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Medial prefrontal activity during self-other judgments is modulated by relationship need fulfillment

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ABSTRACT

The medial prefrontal cortex (MPFC) plays an important role in representing semantic self-knowledge. Studies comparing semantic self-judgments with judgments of close others suggest that interpersonal closeness may influence the degree to which the MPFC differentiates self and other. We used optical neuroimaging to examine if support for competence, relatedness, and autonomy from relationship partners moderates MPFC activity during a personality judgment task. Participants (N = 109) were asked to judge the descriptive accuracy of trait adjectives for both themselves and a friend. Participants who reported lower need fulfillment with their friend showed elevated activity only in the self-judgment condition; in contrast, participants who reported higher need fulfillment with their friend showed similarly high levels of MPFC activity across the conditions. These results are consistent with the idea that the MPFC differentially represents others on the basis of the need fulfillment experienced within the relationship.

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The medial prefrontal cortex (MPFC) – specifically, the anterior portion of Brodmann's area (BA) 10 – appears to play an important role in representing semantic self-knowledge (Wagner et al., 2012). In a seminal functional magnetic resonance imaging (fMRI) study, Kelley et al. (2002) asked participants to judge personality trait adjectives in three conditions: *Self-referential* ("Does the adjective describe you?"), *Other-referential* ("Does this adjective describe the U.S. President George Bush"?), and *Case-referential* ("Is the adjective presented in uppercase letters?"). Their results indicated that regions within the MPFC were selectively engaged during self-referential judgments. Although this early study was undertaken to examine the memorial advantage of information that is processed in a self-referential manner (Rogers et al., 1977), one of its enduring insights was that self-referential processing is functionally dissociable from other forms of semantic processing in the brain. Since Kelley et al. (2002), the idea that the MPFC plays a key role in representing semantic self-knowledge has been bolstered by numerous other studies and meta-analyses (Martinelli et al., 2013; Northoff et al., 2006; Van der Meer et al., 2010).

Given the association between semantic self-knowledge and the MPFC, a natural turn of interest has been to examine whether relationship characteristics moderate the extent to which the MPFC differentiates the self from others. One illustrative example comes from Krienen et al. (2010). In a careful set of experiments, Krienen et al. (2010) adapted the design of Kelley et al. (2002) to examine the effects of both self-similarity and interpersonal closeness on MPFC activity during self- and other-referential judgments. They found that although activity within the MPFC differentiated close friends from unknown others, it did not distinguish similar and dissimilar friends or similar and dissimilar others. Their results therefore suggested that the MPFC is specifically responsive to the degree of interpersonal closeness that one has with target individuals.

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The optical brain imaging instrumentation utilized in the present research was manufactured by fNIR Devices, L.L.C. Hasan Ayaz was involved in the development of the technology and thus offered a minor share in the firm fNIR Devices, L.L.C.

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Chen et al. (2015) leveraged cultural differences in self-construal to examine the MPFC's responsiveness during self- and other-referential cognition. Interdependent self-construals, more common among Easterners, lead people to see themselves as being connected with others and to define themselves in terms of their relationships; independent self-construals, more common among Westerners, lead people to see themselves in terms of their distinguishing traits and preferences (Markus & Kitayama, 1991). Chen et al.'s (2015) study recruited new Chinese immigrants to the United States. In two fMRI scanning sessions, participants completed a trait-judgment task adapted from Kelley et al. (2002). The first scan, obtained within two months of the immigrants' arrival, found the typical result: greater MPFC activity when participants made trait judgments about themselves relative to when they made judgments about target others – in this study, participants' mothers. During the second scan six months later, this difference remained among those immigrants who became more independent in their self-construal but disappeared among those who became more interdependent in their self-construal. The extent to which the MPFC distinguishes the self from others seems to therefore depend on the importance of that relationship to one's identity.

Other studies seem to contradict the hypothesis that relationship closeness moderates the differences in MPFC activity between self- and other-referential processing. For example, Heatherton et al. (2006) showed that the MPFC is preferentially activated when participants reflected upon their own personality characteristics relative to those of their best friend. Nevertheless, it appears that the preponderance of evidence converges on "the theory that the neural representation of close others in the VMPFC [here, simply the MPFC] lies somewhere between self and unknown others" (Wagner et al., 2012, p. 456). However, a key limitation of the particular studies described above and others in this line is that "relationship closeness" was not directly operationalized and examined. Our goal in the present research was to therefore test the hypothesis that relationship closeness moderates the extent to which the MPFC represents semantic information about the self and others using a more detailed conceptualization and measurement of relationship closeness.

People's fulfillment of basic psychological needs for relatedness, competence, and autonomy is a useful perspective from which to conceptualize and operationalize relationship closeness (Ryan & Deci, 2017). *Relatedness* refers to feelings of being responded to, respected, and important to others. *Competence* refers to feelings of effective and, in the context of relationships, means feeling encouraged and capable. Finally, *autonomy* refers to feeling authentic and being able to openly communicate. A large body of research indicates that when individuals experience their relationship partners as being responsive and supportive of these needs, they are more willing to emotionally rely on those partners and turn to them for support, feel greater relationship satisfaction, security, and commitment, and feel free to "be themselves," especially when it means disclosing aspects of themselves that they generally conceal from others (Ryan & Deci, 2017).

The effects of relationship need fulfillment described above have been understood within the motivational framework of Self-Determination Theory (SDT; Ryan & Deci, 2017). According to SDT, need fulfillment facilitates people's inherent tendencies to continually organize and integrate their experiences and actions into a core sense of *self*. This definition of the self refers to one's direct experience of oneself as an agent that feels, thinks, and behaves. SDT posits that the more one is able to develop and express their self, the more one acts in accord with their abiding values and interests, rather than in response to external social pressures. According to SDT, the psychologically closest relationships – those that people feel most connected to and internalize into their core self – are those in which people experience acceptance and support of the self through the fulfillment of basic psychological needs.

In the present research, we therefore sought to test the hypothesis that relationship need fulfillment moderates MPFC activity when people make self- and other-referential trait judgments. Given that need-fulfilling relationships are psychologically closest to the self, we hypothesized that people reporting higher levels of relationship need fulfillment with a target friend would show similarly high levels of MPFC activity when making self- and other-referential trait judgments; in contrast, those reporting lower levels of relationship need fulfillment were expected to show the typical pattern of greater MPFC activity during the self-referential condition.

Another contribution of the present study is the use of a novel neuroimaging technology with which to compare self- and other-referential judgments. Specifically, we used continuous-wave functional near-infrared spectroscopy (fNIRS), an optical brain imaging technique that measures relative changes in the concentrations of oxygenated and deoxygenated hemoglobin based on the differential absorption and backscattering of infrared light in cortical tissue (Curtin & Ayaz, 2018; Ferrari & Quaresima, 2012; Irani et al., 2007). Previous studies have mostly examined the relationship between self-referential processing and

the MPFC using fMRI and positron emission tomography (e.g., Denny et al., 2012; Moran et al., 2013; Northoff et al., 2006; Van der Meer et al., 2010). To our knowledge, research has yet to examine self- and other-referential processing using fNIRS. FNIRS generates measures of cortical activation that may convey information that is distinct from the fMRI blood-oxygen level dependent signal (e.g., Steinbrink et al., 2006; Strangman et al., 2002). FNIRS therefore affords an opportunity for multi-method validation (Campbell & Fiske, 1959) of the involvement of the MPFC during self-reflection.

Method

Participants

The study was approved by the Social Sciences, Humanities, and Education Research Ethics Board at the University of Toronto. One hundred ten individuals participated in this study for course credit or monetary compensation ($45 CAD).[1] One participant did not complete the study because of problems with the experimental apparatus. The final sample of 109 participants (78 females, 31 males) ranged in age from 18 to 27 (M = 20.30, SD = 2.02). Participants named a friend to serve as the target other in the trait-judgment task. They then completed questionnaires and the trait-judgment task. To prevent order effects, half the participants randomly completed the questionnaires after the task.

Measures

Relationship need fulfillment

Participants completed the 9-item Basic Need Satisfaction in Relationships Questionnaire (BNSRQ; La Guardia et al. (2000) and the 13-item Friendship Need Support Questionnaire (FNSQ; La Guardia et al., 2000) with respect to their nominated friend. Both instruments were used for maximal construct coverage given that the items on these scales might assess different aspects of relationship need fulfillment. Items from the BNSRQ include: "When I am with my friend, I feel free to be who I am" (autonomy), "When I am with my friend, I feel like a competent person" (competence), "When I am with my friend, I feel a lot of closeness and intimacy" (relatedness). Items on the FNSQ include: "My friend tries to understand how I see things," "I feel able to share my feelings with my friend," and "I feel a lot of trust in my friend." Responses on both instruments ranged from 1 (*Not at all true*) to 7 (*Very true*). The BNSRQ (M = 5.83, SD = .82, α = .83) and FNSQ (M = 5.92, SD = .74, α = .90) were highly correlated, r = .76, p < .0001, and thus were averaged into a composite measure of relationship need fulfillment.

Given our hypothesis – that relationship need fulfillment moderates MPFC activity when people make self- and other-referential trait judgments – we were interested to rule out "third variables" that may provide alternative explanations for the expected findings. We expected that relationship need fulfillment would be positively associated with both *relationship length* and people's *global need fulfillment*. We reasoned that relationship length may foster a greater sense of familiarity and wanted to statistically partial-out familiarity from relationship need fulfillment. We also reasoned that global need fulfillment may generally dispose people to internalize representations of important others, bringing those representations subjectively closer to their sense of self (Ryan & Deci, 2017). We therefore also planned to partial-out global need fulfillment from relationship need fulfillment.

Relationship length

Participants indicated the length of their relationship. Relationship length ranged from .5 to 15 years (M = 5.02, SD = 4.21).[2]

Global need fulfillment

To isolate the association between relationship need fulfillment and MPFC activity during the trait-judgment task, we aimed to control for participants general feelings of need fulfillment. We therefore also administered two scales that assess people's general experiences of need fulfillment: the 21-item Basic Psychological Needs Scale (BPNS; Gagné, 2003) and the 18-item Balanced Measure of Psychological Needs (BMPN; Sheldon & Hilpert, 2012). Items include: "I feel like I am free to decide for myself how to live my life" (autonomy), "I have been able to learn new skills recently" (competence), "People in my life care about me" (relatedness). Responses on both instruments were made using a scale ranging from 1 (*Not at all true*) to 7 (*Very true*). The BPNS (M = 5.03, SD = .71, α = .81) and BMPN (M = 4.97, SD = .78, α = .85) were highly correlated (r = .84, p < .0001) and thus were averaged into a composite measure of global need fulfillment.

[1] Different findings from this sample are reported in Di Domenico et al. (2019). This other report did not include measures of relationship need fulfillment, the focus of the present study.

[2] Two participants indicated that they have known their friend "all their life." These responses were winsorized to 15 years, the maximum value indicated by participants who provided numerical responses to this survey question.

Trait-Judgment task

Participants were asked to rate themselves and their nominated friend on 120 trait adjectives obtained from Saucier and Goldberg (1996). The adjectives described two of the "Big Five" personality traits, Conscientiousness and Extraversion. Conscientiousness reflects a tendency to be achievement oriented, self-controlled, and organized. Extraversion, on the other hand, reflects a tendency to be assertive, sociable, and to experience positive emotions. We chose two of the Big Five traits to minimize participant fatigue. Conscientiousness and Extraversion have clear behavioral expressions and are the most accurately perceived of the Big Five (Connelly & Ones, 2010). We accordingly reasoned that they would bolster participants' perceptions to make meaningful responses in the trait-judgment task.

Adjectives for Conscientiousness and Extraversion were taken from Saucier and Goldberg's (1996) factor analysis of familiar English personality adjectives. We used the 60 adjectival markers with the strongest factor loadings on each trait (see Table 2; Saucier & Goldberg, 1996). The trait-judgment task was presented to participants using a block design. The task consisted of 24 blocks in total, 12 for each the self- and friend-conditions. Each condition contained six blocks for Conscientiousness and six blocks for Extraversion. Three blocks contained adjectives for high Conscientiousness and Extraversion (e.g., exacting, assured) and three blocks contained adjectives for low Conscientiousness and Extraversion (e.g., indecisive, shy). Each block consisted of 10 consecutive adjectives for either Conscientiousness or Extraversion.

Figure 1 shows the flow of one trial in the trait-judgment task. Each block began with the presentation of a 3500 ms instruction cue (e.g., *How accurately does this word describe YOU?*) and a rating scale that ranged from 1 (*Inaccurate*) to 9 (*Accurate*). Each trial began with a 500 ms cross-hair fixation in the same display that was followed by the presentation of an adjective for 3500 ms. Participants responded to these adjectives by sliding and clicking a computer mouse cursor with their right hand over the appropriate scale response. Participants were instructed to respond as quickly as possible to each trial. Reaction times (RTs) were defined as the time elapsed from the onset of each trial to the registration of participants' mouse click. After each mouse click, the cursor disappeared. To provide participants with visual feedback, their selected responses flashed on the screen

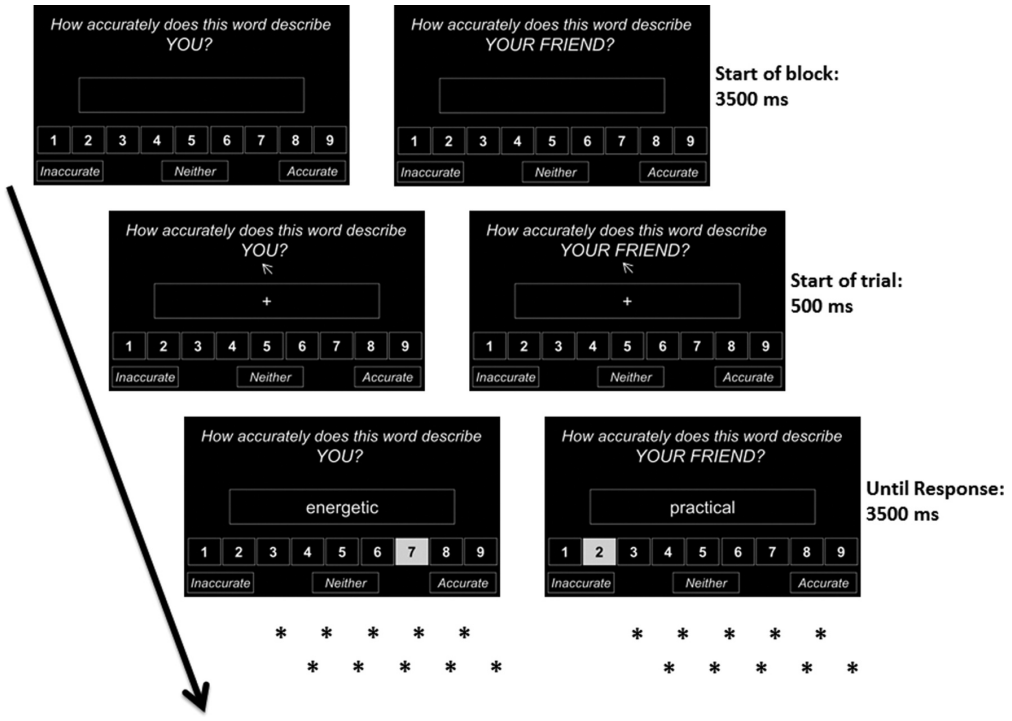

Figure 1. The flow of one trial (4000 ms total) in the personality-reflection task.

for the duration of each mouse click. Participants were instructed to slide the mouse to its original position on the mouse pad after each response. After 3500 ms had elapsed, a new trial began and the location of the mouse cursor was reset to its original position in the middle of the screen.

Pilot testing indicated that some participants experienced difficulty switching between the self- and friend-conditions. To ensure that participants were able to follow task instructions and to reduce the number of times that participants had to switch between conditions, six blocks of each condition were presented consecutively. The order with which the conditions were presented was randomized with the restriction that the 12 blocks of each condition could not be presented consecutively. The order with which the adjectives were presented within each condition was randomized. Before beginning the experiment, participants completed a series of practice trials (five for each condition) to familiarize themselves with the task. The adjectives used for practice were not used in the experiment.

fNIRS procedures and signal processing

Throughout the trait-judgment task, activity of the prefrontal cortex was monitored using the fNIR Imager 1000®, a 16-channel continuous-wave fNIRS system manufactured by fNIR Devices LLC (Potomac, MD; www.fnirdevices.com). The system is composed of two components: a sensor pad with a source-detector separation of 2.50 cm and a data acquisition control box running Cognitive Optical Brain Imaging (COBI) Studio software. The sensor pad had a temporal resolution of 500 ms per scan, a penetration depth of 1.25 cm into the prefrontal cortex, and LED light sources with peak wavelengths at 730 nm and 850 nm. The sensor pad was secured in alignment with the electrode positions F_7, F_{P1}, F_{P2} and F_8 based on the International 10/20 system (Jasper, 1958). This positioning corresponds to Brodmann areas 9, 10, 45 and 46. Figure 2 displays the location and registration of each channel of the sensor pad on a standard MRI template (see, Ayaz et al., 2006). Channels covering the anterior frontal pole (7, 8, 9, and 10; BAs 9 and 10) defined the MPFC, our *a priori* region of interest.

After acquisition, a trained experimenter visually inspected the recorded light intensities and excluded all saturated channels. Signal and physiological artifacts were then excluded with a low-pass filter consisting of a finite impulse response and with a linear phase filter with an order of 20 and a cutoff frequency of 0.1 Hz (Ayaz et al., 2012; Izzetoglu et al., 2005). A sliding-window motion artifact rejection algorithm was then applied to the filtered light-intensity data to exclude motion artifacts (Ayaz et al., 2010). Activation segments were extracted using time-synchronization markers received via a serial connection from the computer used to display the trait-judgment task. Relative changes in concentrations of oxygenated hemoglobin (Δoxy-

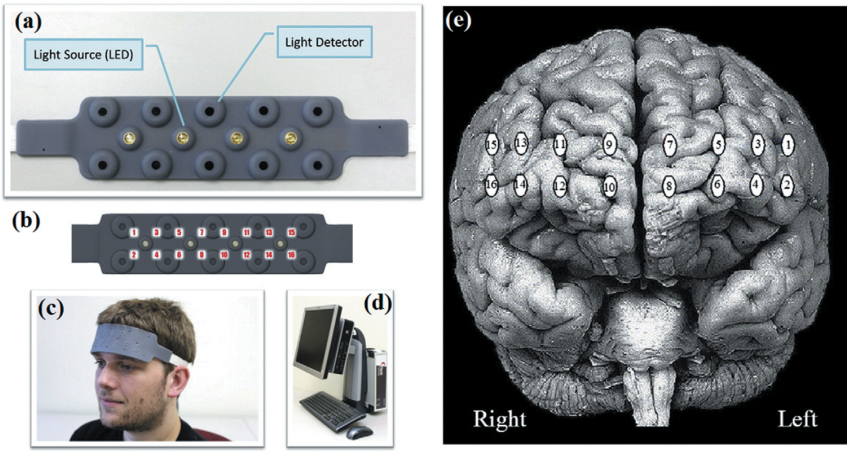

Figure 2. (a) fNIR sensor pad with four light emitting diodes (LEDs) and ten photodetectors. (b) The 16-channel sensor pad. (c) Placement of sensor pad in alignment with F7, FP1, FP2 and F8. (d) fNIR Imager 1000® control box running COBI Studio Software. (e) Measurement locations (channels) of the fNIRS sensor pad registered on MRI templates. Channels 7, 8, 9, and 10 defined the MPFC, our a priori region of interest. The brain surface image is from the University of Washington Digital Anatomist Project. Adapted with permission from Ayaz et al. (2012)

Hb) for each activation segment were calculated via modified beer lambert law and local baseline approach using segment at beginning of each task block. Average of each block is then calculated for statistical analysis across all task conditions and participants.

Results

Data analytic approach

The data were analyzed with multilevel regression models (Snijders & Bosker, 2012), which took into account that the experimental trials and blocks were nested within participants, that the data were unbalanced across participants, and that relationship length and need fulfillment were continuous predictors. We estimated random intercept models using the method of maximum likelihood, an unstructured covariance matrix, and the "between-within" method of estimating degrees of freedom (Schluchter & Elashoff, 1990). Preliminary analyses indicated that relationship need fulfillment was significantly correlated with both relationship length, $r = .32$, $p < .001$, and global need fulfillment, $r = .53$, $p < .0001$. We thus included relationship length and global need fulfillment as covariates when testing the effects of relationship need fulfillment on RTs and MPFC activity across the self- and friend-conditions.

Behavioral analyses

We first examined if RTs differed across the experimental conditions. A multilevel model predicted RTs from an effect-coded variable representing the main conditions of the trait-judgment task (friend = −1, self = 1). Results indicated that RTs were faster in the self-condition relative to the friend-condition, $b = -24.15$, $SE = 3.60$, $p < .0001$. We then tested an elaborated model which included a conditional effect for relationship need fulfillment and a term for the interaction between the experimental conditions and relationship need fulfillment. This elaborated model provided better fit to the data, $\Delta\chi^2(2) = 14.33$, $p = .001$. The conditional effect for relationship need fulfillment was not significant, $b = -4.42$, $SE = 40.12$, $p = .91$. However, this model did indicate a significant interaction between the experimental conditions and relationship need fulfillment, $b = 18.67$, $SE = 4.93$, $p < .001$. This significant interaction is illustrated in Figure 3. The interaction was examined following the methods of Aiken and West (1991). While participants reporting higher relationship need fulfillment (+ 1 *SD*) exhibited less pronounced differences in RTs across the self- and friend-conditions, $b = -9.07$, $SE = 5.37$, $p = .091$, those reporting lower relationship need fulfillment (−1 *SD*) exhibited significantly faster RTs in the self- relative to the friend-condition, $b = -36.34$, $SE = 4.83$, $p < .0001$. This pattern is consistent with the hypothesis that people who experience higher need fulfillment with a friend process and represent information of that friend in a manner similar to the self.

ROI fNIRS analyses

We first examined if oxy-Hb levels differed across the experimental conditions. A multilevel model predicted oxy-Hb within the MPFC across the conditions of the trait-judgment task (friend = −1, self = 1). As expected, oxy-Hb was greater in the self- relative to the friend-condition, $b = .05$, $SE = .02$, $p = .0294$. We next examined a model that included a conditional effect for relationship need fulfillment and a term for the interaction between the experimental conditions and relationship need fulfillment. This elaborated model provided better fit to the data, $\Delta\chi^2(2) = 7.35$, $p = .025$. The conditional effect for relationship

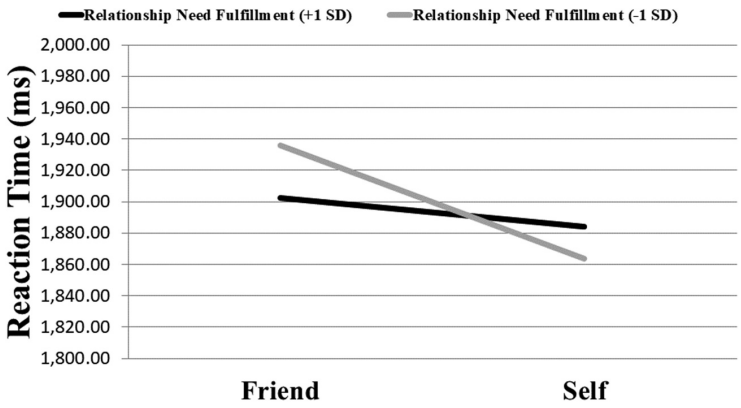

Figure 3. Predicted reaction times across the self- and friend-conditions and levels of relationship need fulfillment.

need fulfillment was not significant, $b = .36$, $SE = .23$, $p = .110$. However, this model did indicate the expected interaction between the experimental conditions and relationship need fulfillment, $b = -.07$, $SE = .03$, $p = .027$. This significant interaction is illustrated in Figure 4. Consistent with hypotheses, whereas participants reporting higher relationship need fulfillment (+ 1 *SD*) exhibited similarly elevated levels of oxy-Hb across the self- and friend-conditions, $b = -.01$, $SE = .04$, $p = .836$, those reporting lower relationship need fulfillment (−1 *SD*) exhibited significantly greater oxy-Hb levels in the self- relative to the friend-condition, $b = .10$, $SE = .03$, $p = .002$.

Supplemental analyses

We conducted two sets of supplemental analyses to test the robustness of our results, which are detailed in the Supplemental Materials. First, we ran multilevel models for both RTs and oxy-Hb that included relationship length, global need fulfillment, and their interactions with the experimental conditions as predictors. This analysis enabled us to test the moderating effect of relationship need fulfillment over and above the possible moderating effects of both relationship length and global need fulfillment during the trait-judgment task. Similar to the results reported above, relationship need fulfillment continued to moderate both RTs and oxy-Hb levels even after statistically controlling for these variables. Second, using the ratings that participants made during the trait judgment task, we examined if participants reporting higher relationship need fulfillment rated themselves more similar to their friends in the trait-judgment task than those reporting lower relationship need fulfillment.[3] Results indicated that participants reporting higher relationship need fulfillment did not rate themselves as being more similar to their friends, suggesting that our findings for both RTs and Oxy-Hb levels were not artifactually produced by perceived self-other similarity in personality traits.

Discussion

Neuroimaging studies indicate that the medial prefrontal cortex (MPFC) plays an important role in representing semantic self-knowledge. Previous studies in this line have specifically shown that the MPFC is preferentially engaged when people are asked to reflect upon themselves relative to when they are asked to reflect upon other people (Denny et al., 2012). The present findings indicate that relationship need fulfillment moderates this well-established finding: participants who reported lower levels of need fulfillment with their friend showed elevated activity only in the self-judgment condition; in contrast, those who reported higher levels of need fulfillment with their friend showed similarly high levels of MPFC activity across the conditions. These results were complemented by behavioral analyses, which indicated that whereas participants reporting lower relationship need fulfillment had longer RTs when making judgments about their friends, those reporting higher relationship need fulfillment had similar response latencies across the conditions.

These results are therefore consistent with the idea that the MPFC differentially represents others on the basis of the need fulfillment experienced within the relationship. These results converge with contemporary relationships research (e.g., Aron et al., 2004) showing that people expand their self-concept to include representations of others with whom they have close relationships. Indeed, the present results align with the results of

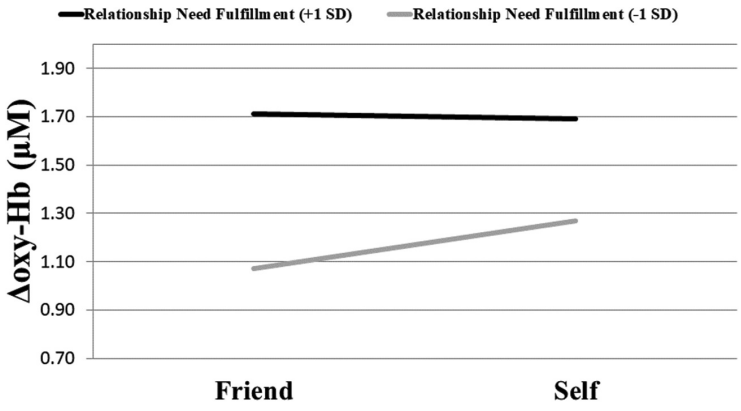

Figure 4. Predicted Δoxy-Hb response in the MPFC across the self- and friend-conditions and levels of relationship need fulfillment.

[3]We thank a reviewer for suggesting this analysis.

Deci et al. (2006), who found that perceived need support from a close friend predicted the extent to which people incorporate that friend into their self-concept.

One question for that warrants attention in future studies is the possible interaction between global need fulfillment and relationship need fulfillment in the prediction of neural self-other similarity. As suggested by a reviewer, people who experience generally low levels of need fulfillment but high levels of need fulfillment in a particular relationship may evidence particularly pronounced self-other similarity effects. Interestingly, phenomenon that is somewhat opposite to this has been previously documented in SDT research. Specifically, Przybylski et al. (2009) found that whereas avid video game players reporting low levels of need fulfillment in daily life were prone to more obsessive passion for need-fulfilling games, those reporting high levels of need fulfillment reported less compulsion to play. The present sample of 109 participants was inadequately small to properly test a three-way interaction between global need fulfillment, relationship need fulfillment, and the experimental conditions on MPFC activity (our unreported test of this interaction was not significant). Future studies ought to explore these possible *need density* effects (Rigby & Ryan, 2011).

Future research should more closely examine the precise mechanisms driving the current findings. One possibility is that the degree of MPFC activity during self-reflection is associated with the self-relevance attached to particular identity representations (D'Argembeau, 2013; D'Argembeau & Salmon, 2012; Northoff & Bermpohl, 2004; Schmitz & Johnson, 2007; Wagner et al., 2012). As D'Argembeau and Salmon (2012, p. 283) put it, "the MPFC might sustain the process of identifying oneself with versus distancing oneself from particular mental contents (e.g., thoughts, opinions, preferences), which would therefore be regarded as 'me' (or 'mine') versus 'not-me' (or 'not-mine')." Considered from the perspective of the present findings, this idea would suggest that people attribute a higher degree of self-relevance to mental representations of need-fulfilling relationship partners and possibly even need-fulfilling activities.

Indeed, motivational psychologists, especially those working within the tradition of SDT, have long used the concept of *internalization* to describe the process by which one takes in values, beliefs, or goals from external sources and transforms them into one's own (Ryan & Connell, 1989) – a process that is facilitated by ambient supports for relatedness, competence, and autonomy and associated with enhanced performance and wellness (Ryan & Deci, 2017). The present results, together with the idea that the MPFC may locate mental representations on a continuum of self-relevance, therefore encourage us to speculate that the MPFC may play a role in the internalization process. Some support for this idea comes from studies of persuasion-induced attitude change. Falk et al. (2010) presented participants with persuasive messages about the safety benefits of sunscreen during fMRI and found that the degree of MPFC activity exhibited during the persuasive message predicted positive changes in participants' sunscreen use in the week following the scanning session. In a similar study, Falk et al. (2011) presented smokers in a cessation program with commercials that encouraged quitting during fMRI and found that the degree of MPFC activity during the commercials predicted reduced smoking. In their discussion of these findings, the authors speculated that the degree of MPFC activity when viewing the commercials might have reflected "an implicit connection between the self and the behavior in question (in this case quitting)" (p. 182). It may thus prove fruitful for future applied studies on the internalization process to adapt the innovative methods of Falk and colleagues to examine the possible mediating role of MPFC in the link between need fulfillment and internalization in the prediction of real-world outcomes.

Three limitations of the present study should be noted. One limitation was that our fNIRS system was only sensitive to hemodynamic changes within the top 2 to 3 cm of the cerebral cortex. While suitable for examining the anterior portion of the MPFC (BA 10), the MPFC is a single component in a broader network of cortical midline structures (CMS) that are commonly recruited during tasks that involve self-referential cognition. The CMS include the anterior cingulate cortex (BA's 24, 25, 32), the posterior cingulate cortex (BA 23), the medial parietal cortex (BA's 7 and 31), the retrosplenial cortex (BA's 26, 29, and 30), as well as the more dorsal aspects of the MPFC (BA 9; Northoff & Bermpohl, 2004; Northoff et al., 2006). Future studies using fMRI will be needed to determine if the effects documented in this study generalize to other CMS. Another limitation concerns the sample from which our population was drawn. We recruited university students who ranged between 18 and 27 years of age. These participants fell within the development period known as *emerging adulthood*, which characterized both by its demographic instability (e.g., changes in residence, marital status, and educational/occupational status) and identity explorations in love, work, and worldview (Arnett, 2000). Given the important changes that define this developmental period, it stands to reason that emerging adults are particularly sensitive to need fulfilling relationships, particularly as they concern matters of

self and identity. Future research should therefore test whether the present effects generalize to other developmental epochs. Finally, the cross-sectional design of the present study should be noted. We cannot ascertain if self-other similarity overlap in the MPFC is caused by relationship need fulfillment or if perceptions of relationship need fulfillment are caused by self-other similarity in the MPFC. Longitudinal designs will be required to properly determine the directionality of this relationship.

Notwithstanding these limitations, we believe the present study offers a meaningful contribution to empirical work examining semantic processing during self- and other-referential judgments. Perhaps most importantly, the present study demonstrates the productive two-way street between neuroscience and relationships research. Frameworks for understanding relationships can help to guide neuroscience hypotheses and synthesize neuroscience findings; neuroscience methods offer new, additional methods for reexamining human relationships.

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