Cerebellum and Emotion in Morality

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Abstract

In the current chapter, I examined the relationship between the cerebellum, emotion, and morality with evidence from large-scale neuroimaging data analysis. Although the aforementioned relationship has not been well studied in neuroscience, recent studies have shown that the cerebellum is closely associated with emotional and social processes at the neural level. Also, debates in the field of moral philosophy, psychology, and neuroscience have supported the importance of emotion in moral functioning. Thus, I explored the potentially important but less-studies topic with NeuroSynth, a tool for large-scale brain image analysis, while addressing issues associated with reverse inference. The result from analysis demonstrated that brain regions in the cerebellum, the right Crus I and Crus II in particular, were specifically associated with morality in general. I discussed the potential implications of the finding based on clinical and functional neuroimaging studies of the cerebellum, emotional functioning, and neural networks for diverse psychological processes.

Keywords: Morality; Emotion; fMRI; Reverse inference; Bayesian inference; Meta-analysis; NeuroSynth; Cerebellum; Default mode network; Executive network

In this chapter, I intend to examine the association between the cerebellum and moral functioning, particularly emotional aspects in morality, that has not been well studied in the fields. So far, findings from studies in neuroscience have provided scholars with additional evidence regarding how human morality is functioning at the neural level (Han et al. 2019). However, the majority of them have paid attention to regions in the cerebrum instead of those in the cerebellum (Demirtas-Tatlidede and Schmahmann 2013). Given emotion plays important roles in human morality (Prinz 2006; Han 2014) and recent works in neuroscience supports the close association between the cerebellum and emotion (Adamaszek et al. 2017), the relationship between the cerebellum, emotion, and morality is worth careful consideration.

Hence, to address the aforementioned gap in the literature, in this chapter, I will briefly overview the historical and theoretical backgrounds related to neuroscience of morality and explore the association between cerebellum and emotion in morality based on large-scale neuroimaging data analysis. First, I will start with overviewing the history of debates regarding the roles of reasoning and emotion in morality to provide background information about why studying emotion is important in moral psychology (Rest et al. 1999; Prinz 2006; Han 2014). Second, recent research on the role of the cerebellum in emotional and social processes (Adamaszek et al. 2017) will be reviewed to elaborate the point why exploring the relationship between the cerebellum, emotion, and morality will be able to provide useful insights to better understand human moral functioning. Third, large-scale brain image analysis, NeuroSynth (Yarkoni 2011;

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Yarkoni et al. 2011), will be introduced as a way to explore the neural correlates of morality in the cerebellum. To examine its methodological strengths in neuroimaging data exploration, I will also briefly discuss limitations associated with reverse inference in the current functional neuroimaging methods (Glymour and Hanson 2016) as well. Finally, I will discuss the potential implications of the finding from the large-scale analysis and directions for future research on morality.

Historical backgrounds about debates on reasoning, emotion, and moral functioning

There have been continuous debates on which psychological functionality (e.g., moral reasoning or moral emotion) constitutes the basis of morality (Kauppinen 2013; Birondo 2017). Such debates have been across different fields that are interested in morality, including but not limited to moral philosophy, psychology, and neuroscience (Prinz 2006; Han 2014), since the ancient era (Parry and Thorsrud 2021). In the modern era, moral psychology concerning about the mechanism of human moral functioning has attempted to answer the aforementioned question based on empirical evidence (Doris et al. 2020). When the cognitive revolution, which significantly contributed to forming the basis of modern psychology and neuroscience (Miller 2003), occurred, the majority of psychologists interested in morality focused on cognitive aspects of morality, particularly those associated with moral reasoning. For instance, Jean Piaget, who proposed the model of moral development among children and was one of psychologists inspired the cognitive revolution, delved into how moral reasoning, particularly reasoning about rules and authorities, develops among children (Piaget 1948). Moreover, Kohlberg (1981) examined more sophisticated forms of moral reasoning and deliberation. He underscored the role of reasoning in moral functioning and proposed the developmental model of moral reasoning based on large-scale interview data (Kohlberg 1984). According to his model, people make moral judgment based on reasoning, particularly reasoning about why a behavioral decision that they make is deemed to be morally appropriate (Kohlberg 1975). Researchers who were inspired by these theoretical models have examined the relationship between moral reasoning and behavior, which is considered as the ultimate outcome of moral functioning (Kohlberg and Hersh 1977; Ketefian 1981).

However, there have been criticisms on the models of moral functioning focusing on the role of moral reasoning (Han 2014). The most fundamental critique is that the result of moral reasoning per se does not necessarily result in moral motivation, and finally, actual moral behavior (Hoffman 1979; Blasi 1980). The gappiness issue (Darnell et al. 2019) regarding the gap between moral reasoning and behavior has motivated scholars to seriously reconsider psychological processes other than reasoning, emotional processes in particular, to better explain the mechanism of moral behavior. Even Neo-Kohlbergians (Rest et al. 1999), who updated the classical Kohlbergian model, have acknowledged the necessity of additional psychological processes in their conceptual model of moral functioning. To address the gappiness issue, they added moral sensitivity, motivation, and character, which are based on affective and motivational processes, to their four components model (Bebeau 2002; Walker 2002). The Neo-Kohlbergians acknowledged the importance of emotional aspects of morality (e.g., empathy) although the classical Kohlbergian model was mainly based on moral reasoning.

As briefly overviewed, the majority of scholars who were interested in morality have eventually endorsed the importance and value of emotional processes in moral functioning. Even moral psychologists who initially underscored the roles of reasoning in morality now attempt to embrace psychological components that are not within the realm of reasoning, emotional components, in explaining moral functioning as shown in the case of Neo-Kolbergians. To better understand the context regarding how the scholars ended up with acknowledging the necessity of emotion in morality, in the following section, I will review philosophical, psychological, and neuroscientific works that support the viewpoint.

Philosophical, psychological, and neuroscience works supporting the roles of emotion in morality

Recent works in the fields of philosophy, psychology, and neuroscience of morality may suggest that it would be impossible to completely reject the role of emotion (or sentiment) in moral functioning in general (Haidt 2003; Moll et al. 2003; Prinz 2006). For instance, philosophers who support moral sentimentalism, particularly those propose a strong form of sentimentalism, argue that emotion plays fundamental roles in moral functioning, including moral judgment, which has been regarded within the realm of deliberation and reasoning (Prinz 2006). Furthermore, motivational externalists, who argue that either reasoning or emotion per se is not sufficient to generate motivation, such as a group of virtue ethicists, also acknowledge the importance of emotion in moral functioning, particularly production of moral motivation and action (Shafer-Landau 2000; Kristjánsson 2012). Although some moderate motivational externalists do not endorse the strong form of sentimentalism that asserts that moral emotion is a sufficient requirement for moral judgment (Kristjánsson 2012), they acknowledge the point that psychological components other than reasoning, particularly emotions relevant to morality, are required for moral motivation and behavior (Han 2016). These philosophical accounts by moral sentimentalists and motivational externalists propose that emotion should be considered as a necessary component in moral functioning (Kristjánsson 2007, 2012; Han 2014).

Findings from studies in psychology and neuroscience also support the aforementioned philosophical viewpoint. We may start with briefly overviewing the classical case of Phineas Gage (Damasio 2006). When Gage got an injury in his ventromedial prefrontal cortex, his general cognitive abilities, such as arithmetic calculation, were not impacted by the injury. However, his emotional abilities started malfunctioning. Although he was able to make formal judgments within social and moral contexts properly, he became antimoral and antisocial in terms of his behavior. More recent studies that examined patients with brain lesions in the prefrontal areas reported findings that were consistent with the classical case. Saver and Damasio (1991) reported that patients who had lesions in their prefrontal regions showed problems in social and moral behavior even if their abilities of moral judgment and reasoning were not significantly different compared with ordinary people in many instances. In fact, neuroimaging studies have demonstrated that these regions, including the ventromedial prefrontal cortex and orbitofrontal cortex, play fundamental roles in emotional generation and regulation (Moll et al. 2001, 2002). Hence, as proposed by motivational externalists, these classical and recent studies that examined patients with prefrontal lesions may support that emotional processes are inseparable from moral functioning, particularly generation of moral motivation and behavior at the neural level.

The aforementioned accounts and findings in the fields of moral philosophy, psychology, and neuroscience may unequivocally support the point that emotion is essential in moral functioning even if it could not be considered as a sufficient component and the argument made by philosophers who supported the strong form of moral sentimentalism is not the case (Prinz 2006; Kristjánsson 2007; Han 2014). The lack of abilities to generate and regulate emotions is found to cause motivational and behavioral issues in the domain of morality even if they do not necessarily be associated with problems in moral reasoning as shown in the previous studies (Saver and Damasio 1991; Damasio 1994). Based on these empirical works supporting the necessity of emotion in morality, in the next section, I will overview the relationship between the cerebellum, emotion, and moral functioning that has been relatively less studied in previous research in neuroscience (Demirtas-Tatlidede and Schmahmann 2013).

Association between the cerebellum and moral functioning in previous studies

One point to note in a relation with research on the cerebellum, which is the main topic of the current edited volume, is that until recently, only few neuroscientists have seriously considered and examined the association between morality and the cerebellum (Demirtas-Tatlidede and Schmahmann 2013). So far, in the majority of the previous studies related to the aforementioned topics, researchers have paid attention to regions in the cerebrum (Adamaszek et al. 2017). Even if Greene et al.'s (2001, 2004) foundational studies have significantly impacted the field by demonstrating the importance of both cognitive and affective processes in moral functioning, they were mainly concerned about activity in cerebral regions, particularly the prefrontal cortex and inferior parietal lobule. Similarly, almost all of the philosophical, psychological, and neuroscientific works introduced above to substantiate the necessity of emotion in moral functioning have also examined lesions and activity in cerebral regions.

However, recent works examining activity in cerebellar regions associated with emotional, social, and moral psychological processes suggest that we need to pay attention to the cerebellum (Demirtas-Tatlidede and Schmahmann 2013). Neuroscientific studies focusing on the cerebellum, particularly those examined patients with localized lesions in cerebellar regions presented evidence supporting the importance of the cerebellum in emotional, social, and moral functioning (Adamaszek et al. 2017). Related to emotion, social and moral functioning, which are our main interest, for instance, one clinical study demonstrated that lesions in the cerebellum were significantly associated with the decreased intensity of experienced pleasure in response to happiness-evoking stimulations (Turner et al. 2007). Furthermore, lesions in cerebellar regions caused problems in emotional regulation and social behavior across different clinical cases (Schmahmann et al. 2007).

Also, recent functional neuroimaging studies have also reported significant activity in regions in the cerebellum in task conditions related to emotion, social and moral functioning. For example, several previous studies demonstrated the connectivity between the cerebellum and other brain regions in the default mode network, such as the precuneus and medial prefrontal cortex (Habas et al. 2009; Tang et al. 2013); this brain circuitry has been found to be closely correlated with various social and moral functioning (Sevinc and Spreng 2014; Boccia et al. 2016; Garrigan et al. 2016; Han 2017; Eres et al. 2017). Although Han et al. (2016) did not specifically focus on activity in the cerebellum in their fMRI study, they found significant interactions between cerebellar regions and regions in the medial prefrontal cortex and posterior cingulate cortex in moral dilemma resolution.

Several meta-analyses of related previous fMRI studies also support the aforementioned point. In general, Keren-Happuch et al.'s (2014) meta-analysis demonstrated that across different fMRI studies, diverse cerebellar regions showed common activity in different domains of psychological processes, i.e., emotion, executive functioning, language, music, timing, and working memory. Furthermore, in the cases of psychological processes related to higher-order social cognition, Van Overwalle et al.'s (2014) meta-analysis reported that mirroring and mentalizing, which are required for perspective taking and moral cognition (Harenski et al. 2012a), are significantly associated with activity in wide-range of regions in the cerebellum. Given the results from the meta-analyses, it is obvious that activity in the cerebellum is significantly associated with diverse cognitive and affective processes, including those are inseparable from moral functioning (Demirtas-Tatlidede and Schmahmann 2013; Adamaszek et al. 2017), such as emotion, executive functioning, and mentalizing (Harenski et al. 2012b; Han 2014; Barrasso-Catanzaro and Eslinger 2016), and such associations are well supported by accumulated neuroimaging evidence.

These previous works focusing on the associations between emotion, social and moral functioning and the cerebellum, including clinical studies, neuroimaging studies, and meta-analyses, suggest that we need to acknowledge the roles of the cerebellum in the aforementioned domains. Although previous philosophical, psychological, and neuroscientific works about morality have primarily focused on the cerebrum, it would be time to start looking at the relatively less examined realm, the cerebellum, to better understand moral functioning, which requires the cooperation between emotion and reasoning.

How to examine the association between moral functioning and the cerebellum in the current chapter

Although previous neuroimaging studies have provided evidence supporting the association between the cerebellum and psychological processes related to emotion and social and moral functioning, we need to consider methodological issues associated with reverse inference in the previous studies (Poldrack 2008, 2011). Researchers have been concerned about the issues related to reverse inference while associating a specific functionality of interest and activity in a brain region of interest. According to concerns regarding naïve reverse inference, because multiple, not one, psychological and behavioral functions are associated with one brain region, finding significant activity in a certain brain region in a certain task condition could not be a sufficient condition to map the brain region to the task condition (Ramsey et al. 2010; Glymour and Hanson 2016). This can also be problematic in our endeavor to examine the role of the cerebellum in moral functioning. Even if previous neuroimaging studies have found significant activity in the cerebellum in moral task conditions, such results do not necessarily mean that the cerebellar regions showed significant activity specifically play roles in moral functioning.

Thus, to better examine cerebellar regions that are specifically associated with morality, we need to consider how to address the issues associated with reverse inference. As a possible solution, I intend to examine the neural correlates of moral functioning, particularly those in the cerebellum, with large-scale brain image analysis (Yarkoni et al. 2011). To consider why large-scale brain image data analysis can be a possible way to address problems associated with reverse inference, first, I will briefly discuss what are the problems and why the problems make difficult to interpret findings from neuroimaging studies (Poldrack 2008; Ramsey et al. 2010; Glymour and Hanson 2016). Then, I will examine why large-scale analysis can be a potential solution and describe how to perform the analysis (Yarkoni et al. 2011; Poldrack 2011). Based on the aforementioned conceptual and methodological discussions, I intend to demonstrate regions in the cerebellum that are specifically associated with moral functioning with large-scale analysis and discuss the implications of the result. Finally, I plan to suggest several ideas for future research on the relationship between the cerebellum and morality.

Reverse inference in neuroimaging studies: Issues and potential solutions

Neuroscientists have primarily been interested in identifying brain regions or circuitries associated with a psychological or behavioral functionality of interest in their neuroimaging studies. For instance, in the case of fMRI studies focusing on morality, scholars attempt to examine which brain regions or circuitries are significantly associated with the task conditions, moral functioning task conditions (Moll et al. 2003; Han 2016). In the most cases, they compare neural activity in the moral task conditions and that in the control or resting condition to identify which regions show relatively greater activity in the moral task conditions (Friston et al. 1998). Even if several regions are identified to show greater activity through these procedures, it is not possible to argue that the regions are specifically associated with morality without any reservation due to the issue associated with reverse inference (Glymour and Hanson 2016). Because one brain region is associated with multiple functionalities, it is impossible to exactly map a specific functionality of interest to a specific brain region even if the region showed significant activity in a task condition of interest (Poldrack 2008).

Why naïve reverse inference could be problematic in interpreting results from neuroimaging studies, particularly matching identified neural activity to a specific psychological or behavioral functionality of interest, can be explained from Bayesian perspective (Poldrack 2011; Han and Park 2018). As I mentioned, scholars are primarily interested in P(H|D), the likelihood that a specific functionality of interest is associated with a specific region (H) given observed neural activity in the region (D) (Han and Park 2018). However, what we can actually learn from a neuroimaging study is P(D|H), the likelihood to discover a certain pattern of neural activity in a region (D) when a functionality of interest that is tested (H) (Glymour and Hanson 2016). This is the case because in most neuroimaging studies, scholars acquire data about neural activity while participants are engaging in one or a limited number of specific psychological or behavioral tasks. Thus, if we try mapping functionalities of interest to brain regions solely based on observed neural activity patterns from a neuroimaging study, we conflate P(D|H), which can actually be estimated from the study, with P(H|D), our primary interest (Han and Park 2018; Han et al. 2018). Without any further data, only with observed experimental outcomes, P(D|H), we cannot properly examine the specific neural correlates of the functionality of interest, P(H|D). In other words, a naïve trial to reversely infer P(H|D) from P(D|H) with limited data is highly likely to commit a fallacy.

A possible way to address this issue and properly estimate P(H|D) that we are primarily interested in is analyzing large-scale neuroimaging data (Yarkoni et al. 2011). From Bayes Theorem, we can learn about why this can be a potential solution of the issue. According to Bayes Theorem, P(H|D) is estimated as follows (Wagenmakers et al. 2018):

$$P(H|D) = \frac{P(D|H)P(H)}{P(D)} = \frac{P(D|H)P(H)}{P(D|H)P(H) + P(D|\overline{H})P(\overline{H})}$$

In the case of neuroimaging studies, as I described, P(D|H) is the pattern of neural activity (D) in a presented task condition (H) that can be actually acquired from the studies. Now, from the equation, we can see additional terms introduced. P(H) indicates the prior probability of whether a functionality is the case that we assume before observing neural activity. P(D) indicates the baseline of neural activity in general, which is observed across all different functionalities or task conditions. As expanded above, P(D) can be estimated with $P(D|H)P(H)$ and $P(D|\overline{H})P(\overline{H})$. Although $P(D|H)$ is estimable from one or a limited number of neuroimaging studies, we cannot easily estimate $P(D|\overline{H})$ because $P(D|\overline{H})$ means the likelihood to observe neural activity in a specific region (D) when functionalities other than the functionality of our interest to be tested in our neuroimaging study $(\overline{H})$ are tested. To acquire the information, neural activity associated with all psychological and behavioral functionalities should be examined (Poldrack 2008).

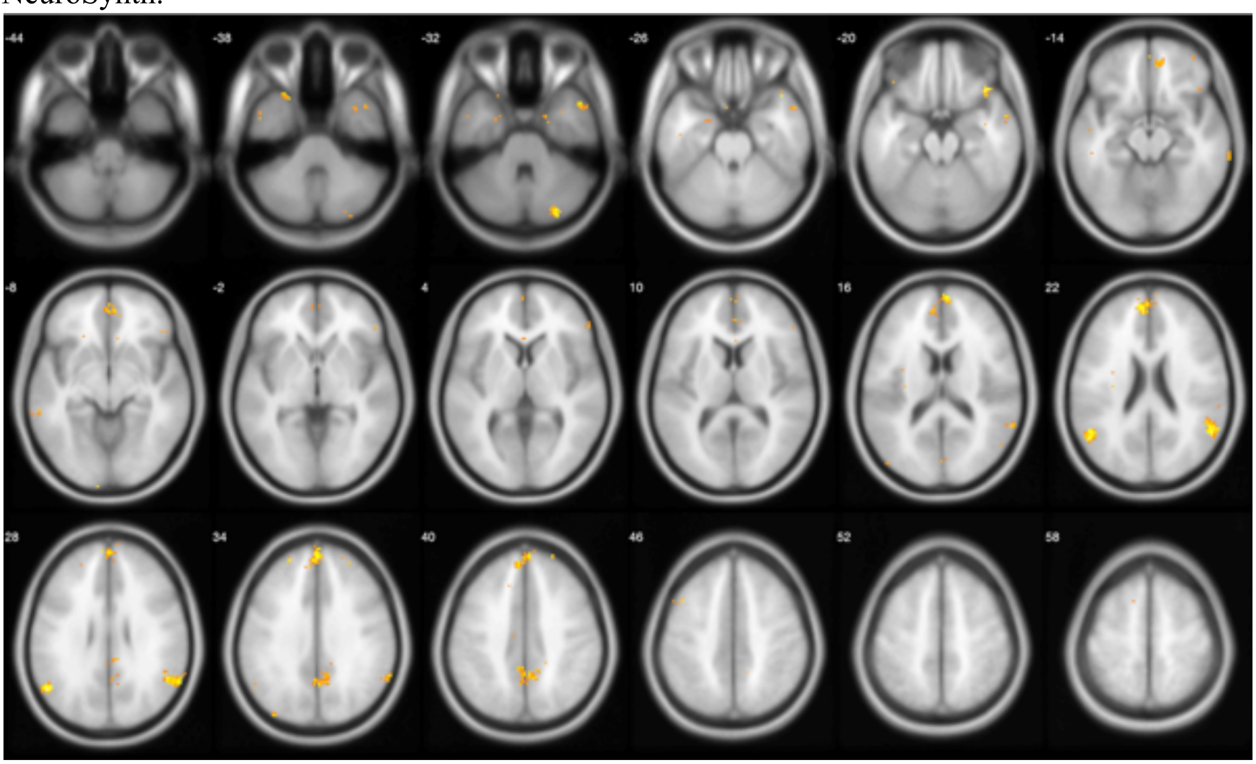
As an effort to address the difficulty, Poldrack (2011) explored a possible way to implement the aforementioned mechanism to estimate P(H|D). In his study, he intended to examine the neural correlates of linguistic functioning. Unfortunately, one practical difficulty that should be addressed during the process was that acquiring the complete information about $P(D|\overline{H})$ is practically impossible, because doing so requires examining neural activity associated with all functionalities and task conditions. Thus, as a way to approximate $P(D|\overline{H})$, Poldrack (2011) estimated the baseline neural activity in previous fMRI studies by exploring BrainMap database (Fox and Lancaster 2002; Fox et al. 2005; Laird et al. 2005). With the acquired baseline information, he estimated P(D|H), neural activity specifically associated with linguistic functioning. Although their estimation was based on information acquired from a limited number of previous studies via BrainMap, there is one major takeaway from their study that can inform scholars who intend to examine P(H|D): utilization of large-scale neuroimaging database can provide a practical solution to estimate baseline neural activity, which is essential in addressing issues related to reverse inference.

At this point, NeuroSynth can be considered as a practical solution to implement the aforementioned technical idea and gather information about the ontology of a functionality of interest (Yarkoni 2011). When Poldrack (2011) conducted the reverse inference study, he had to gather neuroimaging data by manually exploring BrainMap. However, NeuroSynth automatically crawls activation information from published articles and associates the activity information with corresponding task condition information (Yarkoni et al. 2011). As a result, as of February 28, 2021, NeuroSynth database includes 507,891 activation foci reported in 14,371 studies, and 1,335 task condition keywords associated with activity information. Based on the large-scale database, NeuroSynth can automatically generate a brain map presenting P(H|D), once a user specifies the keyword of a functionality of interest to be analyzed. The resultant P(H|D) map demonstrates voxels reporting significant activity associated with a functionality of interest when the baseline activity across all task conditions stored in the database is controlled. Hence, given the size of its neuroimaging database and user-friendly interface for analysis map generation, NeuroSynth would be a viable solution to infer P(H|D). Due to the aforementioned benefits, I also employed NeuroSynth to examine the neural correlates of morality in examination of their association with the cerebellum.

Result of NeuroSynth analysis

I generated a P(H|D) map with a keyword, "moral," with NeuroSynth to examine the neural correlates of morality. In the overall, the map generation procedures were identical to what Han (2020) did in their examination of the neural circuitry of moral functioning. To generate the map, I selected a keyword "moral," which was pre-registered in NeuroSynth (see https://neurosynth.org/analyses/terms/moral/ for further details). Once the keyword was selected, NeuroSynth extracted activation information from 87 studies associated with the keyword, "moral." A total of 2,806 activation foci were extracted. Then, NeuroSynth estimated P(H|D) of "moral" with the extracted activation information and the baseline activity information with the whole database. The estimated P(H|D) map was thresholded at $p < .01$ (false discovery rate corrected). Fig. 1 shows the resultant thresholded P(H|D) map of "moral." Not surprisingly, the result demonstrates that cerebral regions in the medial prefrontal cortex, orbitofrontal cortex, anterior and cingulate cortex, precuneus, and temporoparietal junction showed significant activity in moral-related task conditions after controlling for the baseline activity. This result is consistent with findings from previous fMRI studies that focused on various moral functionalities and reported significant activity in the default mode network and cortical midline structures (see Bzdok et al. 2012; Sevinc and Spreng 2014; Boccia et al. 2016; Garrigan et al. 2016; Han 2017; Eres et al. 2017 for meta-analyses).

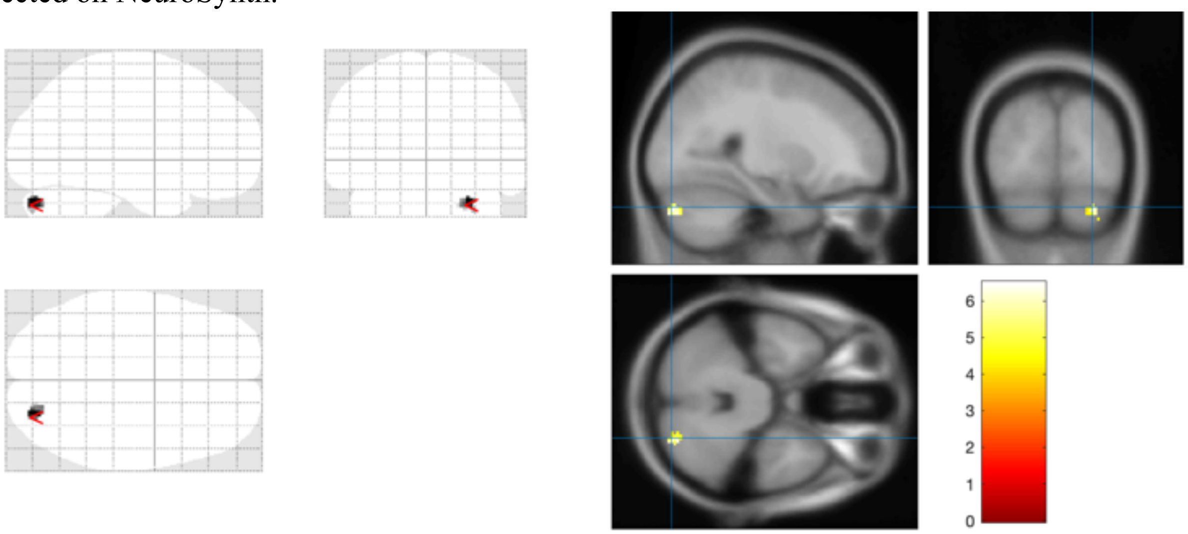
Fig 1. Brain regions reported significant activity when a keyword, "moral," was selected on NeuroSynth.



Note. All significant voxels were thresholded at $p < .01$ (false discovery rate corrected). The slice view was generated with XjView (Cui et al. 2015).

Interestingly, I was able to find a cluster of significant voxels in the cerebellum from the resultant P(H|D) map, which was produced after controlling for the baseline neural activity (see Fig. 2). There were 56 voxels (56 voxels x 8 mm^3/voxel = 448mm^3) showed significant activity in "moral" in the right Crus I and Crus II. This cluster was the only cluster showed significant activity in the whole cerebellar region.

Fig 2. A cluster in the cerebellum showed significant activity when a keyword, "moral," was selected on NeuroSynth.



Note. Peak MNI coordinate: (26 -84 -32). All significant voxels were thresholded at $p < .01$ (false discovery rate corrected). The image was generated with XjView (Cui et al. 2015).

Considering the relationship between moral functioning and the cerebellum with NeuroSynth evidence

In my NeuroSynth analysis, I found that the cerebellar regions in the right Crus I and Crus II reported significant activity in moral task conditions. One point that is worth consideration is that both the right Crus I and Crus II reported significant association with emotional functioning in previous studies focusing on the cerebellum, and social and emotional neuroscience. We may start with revisiting the meta-analyses of fMRI studies that introduced previously to have more ideas about the association between the right Crus I and Crus II and emotional processes. According to Keren-Happuch et al. (2014), the right Crus I reported significant activity in emotion-related task conditions across different studies. A consensus paper based on a wide literature review also presented that the right Crus I and Crus II were significantly associated with the perception of emotion as well as emotional evaluation and regulation based on evidence from clinical and functional neuroimaging studies (Adamaszek et al. 2017). Given these, the Crus I and Crus II seem to be cerebellar regions that are particularly associated with diverse emotional processes. Hence, the findings from my NeuroSynth analysis and the aforementioned previous studies of the cerebellum and emotion may support the arguments made by a group of moral philosophers, psychologists, and neuroscientists that emotion should be considered as a fundamental part of morality (Damasio 1994; Prinz 2006; Moll and de Oliveira-Souza 2007).

However, even if that is the case, it is obvious that brain regions other than Crus I and Crus II, e.g., the amygdala, insula, ventromedial prefrontal and orbitofrontal cortices and other regions in the cerebrum, are also found to be associated with moral emotion (Moll et al. 2002; Decety et al. 2012; Raine 2019; Han 2020). In addition, there was a previous study that demonstrated the significant interaction between the cerebellar and cerebral regions in moral task conditions (Han et al. 2016). These points suggest that exclusively associating moral emotion with the cerebellum could not be convincing. Hence, it would be necessary to examine how the cerebrum and cerebellum are connected and interacting with each other instead of exclusively focusing on the cerebellar regions in understanding the big picture of emotional processes and morality at the neural level.

Several neuroimaging studies have reported that the Crus I and Crus II are functionally connected with other brain circuitries associated with moral functioning (Habas et al. 2009; Tang et al. 2013; Van Overwalle et al. 2014), particularly the default mode network and executive network (Chiong et al. 2013; Han et al. 2016; Han 2017). As previously introduced, Han et al. (2016) reported the significant interaction between the cerebellar regions including the right Crus I and Crus II and the default mode network regions, the medial prefrontal cortex and posterior cingulate cortex in particular, in moral dilemma conditions. The aforementioned right cerebellar regions showed the stronger interaction when emotionally provocative dilemmas were presented versus when less provocative dilemmas were presented (Greene et al. 2001, 2004). These default mode network regions, the medial prefrontal cortex and posterior cingulate cortex, have been found to be significantly associated with morality in pervious meta-analyses (Sevinc and Spreng 2014; Boccia et al. 2016; Garrigan et al. 2016; Han 2017; Eres et al. 2017). Also, the regions significantly overlap with regions associated with self-related psychological processes, such as self-referencing and autobiographical memory processing (Levine et al. 2004; Mitchell et al. 2005; Immordino-Yang et al. 2009; Lou et al. 2010; Han 2017). Given self-related processes constitute the basis of moral functioning in the reality, the integration of moral judgment, emotion, and motivation within oneself in particular (Damon 1984; Colby and Damon 1992), the significant functional connectivity between the cerebellar regions and default mode network regions is worth noting. The result may suggest that the cerebellar regions, the Crus I and Crus II in particular, shall be considered as one of hubs in the brain network that organizes interactions between affective and cognitive processes in moral functioning.

Furthermore, Habas et al. (2009) reported a significant connectivity between the right Crus I and II and the executive network including regions in the lateral prefrontal cortex, dorsomedial prefrontal cortex, lateral parietal cortex, and insula (Seeley et al. 2007). According to research in developmental psychology, executive functioning associated with the executive network at the neural level includes abilities required for cognitive control and emotional regulation, such as planning, inhibit control, attentional control, and working memory (Hinnant et al. 2013). These abilities constituting executive function have been known to be needed for sophisticated moral judgment and moral functioning. For instance, the abilities for cognitive and emotional regulations are required for empathizing with others in difficulties and understanding their perspectives; making a sound moral judgment and implementing moral behavior based on the judgment could not be done without the aforementioned abilities (Lahat et al. 2012; Lahat 2015). Given these, the significant connectivity between the right Crus I and Crus II and the executive functioning can be understood as evidence suggesting that the cerebellar regions are in a brain circuitry that connect emotional processes and regulatory processes. Because moral judgment as well as moral functioning in general rely on the interaction and cooperation between cognitive and affective processes (Moll et al. 2003; Han et al. 2016), the cerebellar regions, the Crus I and Crus II, are deemed to play significant roles in the aforementioned interaction and cooperation.

Findings from clinical neuroscience can provide additional evidence to the aforementioned points related to the connectivity between the cerebellar regions and the default mode and executive networks. Tang et al. (2013) compared the functional connectivity between regions in the cerebellum and the default mode network and executive network between participants with versus without antisocial personality disorder. They demonstrated that presence of antisocial personality disorder was associated with the decoupling between activity in the right Crus I and that in the aforementioned two networks. Given both networks play fundamental roles in morality, including moral judgment (Chiong et al. 2013; Lahat 2015; Han et al. 2016; Han 2017), the disrupted connectivity between the networks and Crus I is worth further consideration. The Crus I is a part of the brain network of emotional processes (Adamaszek et al. 2017), so the aforementioned decoupling might be associated with the deficit in emotional processes required for moral functioning (Saver and Damasio 1991; Damasio 1994; Moll and de Oliveira-Souza 2007), and finally, antisocial traits (Tang et al. 2013).

Aspects related to mentalizing is also interesting. Van Overwalle et al. (2014) reported that the right Crus I was connected to the mentalizing network dealing with person and abstract mentalizing. Since mentalizing is about inferring others' beliefs or intentions, this ability is required to make appropriate moral judgment (Harenski et al. 2012b). Particularly, to be able to properly infer others' emotional statuses within problematic situations, feel empathic concern with them, and implement appropriate moral behavior in such situations, the mentalizing abilities are required (Hooker et al. 2008; Harenski et al. 2012b). The evidence may support the point that the right Crus I constitutes a part of the neural circuitry of mentalizing that plays fundamental roles in emotional and motivational aspects of morality.

The cerebellar regions found to be specifically associated with morality, the right Crus I and Crus II, can be regarded as a part of hubs in brain networks constituting the neural basis of morality as discussed so far. Previous meta-analyses and clinical studies have reported that these regions are particularly associated with diverse emotional processes, including emotional perception and regulation (Schutter and van Honk 2005; Schmahmann et al. 2007; Keren-Happuch et al. 2014; Adamaszek et al. 2017), which are required for moral functioning (Moll et al. 2003; Han et al. 2016). Furthermore, neuroimaging studies have shown that the cerebellar regions are closely connected with brain circuitries associated with psychological processes that constitute the basis of moral functioning, the default mode network, executive network, and metalizing network (Habas et al. 2009; Tang et al. 2013; Van Overwalle et al. 2014; Han et al. 2016). The evidence supports the point that the cerebellar regions, the right Crus I and Crus II in particular, are parts of the hubs in a brain that functionally connect different psychological processes, including emotional processes, for moral functioning. Because morality could not be exclusively explained in terms of either reasoning or emotion, but should be understood based on the interaction and cooperation between reasoning and emotion (Moll et al. 2003; Kristjánsson 2012; Han 2016), the cerebellar regions, which have not been sufficiently studied within the context of morality (Demirtas-Tatlidede and Schmahmann 2013), should be further investigated to improve our knowledge of moral functioning.

Concluding remarks and future directions

In this chapter, I examined the association between the cerebellum, emotion, and morality, which has not been well studied in neuroscience. Debates in the fields of moral philosophy, psychology, and neuroscience support the point that emotion is an essential component constituting human morality (Han 2014). Given both clinical and functional neuroscience studies have shown the relationship between activity in the cerebellum and emotion and social functioning (Adamaszek et al. 2017), it would be worth considering how the cerebellum is related to morality. As a way to explore the association, I employed NeuroSynth, a tool for large-scale fMRI data analysis to address the issues associated with reverse inference (Yarkoni et al. 2011; Poldrack 2011) and found that the right Crus I and Crus II showed significant activity in moral task conditions. Based on this finding, the position of the cerebellar regions as parts of a hub in neural networks for emotional as well as cognitive processes that are required for optimal moral functioning was discussed.

Of course, I do not intend to argue that the current chapter can disclose every single aspect of the cerebellum related to emotional and moral functioning. Instead, it would generate novel research questions for and ask neuroscientists to pay attention to the cerebellum, which has been relatively less studies but is deemed to play fundamental roles in morality, in future studies. One point that shall be considered is that the majority of the previous neuroimaging studies that have addressed the cerebellum and emotion have not directly targeted morality as their primary research focus (Demirtas-Tatlidede and Schmahmann 2013; Adamaszek et al. 2017). Rather, they have focused on emotional and social processes in general while not employing morality-related task conditions. Although Han et al. (2016) reported the significant interaction between the cerebellum and default mode network in moral dilemma solving, they started with examining the cerebral regions in the network; the association of the cerebellar regions was found from the while-brain analysis instead of the region of interest (ROI)-based analysis. Hence, based on examinations and discussion in the current chapter, future studies may need to employ moral task conditions while setting the cerebellar regions as ROIs in their neuroimaging analysis for better topic-specific analysis with improved statistical power (Cremers et al. 2017).

Another point related to methodological concerns may also need to be considered in future studies. Although the concerns related to reverse inference were able to be at least partially addressed by employing NeuroSynth, it would not be a perfect solution in research on the cerebellum and morality. Given NeuroSynth conducts analysis based on information of the coordinates of activation foci reported in published articles, it does not analyze full brain images containing statistical information in each voxel (Yarkoni et al. 2011; Eickhoff et al. 2011). Given the relationship between the cerebellum and morality has not been well studied and supported by evidence so far, it would be more informative if large-scale analysis focusing on this topic is performed with full statistical images that can provide more accurate structural information about neural activity in the cerebellum (Salimi-Khorshidi et al. 2009; Han and Park 2019). Although it would be practically difficult to gather full image data instead of coordinates information data, by utilizing technologies to share statistical images (e.g., NeuroVault (Gorgolewski et al. 2015)), the aforementioned aim will be able to be achieved in the long run. Hence, for better large-scale analysis to get accurate information about the functional association between the cerebellum, emotion, and morality, I suggest researchers share image data from their research projects, and finally, conduct topic- and ROI-focused studies based on the shared data.

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