is to reappraise the emotions experienced by another (i.e., reappraisal). That is, by having a reappraisal that the degree of emotions expressed by the target is an exaggeration of what he/she is

actually experiencing on the inside, it is possible for people to reduce empathy.

Since the publication of Zaki's work, several attempts have been made to find empirical support for the motivated model of empathy. When corroborating psychological theories in the empathy literature, it is important to do so at the neurological level because of the social-desirability bias. That is, responses may be driven by how empathic people would like to *appear*, as opposed to how empathic they really *are* (Klein, & Hodges, 2001). Such a bias is more commonly observed i) in behavioral studies where artificial manipulation of reactions is possible, and ii) among women given that empathy is largely associated with stereotypical feminine roles (Klein, & Hodges, 2001).

In keeping with the best practice recommendations, a few groups of neuroscientists have recently employed fMRI to directly examine the idea of voluntary control (i.e., motivated component) of empathy. For example, Jimenez and colleagues (2020) asked healthy subjects to watch movie clips in which various emotions were expressed while making active efforts to modulate empathy. The results showed that the direct instructions to up-regulate empathy boosted brain activity in the limbic (including putamen and cingulate) and sensorimotor regions (including premotor, primary/secondary somatosensory, and inferior parietal cortices).

Two other groups of neuroscientists (Arbuckle, & Shane, 2016;

Shane, & Groat, 2018) have tested antisocial offenders. Both groups of these researchers found that actively trying to empathize with the painful experience of another boosted vicarious activations in the offenders in the brain regions associated with pain processing including ACC, AI, as well as S1 and S2. These studies provided critical neural evidence that reduced empathy is at least partially attributable to a lack of motivation, as opposed to a lack of inherent ability. That is, even pathologically reduced empathy could be up-regulated, given sufficient motivation.

While experimental evidence in neuroscience has begun to support the motivated framework of empathy, the extant literature still has several limitations. First, the extant literature has, thus far, focused on the question of whether people could up-regulate empathy when making deliberate efforts. As such, it lacks in an understanding of down-regulation of empathy, although there exist various situations in everyday life where empathy must be effectively suppressed. To fill in this gap, the present study adopts a modified version of standard emotion-regulation paradigm^② (Ochsner, Silvers, & Buhle., 2012) where healthy subjects are tested for their capacity to both up- and down- regulate pain empathy.

Another limitation of the extant literature concerns the methodology

^② In the emotion regulation paradigm, subjects are asked to regulate (i.e., increase or decrease) their upcoming emotional response toward emotionally charged (i.e., positive or negative) pictures with the help of different emotion regulation strategies (e.g., distancing or reinterpreting). (Ochsner et al., 2012)

All of the aforementioned studies (i.e., Arbuckle, & Shane, 2016; Jimenez et al., 2020; Shane, & Groat, 2018) approached motivated empathy through fMRI only. In keeping with the principle of converging evidence in science, the present study examines the phenomenon through another neuroscientific approach, namely EEG. The present study is expected to contribute another line of neural evidence to the burgeoning literature on motivated empathy.

Finally, the extant literature is limited in that potential sex-related effects in the phenomenon have never been explored. Thus far, only male participants (for both general (Jimenez et al., 2020) and clinical (Arbuckle, & Shane, 2016; Shane, & Groat, 2018) populations) have been examined. Empathy, however, is sex-biased by nature (Babchuk et al., 1985). This necessitates research that examines how the role of motivation may vary in empathic experience for the two sexes. Drawing upon the Primary Caretaker Hypothesis, I specifically predict that the degree to which people have voluntary control over empathy may depend on biological sex.

2.2.3. Sex-Related Effects in Motivated Empathy

Primary Caretaker Hypothesis posits that empathy may have evolved from offspring care, a task which was predominantly undertaken by female primates in the old days (Babchuk et al., 1985). Empathy was likely a critical cognitive function for female primates, who have historically been responsible for child rearing. In this sense, empathic mothers might have had higher reproductive success compared to emotionally detached ones,

given their sensitivity to the needs of offspring. In contrast, empathy could have been rather detrimental at times for male primates, who were primarily involved in hunting.

To experience empathy to their benefit, men and women would have been evolutionarily equipped with different biological and psychological mechanisms. One experimental study supporting such a notion (Hall, Hutton, & Morgan, 2010) examined the face processing of men and women through eye-tracking experiments, where attention to the eyes was measured during a facial expression recognition task. The results showed that women, compared with men, looked more at the eyes of the target, and were more accurate and faster in their facial expression recognition. The frequent processing of the eye may be an evolutionarily-acquired mechanism to boost empathic experiences in women. On the other hand, the relative lack of processing of the eye in men may allow them to maintain an adequate distance from another's emotions. Under circumstances in which empathetic motives become salient, however, men may use a number of empathic strategies to boost their empathy (e.g., by processing the eye area more frequently).

Another study (Brehm et al., 1984) supporting the notion that men and women may be equipped with different mechanisms associated with empathy tested early adolescents. The authors showed that male children (6- to 7-year-old) donated higher rates of resources to those in need when asked

to imagine themselves in the target's situation, whereas female children were equally empathic whether instructed to do so or not. These results imply that women from early ages tend to "put themselves in the other person's shoes" and this projection of oneself into another may be one of their inherent tactics to boost empathy. In other words, women may have evolved to possess certain strategies/tactics for their pervasive and universal experience of empathy. Taken together, empathy in females may be more automatic, reflexive, and universal, regardless of their motivation, as an evolutionarily selected response. For men, on the other hand, empathy may function as a more controllable and context-dependent response (Brehm et al., 1984; Christov-Moore et al., 2014).

A body of research in neuroscience lends indirect support to this possibility. In one such study (Singer et al., 2006), male and female participants were engaged in an economic game, where two confederates played along either fairly or unfairly. Afterwards, brain activity was recorded with fMRI while these same participants viewed their partners (confederates) inflicted with pain. The results showed that women exhibited similar levels of empathy, regardless of their partners' cooperativeness, as indicated by hemodynamic activity in regions associated with pain processing. Empathy in men, in contrast, decreased significantly when observing non-cooperative confederates in pain compared to the cooperative counterparts.

In another study (Yang et al., 2009), male and female participants viewed pictures depicting painful and non-painful situations, while their brain activity was monitored with EEG. The results indicated that men, but not women, showed a significant decrease in somatosensory cortical activation while viewing non-painful pictures, compared to painful ones.

Similar patterns have been observed in animals (Langford, 2006). Langford (2006) tested male and female rodents in a study where the rodents demonstrated increased writhing while observing familiar others inflicted with pain. However, when paired with an unfamiliar conspecific in pain, only males showed a significant decrease in their writhing, demonstrating greater context-dependency.

This empathic flexibility in males has been further supported by several lines of research conducted with clinical populations. For example, studies have documented that there is a negative association between empathic control and depression (Thoma, Zalewski, von Reventlow, Norra, Juckel, & Daum, 2011), a disorder more prevalent in women than men (Weissman, 1996). On the contrary, it has been shown that psychopathy and autism, disorders known to be associated with a lack of empathy (Gillespie, McCleery, & Oberman, 2014; Senju, Kikuchi, Akechi, Hasegawa, Tojo, & Osanai, 2009), are more prevalent in men than women (Baron-Cohen, Knickmeyer, & Belmonte, 2005; Cale, & Lilienfeld, 2002).

Taken together, the extant literature indirectly but consistently lands

support to the possibility that there is a greater likelihood of aspects of higher cognition such as motivation being involved in male empathy. In many societies, men are socialized to control their external expressions of emotion (Eisenberg, Schaller, Fabes, & Bustamante, 1988). Considering the extensive evidence across many academic fields reviewed thus far, I predict that *men might also better control their internal experience of empathy itself*.

To our knowledge, however, no controlled experiments to directly test such a hypothesis have been conducted yet. In fact, calls have been raised in the literature to fill in this missing piece of the empathy puzzle (e.g., Christov-Moore et al., 2014). In response to these calls, the present study engages male and female volunteers in an active empathy-modulation paradigm—a modified version of a standard emotion-regulation paradigm (Ochsner, Silvers, & Buhle., 2012)—while measuring their real-time brain activity associated with pain processing through EEG.

2.3. Research Objectives and Hypotheses

In the present study,

1. I aim to contribute to the literature on motivated empathy by examining people's capacity for both up- and down-regulation of empathy.
2. I aim to contribute to the literature on motivated empathy by examining the phenomenon with EEG for the first time.
3. I aim to contribute to the literature on motivated empathy by

examining sex-related effects in the phenomenon for the first time.

In line with theory and prior research, I hypothesize that men will demonstrate more empathic control than women, indicated by the brain activities measured through EEG. In other words, men will be more successful in their attempts to “turn up” or “turn down” their neural activity associated with pain, based on their motives to empathize with the target or to remain detached. For women, the pain-related neural activity is expected to be more consistent regardless of motivation. Therefore, the difference in the degree of female empathy between the situations in which they are motivated to enhance or reduce empathy will be smaller than that of men.

3. Methodology

3.1. Electroencephalogram (EEG)

Electroencephalogram (EEG) is a neurophysiological method, which measures real-time electrical activity in the brain (Luck, 2014). When information is processed in the human brain, an electrical current is generated through the workings of synapses between neurons, the fundamental units of the nervous system. An electrical current in a single synapse is very tiny. However, when synapses between a multitude of cells are at work, the electrical current generated in all the synapses is summated, increasing the voltage, and is sent up to the skull. The electrical current delivered to the skull flows to the scalp and can be measured by placing electrodes on the surface of the scalp. Based on the electrical waves

measured this way, brain functions can be identified on the basis of the level of neural activity. In short, EEG is used to investigate cognitive processes by measuring the electrical current generated through the workings of neuronal synapses while information is being processed in the brain (Luck, 2014).

EEG is non-invasive, highly accessible and inexpensive. Additionally, the temporal resolution of the EEG is in milliseconds, and thus it can assess the immediate responses in the brain that are constantly changing in the presence of a stimulus (Luck, 2014). This feature distinguishes EEG from fMRI, which has an excellent spatial resolution but a poor temporal resolution.

The present study is the first attempt to examine sex differences in the voluntary modulation of empathy using EEG. By utilizing the features of EEG, the study will provide the first-ever opportunity to present temporal trends in the voluntary modulation of empathy.

3.2. Time-Frequency Analysis

Time-Frequency Analysis (TF analysis) is an analytical method, used to interpret the brain waves collected through EEG. TF analysis is based on the following principle regarding the brain waves: Brain waves recorded through EEG can be expressed in the summation of sine waves of various frequencies, which reflect the activation of various neuronal regions (Cohen, 2014). Frequency ranges, commonly analyzed in the TF analysis

include the delta waves (<4 Hz), theta waves (4-8 Hz), alpha waves (8-13 Hz), beta waves (13-30 Hz), and gamma waves (>30 Hz) (Basar, Schürmann, Demiralp, Başar-Eroglu, & Ademoglu 2001). Different levels of amplitude/power in the brain waves in each frequency band over time are indicative of the degree of activation of a specific brain region (and a specific cognitive function associated with it) and real-time changes in it (Cohen, 2014). Given these features of TF analysis, neural activities in a specific frequency band corresponding to the purpose of the investigator can be extracted.

Specifically, TF analysis is performed in the following procedure. First, the researcher presents a particular stimulus while simultaneously recording brainwaves in the study participants using EEG. After pre-processing such as filtering, the brainwave data are segmented into specific time intervals, based on the timing of stimulus onset. Subsequently, a technique such as the short-time Fourier transformation or the wavelet transformation is applied, through which decomposed signals are displayed in spectrograms to reveal how the amplitude in each frequency band changes over time. Then, the spectrograms are averaged across all the trials, and the power values for a frequency band of interest are extracted for statistical analyses.

3.3. Mu Rhythm

In the present attempt, I focus on the mu rhythm as the

methodological index. Mu rhythm refers to the cortical oscillations in the frequency range of 8-13 Hz and shares the same frequency band with the alpha rhythm (Niedermeyer, & Lopes, 2005). The mu rhythm is differentiated from the alpha rhythm with respect to its source of origin; it is generated in the sensorimotor cortex (Niedermeyer, & Lopes, 2005). A change in its amplitude can, therefore, be used as an index of the activity of the sensorimotor cortex. Specifically, its power increases during sensorimotor “idling” or physical rest (Pfurtscheller et al., 1996), while sensorimotor activity (i.e., movement or touch) desynchronizes the firing of the region, reducing the mu power (i.e., mu suppression) (Muthukumaraswamy, & Johnson 2004). The mu rhythm is also indicative of *vicarious* sensorimotor activity because it is suppressed in response to *observed* movements (Babiloni, Babiloni, Carducci, Cincotti, Coccozza, Percio, & Rossini, 2002; Muthukumaraswamy et al., 2004; Pineda, 2005) or *observed* touch (Yang et al., 2009; Hoenen et al., 2015) (Figure 2).

More recently, the mu rhythm has been utilized as an index of pain empathy. As described in Chapter 2.1.1, empathy, from the neurological perspective, refers to the vicarious neural activation (i.e., neural resonance) that occurs in response to a target’s emotional experiences. In the case of pain empathy, both the affective-motivational components (i.e., the subjective unpleasantness or discomfort) and the sensory-discriminative dimensions (i.e., the intensity, duration, and bodily location of the noxious

stimulus) can be emulated in the observer (Akitsuki, & Decety, 2009; Botvinick et al., 2005; Cheng et al., 2008; Decety, & Michalska, 2010; Decety et al., 2008; Jackson et al., 2005). Accordingly, the degree of pain empathy can be assessed by measuring the mu rhythm in the observer, which is indicative of the level of activation in the somatosensory regions. Numerous studies have previously used the mu rhythm as a reliable index of empathy for pain (e.g., Cheng et al., 2010; Hoenen et al., 2015; Yang et al., 2009). The present study focuses on the mu rhythm to evaluate the extent to which study participants project themselves into a painful situation experienced by another. The mu rhythm can be observed from the Cz, C3 and C4 electrodes in the international 10–20 system (Hoenen et al., 2015).

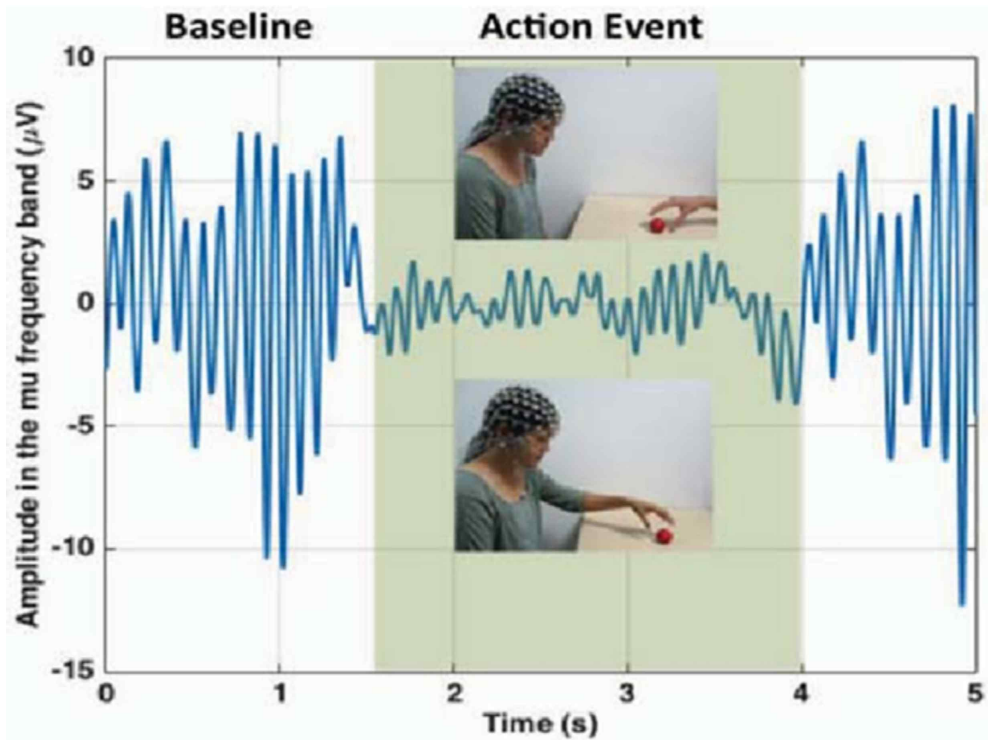


Figure 2. Simulation of mu suppression in the 8-13-Hz frequency band. During action observation as well as execution, there is a reduction in amplitude of the mu rhythm relative to the baseline. The action event is highlighted in green in the middle of the timeline (Fox, Bakermans-Kranenburg, Yoo, Bowman, Cannon, Vanderwert, Ferrari, & van IJzendoorn, 2016)

3.4. Alpha Rhythm

One thing of import regarding the mu rhythm is that it could easily be confounded with the alpha rhythm, characterized by the same 8-13 Hz range, but detected over the visual cortex in the posterior occipital lobe (Klimesch, 1999; Pfurtscheller, 1992). The alpha rhythm is indicative of the level of activation of the visual cortex. Specifically, its power decreases (i.e.,

alpha suppression) while visual information is actively being processed, whereas its power markedly increases if the eyes are closed and therefore visual information is blocked (Pfurtscheller, 1992). In addition to visual processing, the alpha rhythm is also suppressed when a person is engaged in solving a mathematical problem or performing a task that requires focused attention (Klimesch, 1999, Klimesch et al., 2012). Hence, alpha suppression has also been utilized as an index of attentional engagement (Fox et al., 2016). Because of the frequency overlap, alpha waves could become a confounding variable in the mu rhythm research. To preclude this possibility, studies using the mu rhythm typically measure and analyze the alpha rhythm as well (e.g., Hoenen et al., 2015). Furthermore, it has recently been suggested that mu suppression experiments should implement designs that tightly control for attentional engagement (Hobson, & Bishop, 2016). In keeping with these recommendations, the present study also measures the alpha rhythm, which can be recorded over the Oz, O1 and O2 electrodes in the international 10–20 system (Hoenen et al., 2015).

3.5. Overview of Studies

The present study, by employing EEG, aims to clarify whether biological sex predicts the degree to which people have regulatory control over pain empathy in an active empathy regulation paradigm. In line with theory and prior research, I predict that while both men and women will be capable of regulating pain empathy to some degree, men will demonstrate

more efficiency in empathic control. Specifically, I predict that men will be more successful at their attempts to “turn up” or “turn down” their vicarious somatosensory activation (indicated by mu suppression), based on their motives to empathize with the target or remain detached. In other words, for women, the difference in the level of mu suppression between the conditions in which they are motivated to up- or down-regulate empathy will be smaller than that of men.

4. Experiment

4.1. Participants

Originally, 25 undergraduate/graduate students from Seoul National University were recruited for the study via a participant-recruiting website. One group of the original sample consisted of 10 females (*M* age 21.4, *SD* 3.3), while the other group, matched for age, educational level, and handedness, consisted of 15 males (*M* age 23.6, *SD* 2.4). All subjects confirmed that they were free of any neurological or psychiatric medications. They also reported having no visual/hearing impairments or trypanophobia (i.e., needle phobia; as the painful stimuli used in the study contained images of needles and knives). Participants were monetarily compensated for their participation. Prior to data analysis, one man was excluded due to excessive artifacts, leading to an insufficient amount of clean EEG data. The final sample, therefore, was composed of 14 male and 10 female university students.

4.2. General Procedures

Prior to the experiment, participants were sent an online personality questionnaire with psychometrically validated measures to complete. They were a series of self-report measures of empathic tendency (i.e., the emotional contagion scale (ECS; Doherty, 1997), the empathizing quotient (EQ; Wakabayashi et al., 2006), and the interpersonal reactivity index (IRI; Davis, 1980, only the subscales for perspective-taking and empathic concern were included)). Participants also completed the pain sensitivity questionnaire (PSQ; Sullivan, & Bishop, 1995) as a psychologically relevant control variable. That is, PSQ was completed to tear out the amount of variance in mu suppression that might be driven by pain sensitivity.

On the day participants signed up for, they attended an offline session on campus. They were informed about the nature of the study, assured of confidentiality, and secured their informed consent. Seated inside an acoustically and electromagnetically shielded room, participants performed an empathy-regulation task, while their brain activity was simultaneously recorded through EEG. In this empathy-regulation task, they were presented with images depicting people in various painful situations. In three different blocks, they were either instructed i) to respond naturally, ii) to boost or iii) to reduce their empathic reaction for the target in the painful pictures. Specifically, in the "INCREASE" block, participants were instructed to maximize their empathic feelings towards the target's pain. In

the "DECREASE" block, they were instructed to minimize their empathic feelings towards the target's pain. In the "WATCH" block, these same participants were instructed to view the target in pain naturally as if they were watching their daily cartoons. The "WATCH" block was designed to measure the participants' baseline empathy level for the target's pain.

Importantly, the male and female participants were not provided with any specific strategies or tactics (as described in Chapter 2.2.2) as to *how* they should up- or down-regulate their empathic reaction. The present study was intended to serve as an initial foray to investigate whether men have more voluntary control over pain empathy than women *per se* (i.e., in any manner whatsoever). Depending on the results of the current study, subsequent work may further explore specific strategies and/or tactics employed by the two sexes for their empathic control.

Each block began with an instruction describing the task ahead. Then a fixation cross appeared in the middle of the screen for 4000 ms. For the next 4000 ms, a picture (out of a total of 36 in each block) depicting a person's hand or foot in a painful situation was presented. Following an intertrial interval (i.e., a black screen of 500 ms, 1000 ms, or 1500 ms), the next trial began (Figure 3). The order of the three blocks was randomized among the participants. The task, therefore, included three different blocks of trial types/conditions (i.e., WATCH, INCREASE, and DECREASE) for both male and female participants. After each block, the word "break"

appeared, allowing participants some time to move their eyes and take rest. When the participants were ready to resume the experiment, they pressed the spacebar to proceed with the next block. Participants were asked to minimize blinking and bodily movement when performing the tasks except during breaks.

A confounding factor in the experiment (and therefore a factor that should be controlled for) was the degree to which participants paid attention to the task in each block. For example, in order to suppress empathy in the DECREASE block, a subject could simply divert attention from the painful pictures. If the degree of attentional engagement varies between conditions, mu suppression may be overshadowed by occipital alpha suppression (reflecting attentional engagement) and become difficult to interpret (Hobson, & Bishop, 2016). A question may arise with respect to the validity of interpretation of central mu suppressions.

To ensure that participants equally attended to the stimuli across blocks, I used a continuous performance task. Specifically, two photographs appeared after each block, and the participants were instructed to correctly identify whether they had seen the pictures or not in the preceding session. By informing the participants ahead about this continuous performance task, it was ensured that they pay an equal amount of attention to the task regardless of the experimental condition.

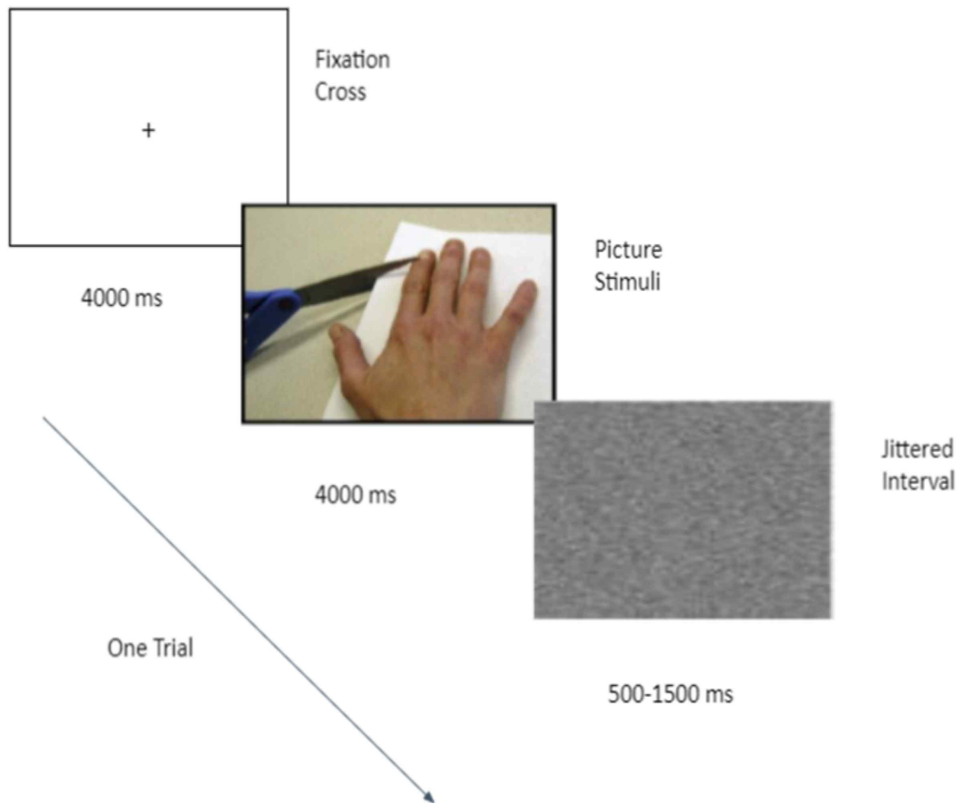


Figure 3. Sequence of events in one trial in the empathy modulation paradigm

4.3. Picture stimuli

Originally, a total of 120 digital color pictures depicting a right hand or foot in painful situations were prepared. 48 of them were taken from a previous study (Jackson et al., 2005) while the remaining 72 were newly shot for the current study. The painful pictures depicted commonly-occurring noxious events including mechanical, thermal and pressure pain. To validate the effectiveness of the painful pictures, pain intensity of the pictures was assessed by 34 undergraduate/graduate students (17 males)

from Seoul National University in a pilot study using a 7-point Likert scale (0 = no pain, 6 = unbearable pain). Pictures rated below 3 were eliminated, and a total of 108 pictures (*Mean* 4.03, *SD* 0.58) were selected as empathy-evoking stimuli. Examples of photographs used in the experiment are presented in Figure 5. The descriptive statistics of pain intensity for the final set of pictures are summarized in Table 1. There were no sex differences in the pain intensity ratings ($p = .82$).

The 108 pictures were randomly divided into three different sets. The average pain intensities of the three sets of the pictures were assessed and confirmed to have no significant differences ($p = .25$). The order of the three picture sets was counterbalanced.

Table 1. *The descriptive statistics (mean values and standard deviations) of pain intensity for the final set of pictures*

	Painful Pictures	$t(df=107)$	p
Men (n=17)	4.02(0.60)	68.966	< .001
Women (n=17)	4.04(0.66)	63.471	< .001
Total (n=34)	4.03(0.58)	72.702	< .001

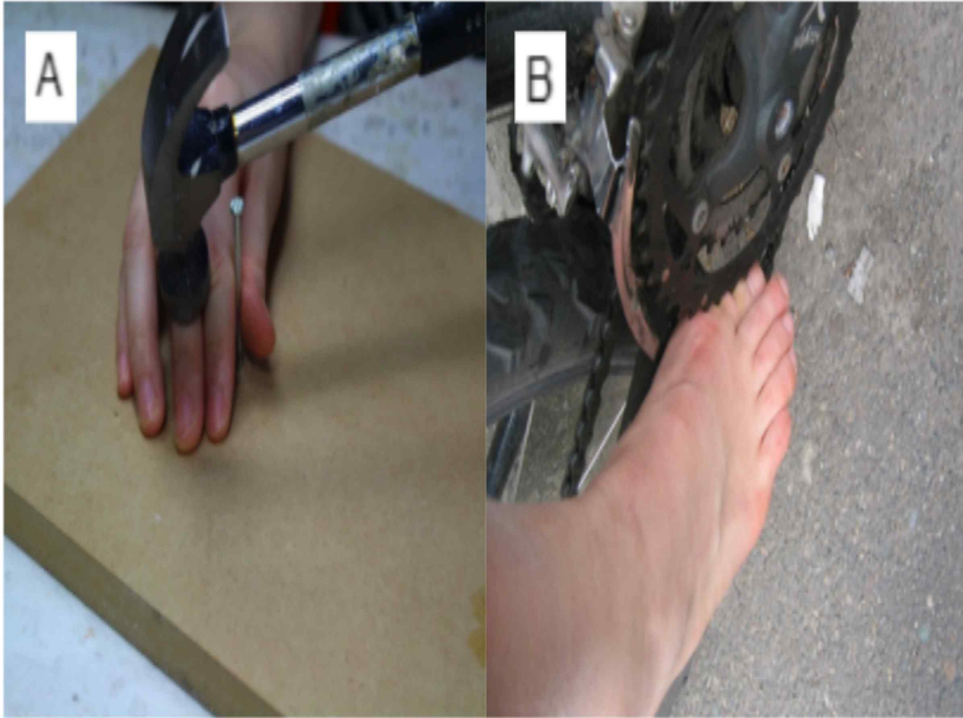


Figure 4. An example of painful pictures ((A) hand, (B) foot) used in the study. It describes the physical pain commonly encountered in everyday life.

4.4. EEG Data acquisition

EEG data were recorded from the 61 electrodes embedded in a whole-head elastic cap (the international 10–20 method of electrode placement, Brain Products GmbH, Germany). For bipolar vertical and horizontal electro-oculograms (EOG), additional disc electrodes were attached to the areas below the left eye and around the external canthi, respectively. The Cz was used as the reference electrode. After the placements of the cap, each electrode site was injected with electrolytic gel.

Then, the skin surface was slightly abraded to minimize the electrode-skin impedance. Before and after testing, it was ensured that the impedances on all electrode sites were less than 10 k Ω . EEG was amplified via actiCHamp (Brain Products GmbH, Germany), and recorded using a BrainVision Recorder (Brain Products GmbH, Germany). The data were recorded at a sampling rate of 500 Hz.

4.5. EEG Data Preprocessing and Time-Frequency Analysis

Prior to analyzing the EEG data, the number of correct answers was counted on the continuous performance task for each participant. All participants correctly identified the pictures which they had/had not seen in each block more than 88.89% of the time (i.e., 8 out of the 9 pictures). Furthermore, there were no significant differences in the number of correct answers across conditions (for men, $p = .34$, for women, $p = .32$) or sexes ($p = .68$). Data from all participants, as such, were included in the analysis.

Data preprocessing and main analysis were all conducted using the Brain Vision Analyzer 2.2 (Brain Products). EEG records were initially re-referenced to the average of the two mastoids, and a band-pass filter of 0.5~40 Hz was applied. Through an ICA procedure, eye blinks and movements were corrected semi-automatically (Jung et al., 2000). Upon completing the EOG correction, further analysis was conducted only with the data without eye blink/movement artifacts. In each experimental block, the data were segmented into epochs of 8000 ms. Each segment started at

the onset of the fixation cross (i.e., baseline data) and ended at the termination of the picture (i.e., experimental data). The segmented data were baseline-corrected to the mean value of the signal in the time window of -200-0 ms before the stimulus (picture) onset. Remaining artifacts exceeding $\pm 100 \mu\text{V}$ in amplitude within a 200-second window were identified on the relevant sites (i.e., C3, C4, Cz, O1, O2, Oz). Epochs containing these artifacts were removed. The EEG records of one man were excluded, as they contained excessive movement artifacts.

TF (time-frequency) analysis was performed for each segment via continuous complex Morlet wavelet transformation in the frequency range of 5-30 Hz in logarithmic steps of 1 Hz. The Morlet parameter was set to 5. The absolute power values were averaged across trials at each time-frequency point at each electrode site. Then the suppression indices were calculated for each data point of the time-frequency spectrum. Suppression indices in the present study were computed as the log-transformed ratios of the power during the experimental data relative to the power during the baseline (Cohen, 2014). Epochs starting 500 ms after the onset of the fixation cross (3500 ms) or the picture (3500 ms) were used for baseline and experimental data, respectively. The first 500 ms were removed to minimize the attention transients, caused by stimulus initiation and termination. I used the ratio, as opposed to simple subtraction, for the purpose of controlling potential variability in absolute EEG power between the subjects. This

individual variability is attributable to differences in electrode impedance and scalp thickness. For each of the three conditions for male and female participants, an average suppression value of the three electrodes was computed in the central region (i.e., Cz, C3, C4) to obtain a single mu suppression value (e.g., see Hoenen et al., 2015; Karakale et al., 2019 for similar procedures). The same procedure was done in the three occipital electrodes (i.e., Oz, O1, O2) to obtain a single alpha suppression value. Consequently, six suppression indices for INCREASE, DECREASE and WATCH at the central and occipital areas for each subject were obtained.

Ratio data, however, have a non-normal distribution due to lower bounding. As such, I used a log transform for further statistical analysis. A log ratio of smaller than zero reflects a decrease of the power, while a log ratio greater than zero reflects an increase of the power.

4.6. Statistical Analysis

I used R studio (R Studio Team., 2016) for all the statistical analyses. In the analyses, data from 24 participants were used. For both sexes, two brain regions (i.e., central, occipital) and three conditions (i.e., INCREASE, DECREASE, WATCH) were examined. Prior to testing the hypotheses, one-sided t tests against zero for each condition were conducted to make sure that suppression occurred during the experimental compared to the baseline segment (all p-values < .05, Bonferroni-corrected). Upon validating suppression for all the brain regions and conditions, a 2 x 3 x 2

mixed design ANOVA was performed to compare the suppression indices in 8–13 Hz across sex (men, women), empathy modulation (increase, decrease, watch), and brain region (central, occipital). In correcting the degrees of freedom, the Greenhouse-Geisser epsilon values (G-GE) were used whenever necessary.

5. Results

5.1. Behavioral Results

The between-group analysis revealed no significant sex differences for the scores in all of the behavioral measures of empathy (i.e., the empathizing quotient (EQ), the emotional contagion scale (ECS), and the interpersonal reactivity index (IRI)). Furthermore, there were no outliers or significant differences in pain sensitivity between the male and female participants, indicating that this individual-difference variable was effectively controlled across the two sexes. These results are summarized in Table 2.

Table 2. Behavioral measures of empathy (on a scale of 1-5) and pain sensitivity (on a scale of 1-10) in the male and female subgroups.

	MALES (n= 14)		FEMALES (n= 10)		BETWEEN-GROUP ANALYSIS	
	Mean	SD	Mean	SD	<i>t</i>	<i>p</i>
Empathizing Quotient (EQ)	2.89	0.40	3.22	0.36	1.67	0.11
Empathic Contagion Scale	3.53	0.35	3.70	0.35	1.19	0.25
Interpersonal reactivity index	3.12	0.24	3.25	0.14	1.83	0.08
Pain Sensitivity	4.15	1.77	4.26	1.33	0.19	0.85

5.2. EEG Results

The mix-design ANOVA results revealed that there was a significant three-way interaction effect between sex, condition, and brain region ($F(2,44) = 3.458, p = .047, \eta^2^{(3)} = 0.01$). The three-way interaction effects are depicted in Figure 5. As indicated in the figure, mu and alpha rhythms over the central and occipital regions showed significant different suppression patterns, warranting further investigation at each brain region.

³ a generalized eta squared, as reported in R

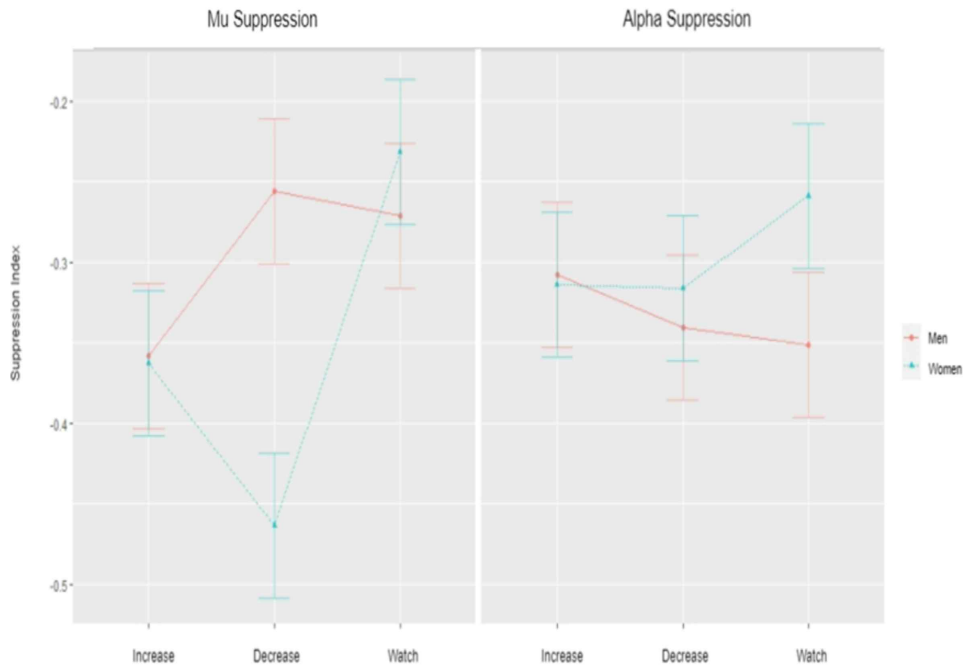


Figure 5. Mu suppression indices for the increase, decrease, and watch conditions for men (red) and women (blue) in central (left) and occipital (right) regions.

The two-way interaction term between sex and condition at the central regions was further probed in a two-way mixed-design ANOVA. Upon confirming its significance ($F(2,44) = 20.12, p < .001, \eta^2 = .10$), pairwise t-tests were conducted to investigate the effect of condition on mu suppression in men and women, separately (i.e., simple effect analysis). The Bonferroni correction was applied to adjust for the multiple comparisons. For men, there was significantly stronger mu suppression in <INCREASE> compared to <WATCH> ($p = .02$) and <DECREASE> ($p = .03$). However,

there was no significant difference in mu suppression between <DECREASE> and <WATCH> ($p = .55$). In the case of women, significantly stronger mu suppression was observed in <INCREASE> relative to <WATCH> ($p = .01$). More interesting was the finding that for women mu suppression in <DECREASE> was greater than that induced in <INCREASE> ($p = .01$) or <WATCH> ($p < .001$).

Taken together, while for men, the strongest mu suppression was elicited in the <INCREASE> condition as expected, for women, the pattern was reversed: contrary to the expectation, the strongest mu suppression was observed in the <DECREASE> condition.

The same analysis was conducted on the occipital regions. The suppression indices showed that the interaction term for sex and condition was not a significant predictor of alpha suppression ($F(2,44) = 1.15, p = .32, \eta^2 = .006$). Post hoc pairwise t-tests were performed, and the Bonferroni-corrected results indicated that none of the comparisons had significant effects (all $ps > .25$), strengthening the notion that the central effects examined through mu suppression indices were independent of a general attentional effect. These results are summarized in Table 3 and Table 4.

Table 3. *Suppression indices in the central regions and their pairwise comparisons*

	INCREASE	DECREASE	WATCH	INCREASE- DECREASE	INCREASE- WATCH	DECREASE- WATCH
	Mu Suppression Index			P value		
MEN	-0.36(0.21)	-0.27(0.12)	-0.26(0.14)	0.03*	0.02*	0.55
WOMEN	-0.36(0.19)	-0.46(0.16)	-0.23(0.14)	0.01*	0.01*	<0.001*

Table 4. *Suppression indices in the occipital regions and their pairwise comparisons*

	INCREASE	DECREASE	WATCH	INCREASE- DECREASE	INCREASE- WATCH	DECREASE- WATCH
	Alpha Suppression Index			P value		
MEN	-0.31(0.22)	-0.34(0.25)	-0.35(0.22)	0.96	0.27	0.95
WOMEN	-0.31(0.19)	-0.32(0.28)	-0.26(0.37)	0.97	0.70	0.96

Note. ‘*’ indicates statistical significance; All p-values were Bonferroni-corrected.

To visualize the temporal patterns of these effects in pain empathy, suppression indices were plotted in the time-frequency spectra for each condition at the central regions. Results are presented in Figure 6.

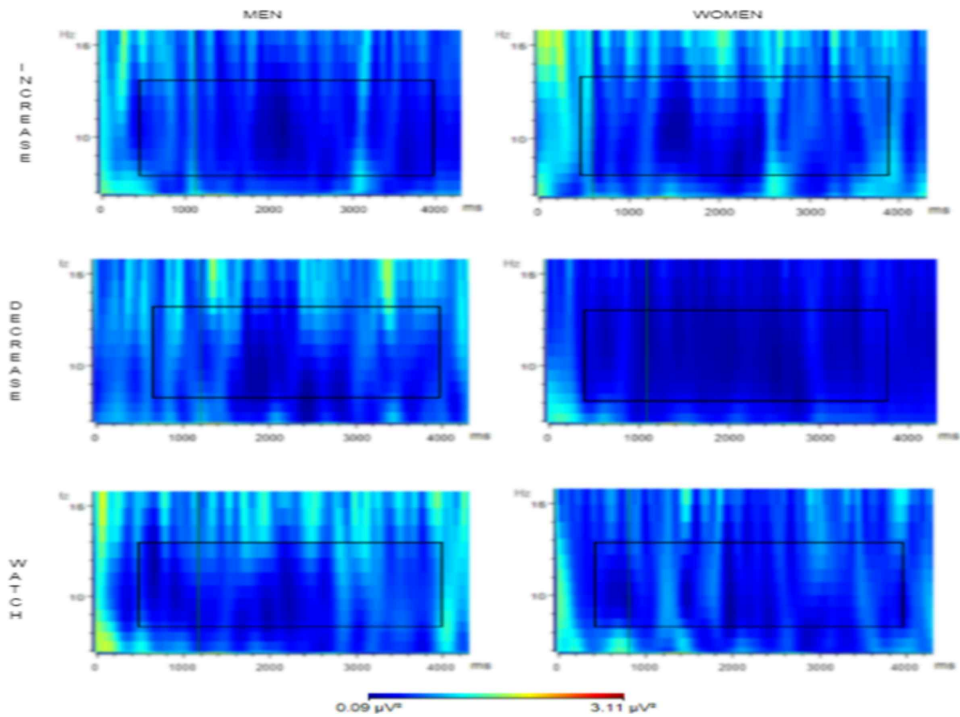


Figure 6. Raw time-frequency spectra for the increase, decrease, watch conditions for men and women in central brain regions. Spectra are averaged across the three (Cz, C3, C4) electrodes.

*Note. The box indicates the time/frequency range analyzed. Time 0 (ms) indicates the onset of the picture stimuli.

5.3. Correlation of MuSuppressions and Self-report Measures of Pain Empathy

The mu suppression indices for the WATCH condition (i.e., baseline empathy levels) were negatively correlated with pain sensitivity (on a scale 0–10) in both females ($r = -0.63, p = .049$) and males ($r = -0.07, p = .005$)

(Figure 7). Otherwise, no other self-report scores of empathy showed significant correlations with mu suppression values.

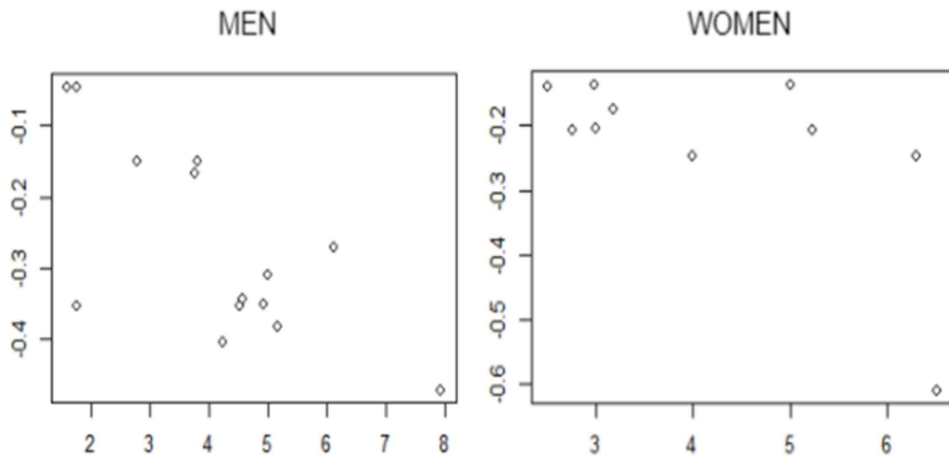


Figure 7. Correlations between the mu suppressions and the self-report ratings on the pain sensitivity scale in male (left) and female (right) subgroups.

6. Discussion

6.1. Summary and Interpretation of the Results

Empathy has long been understood as an automatic process in academia (Cameron et al., 2019; Zaki, 2014). In the present study, I examined empathy through a novel lens of motivation at the neural level by measuring the EEG mu rhythm. In doing so, I drew upon the Primary Caretaker Hypothesis (Babchuk et al., 1985) and predicted that male

empathy may be more motivational in nature. Specifically, I predicted that men may be more capable of controlling pain empathy based on their motives—enhancing it when they expect empathy to be beneficial and reducing it when they expect it to be detrimental. For women, the pain-related somatosensory activity was expected to be more consistent regardless of motivation. In other words, the difference in the level of female empathy between the situations in which they were motivated to up- or down-regulate it was expected to be smaller than that of men.

Research findings can be summed up as follows. As for the male participants, actively trying to empathize with the target's pain induced significantly stronger mu suppression than usual (i.e., INCREASE > WATCH). However, when deliberately trying to reduce pain empathy, these attempts were not successful (i.e., DECREASE = WATCH). Although attempts to suppress empathy failed, it can be argued that men appear to have a reasonable degree of voluntary control over pain empathy based on their goals. This claim is supported by the finding that male participants exhibited a significant difference in the level of pain empathy between the situations in which they were motivated to increase or decrease empathy (i.e., INCREASE > DECREASE).

In the case of female participants, actively trying to empathize with the target's pain elicited significantly stronger mu suppression than usual (i.e., INCREASE > WATCH). Interestingly however, trying to reduce pain

empathy elicited even stronger mu suppression than making active efforts to increase empathy (i.e., DECREASE > INCREASE) or viewing a target's pain naturally (i.e., DECREASE > WATCH). That is, women exhibited the greatest level of pain empathy when they tried to inhibit it. These results are inconsistent with the initial prediction that the difference in the level of female empathy between the <INCREASE> and <DECREASE> conditions would be smaller than that of men—in fact, the degree of difference was comparable to that of men (see Figure 7), but *importantly in the opposite direction*.

Taken together, the results can be summarized as follows: as hypothesized, men demonstrated more voluntary control over pain empathy than women, based on their goals and choices. The specific patterns for females in controlling pain empathy, however, were contrary to the expectations. In sum, the research findings found partial support for the hypotheses in the current study.

In the present study, both men and women experienced a significantly greater (than usual) level of pain empathy when motivated to do so. These results replicate and add to the previous fMRI studies, which have shown that people (particularly, men) can up-regulate empathy, given sufficient motivation (e.g., Arbuckle, & Shane, 2016; Shane, & Groat, 2018). As for the down regulation, although both men and women found it difficult to reduce pain empathy, women experienced even greater difficulty, leading

to an unexpectedly high level of pain empathy.

I offer two possible explanations for these unexpected results. Firstly, the strongest μ suppression in the DECREASE condition for women can, in fact, be explained within the context of the Primary Caretaker Hypothesis, the theoretical foundation of the present work. According to the Primary Caretaker Hypothesis, distinct biological/psychological mechanisms may have evolved for men and women to serve their (respective) best interests associated with empathy. The female system, evolved to accommodate their pervasive and universal experience of empathy, may make it difficult for women to maintain a detached view from others' emotions. Trying deliberately to reduce empathy may be an effort against automated biological processes and can be counterproductive. In men, on the other hand, various mechanisms may be in place to allow them to maintain a distance from the other's emotions as a default state, unless empathic motives are specifically activated. That is, men may be more acquainted/knowledgeable/skilled with strategies/tactics which will allow them to stay unaffected by others' emotions. Therefore, efforts to suppress empathy (i.e., returning to their default state) do not appear to have backfired as much. Despite the absence of unwanted additional pain empathy though, even men found it difficult to deliberately suppress pain empathy and maintain their default state during an emotional encounter.

Another explanation for the findings—i.e., active efforts to inhibit empathy did not backfire as much in men—could be simply that men did not engage much in the task of suppressing empathy. However, both male and female participants were instructed to pay equal degrees of attention across tasks and notified in advance that their brain waves would be monitored in real time during each and every session. Therefore, there seems to be no particular reason why male participants, unlike female participants, would pay less attention to the <DECREASE> task. In fact, there were no significant differences in the number of correct answers across conditions for men on the continuous performance task (as discussed in Chapter 4.5)

Furthermore, in the present study, suppression was measured not only over central (somatosensory) but also over occipital ones, which reflects attentional engagement (i.e., the degree of immersion) experienced by participant (Fox et al., 2016). Alpha suppressions were confirmed to have no significant differences across all conditions for both men and women. These results indicate that men were not “idling” or diverting attention from the task during the <DECREASE> condition.

Additionally, these results regarding alpha suppression (i.e., no significant differences across conditions) justify the differences in mu suppression across conditions are solely attributable to empathy, and not to attentional engagement. This conclusion is further supported by the way in

which the mu suppression indices were compared and analyzed in the study. That is, in the present study a pairwise comparison between the <INCREASE> and <DECREASE> conditions was made within each (male and female) subgroup with the assumption that both up and down regulation of emotional reaction would require similar degrees of top-down control or visual processing. Therefore, a comparison between these two within-subject conditions, in which only empathic motives were manipulated while all the other factors were controlled for, could tear out the difference in the degree to which pain empathy occurred. All in all, it could be concluded that the differences in mu suppression in the present study were likely to reflect genuine differences in vicarious somatosensory (i.e., pain) activation.

In the present study, mu suppression was found to have no significant correlations with the self-report measures of empathy in both men and women. These results contradict the previous finding that MEG mu suppressions associated with pain empathy were correlated with the perspective taking subscale of the IRI (Cheng et al., 2008). In another study by Davis, Conklin, Smith, & Luce (1996), scores on the personal distress scale significantly accounted for emotional sharing when faced with others in distressful situations.

Contrary to these findings, however, there also exists research in which mu suppressions do not have any noticeable relations with the self-report scores on various empathy questionnaires. For example, a study by

Yang and colleagues (2009) showed no significant correlation between mu suppressions and scores on the empathizing quotient (EQ), the emotional contagion scale (ECS), and the interpersonal reactivity index (IRI; subscales for perspective-taking and empathic concern).

These results imply that implicit (neural) and explicit (behavioral) measures may tap into different aspects of the same construct (Koopman et al., 2013). For example, the present study defined empathy as “*sharing and vicariously experiencing others’ mental states*” and, in line with this definition, measured the degree to which participants shared the target’s pain. However, when rating themselves on the empathy scales, the participants might have also reflected on and included those incidents where they *cognitively understood* the target’ affective states, *without necessarily sharing the feelings*. In fact, Koopman and colleagues (2013) showed that while implicit and explicit measures are generally moderately correlated, the correlation may drop low when the construct is socially sensitive. Empathy is known to trigger socially desirable responses (Klein, & Hodges, 2001).

Indeed, pain sensitivity—a construct without any social connotations—showed a significantly positive correlation with mu suppression for both men and women in the present study. This attests to the validity of mu suppression as a biological index of (vicarious) painful experience, because the more sensitive to pain one rated oneself, the stronger somatosensory activation occurred during (vicarious) painful

experience.

6.2. Theoretical Contributions and Practical Implications

The present study has a few important theoretical and practical implications. First, by theoretically framing empathy as a phenomenon modulated by motivation, the present research presented novel insights to address real-world issues associated with a lack of empathy. For a long time, a deterministic view (e.g., empathy is an innate ability) has rendered individuals with empathy deficit (e.g., psychopaths) “incurable and doomed.” The current study gives messages of encouragement by showing that people, regardless of their sex, are capable of boosting empathy for others’ pain when sufficiently motivated. A lack of empathy is a matter of motivation, not ability. Such a finding may be used to inform and determine programs to cultivate empathy in a longer term among both general and clinical populations.

Second, “empathy deficit” has been referred to as a “more pressing problem than the federal deficit” by the former U.S. president Barack Obama (2006). Likewise, academia has largely focused on a variety of ways to grow empathy. As a consequence, the literature lacks in an understanding of down-regulation of empathy, although people encounter situations in which empathy must be effectively suppressed on a daily basis. Moreover, certain professionals are required to reduce empathy to effectively carry out their duties (e.g., doctors, pro boxers). As one of few attempts to elucidate

the phenomenon of down-regulation of empathy, the current study showed that i) although both men and women found it difficult to reduce pain empathy, ii) women experienced more difficulty, indicated by noticeable reverse effects. These findings imply an interesting interplay between the nature of empathy and biological sex. A better understanding of this interaction will be critical in solving the real-world, empathy-related problems, which are often manifested in highly sex-specific manners (see Chapter 2.2.3 for more details).

6.3. Limitations and Future Directions

I acknowledge a few limitations to the research findings. In light of these limitations, several directions for future research are also suggested. First, due to time and resource constraints, the present study has limited the scope of investigation to pain only in examining empathic control. Accordingly, the research findings should be interpreted with a caveat. Future research is called upon to explore whether these preliminary findings are replicated for other emotions such as happiness or sadness. Second, the samples used in the current study were relatively small due to the COVID-19 pandemic. In fact, the mu literature has been afflicted with the unfortunate issue of small sample size (Hobson, & Bishop, 2016). Although the present study has begun to shed light on the sex-related effects in the role of motivation in empathy, subsequent work should include larger samples to verify these results. Third, the present study revealed that men

have more regulatory control over pain empathy than women *per se* (i.e., in any manner whatsoever). It, however, does not add any valuable insights to the question of *how*. I, therefore, present one last possibility for future research: subsequent research should shed light on the specific strategies that cause these effects. This knowledge may help to further identify the nature of empathy, including its origin and evolutionary history. Understanding this nature can ultimately provide clues for solving problems related to empathic failures, which are emerging as global issues in this era.

7. Overall Conclusions

The present study used EEG to examine the phenomenon of empathy through the novel lens of motivation. Drawing upon the Primary Caretaker Hypothesis as its theoretical foundation, this study predicted that men would have more regulatory control over pain empathy compared to their female counterparts. In investigating such hypotheses, participants were engaged in an active empathy regulation paradigm where motivation (i.e., independent variable I) was manipulated, resulting in various levels of somatosensory activation (i.e., dependent variable) among male and female subgroups (i.e., independent variable II).

Research findings showed that men and women were both capable of boosting pain empathy when motivated to do so, replicating the previous fMRI research. Women, however, showed even stronger pain empathy when they were making efforts to reduce it than when making efforts to enhance it.

Men, on the other hand, showed significantly stronger mu suppression when they were motivated to increase empathy than when they were motivated to decrease it. In short, male participants demonstrated more empathic control when faced with another in pain. These results support the possibility that different biological mechanisms may have evolved for men and women to accommodate their respective roles, resulting in different empathic propensities.

Taken together, the present study addressed the literature's three problems discussed in Chapter 2.2.2 and 2.2.3. That is, it contributed a line of neural evidence for motivated empathy through EEG, while expanding the literature by generating insights into both up- and down-regulation of pain empathy among men and women, separately.

Overall, the findings from the present research suggest that i) empathy is not hard-wired; it should be treated as a flexible *skill* which can be grown with sufficient motivation for both men and women. At the same time, ii) a better understanding of sex differences in empathy regulation is essential when approaching real-world issues associated with empathy. It has been observed that men lack empathy (i.e., men control empathy too much; Gillespie et al., 2014), while women have difficulties controlling empathy (Thoma et al., 2011). Taking a homogeneous approach for the two sexes would be pointless when the phenomenon itself is complex in nature.

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Appendix A: Emotional Contagion Scale (ECS)

1. 이야기를 하고 있는 상대방이 울기 시작하면, 나 또한 눈물이 나곤 한다.
2. 행복한 사람과 함께 있으면, 안 좋았던 기분이 사그라들곤 한다.
3. 누군가 나에게 따뜻하게 미소 지으면, 나 또한 미소로 답하곤 하며, 내면까지 따뜻해지는 느낌이 든다.
4. 사랑하는 사람의 죽음을 경험한 사람들의 이야기를 듣고 있으면 나는 슬픔으로 가득차곤 한다.
5. 뉴스에서 화가 난 사람들이 등장하는 것을 보고 있으면, 나 또한 어금니를 짹 깨물게 되고 어깨가 경직되곤 한다.
6. 사랑하는 사람의 눈을 쳐다보고 있으면, 나의 마음은 애정의 기분으로 가득찬다.
7. 화난 사람들 사이에 둘러싸여 있으면 나 또한 짜증이 나곤 한다.
8. 뉴스에서 범죄 피해자들이 두려워하는 모습을 볼 때, 나는 그들의 기분이 어떨지 상상하곤 한다.
9. 사랑하는 사람이 나를 안으면, 나는 녹을 것 같다.
10. 싸움이 일어난 것과 같은 소리가 들려오면, 나는 긴장되곤 한다.
11. 행복한 사람들과 함께 있으면, 나의 마음은 행복한 생각으로 가득차곤 한다.
12. 사랑하는 사람이 스킨십을 할 때, 나는 몸이 반응하는 것을 느낀다.
13. 스트레스를 많이 받고 있는 사람들과 함께 있으면, 나는 긴장되고 힘이 들어가곤 한다.
14. 나는 슬픈 영화를 볼 때 울곤 한다.
15. 어린 아이가 진료 중 소리를 지르고 있는 것을 치과 대기실에서 듣고 있으면, 긴장된다.

Appendix B: Interpersonal Reactivity Index (IRI)

1. 나보다 형편이 좋지 않은 사람을 보면 걱정하는 마음이 자주 들곤 한다.
2. 나는 때때로 상대방의 관점에서 세상을 바라보는 것이 어렵다고 느껴진다.
3. 나는 어려움을 겪고 있는 사람들을 봐도 때때로 그다지 동정심이나 걱정이 들지 않는다.
4. 나는 의견의 충돌이 있을 때, 모든 사람의 입장을 고려하도록 노력한 후에, 결정을 내린다.
5. 나는 누군가 이용당하고 있을 것을 보면, 그들의 편에 서게 된다.
6. 나는 때때로 친구들의 관점과 시각은 어떨지 상상하면서, 그들을 더 잘 이해하려고 노력한다.
7. 다른 사람들의 불행이 나를 정신적으로 괴롭힌다거나 하지는 않는다.
8. 나는 어떤 문제에 대하여 나의 생각이 맞다는 확신이 있으면 다른 사람들의 주장을 듣는 것에 많은 시간을 낭비하지 않는다.
9. 누군가 불공평한 대우를 받고 있는 것을 봐도, 나는 때때로 그렇게 큰 동정심을 느끼지는 않는다.
10. 나는 주위에서 일어나는 일들로 인하여 자주 감명을 받는다.
11. 나는 모든 문제에는 양면이 존재한다고 믿고, 그 양면을 모두 보기 위해 노력한다.
12. 나는 내 자신을 꽤 상냥한 사람이라고 생각한다.
13. 나는 누군가에게 화가 났을 때, 잠시 그 사람의 입장이 되어 보려고 노력한다.
14. 나는 누군가를 비판하기 전에, 내가 그 사람 입장이었으면 어땠을까 상상해 본다.

Appendix C: Empathizing Quotient (EQ)

1. 나는 누군가 대화에 끼어려고 싶어할 때, 그것을 금방 알아차릴 수 있다.
 2. 나는 다른 사람들을 돌보는 것을 정말 좋아한다.
 3. 나는 사회 생활을 하면서, 무엇을 어떻게 하는 것이 맞는지 잘 모르겠다.
 4. 어떤 행동이 예의가 바른 것인지 무례한 것인지 판단하는 것이 자주 어렵게 느껴진다.
 5. 나는 대화를 할 때, 상대방이 무슨 생각을 하고 있을지보다는 내 생각들에 더 집중한다.
 6. 나는 상대방이 겉으로 하는 말과 속뜻이 다를 때 금방 알아차릴 수 있다.
 7. 나는 사람들이 왜 여러 일들에 그리도 분노를 하는지 이해하기 어렵다.
 8. 나는 상대의 입장에 서서 그 사람을 이해하는 것이 수월하다고 느낀다.
 9. 나는 상대방의 감정을 예측하는 것에 능숙하다.
 10. 나는 그룹 내에서 누군가 어색해하고 불편해하는 것을 빨리 눈치챈다.
 11. 나는 어떤 발언이 누군가를 화나게 했을 때, 그 사람이 화난 이유가 항상 잘 이해되지는 않는다.
 12. 사회에서 일어나는 상황들을 파악하고 이해하는 것이 어렵지 않다.
 13. 사람들은 내가 그들이 어떻게 느끼고 생각하는지를 잘 이해한다고 말한다.
 14. 나는 상대방이 내 이야기를 흥미롭게 듣고 있는지 지루해하는지 쉽게 캐치할 수 있다.
 15. 친구들을 내가 자신들을 잘 이해해준다고 하며, 자신들의 문제를 나와 자주 상담하곤 한다.
 16. 상대방이 말하지 않아도 나는 내가 선을 넘을 때 그것을 잘 알아차린다.
 17. 사람들을 나에게 둔감한 편이라고 말하는데, 나는 잘 모르겠다.
 18. 나는 상대방의 기분이 어떤지 본능적으로 빨리 감지할 수 있다.
 19. 나는 상대방이 무엇에 대하여 이야기하고 싶은지 쉽게 파악할 수 있다.
 20. 상대방이 자신의 진짜 감정을 감추고 있을 때 나는 그것을 잘 알아차릴 수 있다.
 21. 나는 상대방이 어떤 행동을 할지 예측하는 데에 능숙하다.
 22. 나는 친구가 겪고 있는 문제들에 감정적으로 이입되곤 한다.
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Appendix D: Pain Sensitivity Questionnaire (PSQ)

1. 당신의 정강이(다리 앞쪽)를 유리 테이블에 짚었다고 상상해 보라. 얼마나 아플 것인가?
2. 당신의 혀를 아주 뜨거운 음료에 데었다고 상상해 보라.
3. 신체 활동으로 인하여 당신의 무릎 근육이 살짝 빠근하다고 상상해 보라.
4. 당신의 손가락이 서랍에 끼었다고 상상해 보라.
5. 미지근한 온수에 샤워를 하고 있다고 상상해 보라.
6. 어깨 부위에 햇볕으로 인한 미약한 화상을 입었다고 상상해 보라.
7. 자전거에서 떨어져서 무릎이 까졌다고 상상해 보라.
8. 음식을 씹다가 당신의 혀나 볼 안쪽을 심각하게 깨물었다고 상상해 보라.
9. 차가운 타일의 바닥을 맨발로 걷고 있다고 상상해 보라.
10. 당신의 손가락을 약간 베었는데, 실수로 그 상처에 레몬 주스를 쏟았다고 상상해 보라.
11. 당신의 손끝을 장미 가시에 찔렸다고 상상해 보라.
12. 당신의 손을 눈 속에 집어넣고 몇 분 동안 머물러 있다고 상상해 보라. 또는, 눈사람을 만들면서 당신의 손이 눈과 꽤 오랜 동안 접촉해 있다고 상상해 보라.
13. 평상시와 마찬가지로, 상대방과 악수를 하고 있다고 상상해 보라.
14. 손을 굉장히 세게 잡는 사람과 악수를 하고 있다고 상상해 보라.
15. 냄비를 들어올리려다, 굉장히 뜨거운 손잡이를 실수로 잡았다고 상상해 보라.
16. 샌들을 신고 있는데, 굽이 두꺼운 부츠를 신은 사람이 실수로 당신의 발을 밟았다고 상상해 보라.
17. 당신의 팔꿈치를 책상의 모서리에 짚었다고 상상해 보라.

국문초록

공감이란, 타인이 겪고 있는 감정적 상황을 마주할 때, 그 감정을 공유하는 인지적 현상을 의미한다. 학계의 인식과 대중의 통념을 막론하고, 공감은 자동적인 현상으로 오랫동안 이해되어 왔다. 즉, 공감은 단순 반사와 같은 현상으로서 선천적으로 부여된 기질이자 능력이기에, 그 경험을 크게 향상시키거나 억제하는 등의 자발적 조절은 쉽지 않다고 여겨져 왔다. 하지만, 공감의 경험에 있어 주체의 선택이나 의지가 갖는 역할이 간과되어서는 안 되며, 본 연구는 이러한 공감의 하향식(top-down) 조절에 주목하고자 하였다. 본 연구는 ‘일차양육자 가설’을 그 이론적 기반으로 차용하여, 공감의 하향식 조절에 있어 생물학적 남녀차가 있을 것임을 예측하였다. 이러한 가설을 경험적으로 확인하기 위하여, 총 24명(남성 14명, 여성 10명)의 참여자가 모집되었다. 이들은 고통스러운 상황을 묘사하는 사진을 총 세 가지 조건 아래에서 감상하였다. 첫째, 평소와 같은 상태, 둘째, 상대의 고통에 대한 공감을 최대화하기 위하여 적극적으로 노력하는 상태, 셋째, 상대의 고통에 대한 공감을 최소화하기 위하여 적극적으로 노력하는 상태가 상기한 세 가지 조건이었다. 이 때, 상이한 조건들 아래에서 참여자가 보이는 고통 공감의 정도는 EEG(electroencephalogram)를 통하여 뇌파의 형태로써 기록되었다. 보다 구체적으로, 고통 공감의 정도는 참여자의 체감각피질의 간접적 활성화 정도를 반영하는 뮤리듬을 통하여 측정되었다. 실험 결과, 남성들은 공감을 증가시키기 위하여 노력할 때, 가장 강한 체감각피질의 활성화를 보였다. 그러나 여성의 경우, 공감을 억제하기 위하여 노력하는 동안 역설적으로 가장 강한 체감각피질의 활성화를 보였다. 이러한 결과는, 인위적으로 고통 공감을 억제하려는 노력이 오히려 역효과를 야기하였을 가능성을 비친다. 즉, 본 연구의 결과는, 여성의 공감이 남성의 그것에 비해 더욱 자동적이며 보편적으로 체화된 생물학적 반응일 수 있음을 함의한다. 반면, 남성의 고통 공감은 더 유연하며 선택적 성질을 띌 수 있는 것으로 보인다. 따라서, 이들의 고통 공감에 대한 의지적 조절은 상대적으로 더 수월할 수 있었다고 해석 가능하다. 본 연구의 이러한 발견은, 공감의 진화적 근원은 ‘육아’라는 여성의 역할이라고 추정하는 ‘일차양육자 가설’에 뇌과학적 근거를 기여할 수 있을 것으로 판단한다. 그 밖의 이론적, 실용적 함의가 논의된다.

주요어 : 공감, 고통, 동기부여, 성차, EEG, 뮤리듬
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