

RUNNING HEAD: Fulfilling the need for social connection

Recalling prior experiences with a close other can fulfill the need for social connection

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Link to Data from Study 1 and 2 is available on the Open Science Framework at the following link (Ross & Inagaki, 2022):

https://osf.io/nue32/?view_only=4c63091eb51340c89abe5749cf47783

Abstract

Humans need social connection to thrive, but how we fulfill this need is not well understood. Numerous theoretical perspectives propose that continual positive experiences with a close other fulfill the need for social connection. Despite popular acceptance for this notion, little research has investigated the consequences of having multiple experiences with a close other. As a first step toward this goal, the current studies assessed whether recalling prior experiences of social connection with a close other alters feelings of satisfaction toward the same person, the implications of such feelings for social desires outside of the lab (Study 1), and possible brain mechanisms related to fulfilling the need for social connection (Study 2). Consistent with hypotheses, recalling experiences increased feelings of satisfaction toward the close other, but not toward an acquaintance. Further, recalling prior experiences uniquely increased the desire for additional social interaction with the close other, as compared to others in general. In Study 2, brain regions related to satiety – the ventral striatum (VS) and ventromedial prefrontal cortex (VMPFC) – showed different patterns to recalling prior experiences with a single close other such that VS activity decreased over recalled experiences, while VMPFC activity remained stable. VMPFC activity, but not VS activity, to recalling experiences with a close other was associated with greater feelings of satisfaction. Together, results are consistent with the proposal that positive experiences, particularly with close others, satisfy the need for social connection. Implications for preventing feelings of social disconnection and maintaining social relationships over time are discussed.

Keywords: need to belong; satiation; loneliness; habituation; sensitization;
autobiographical recall

Humans share a persistent need for close social connection. Strong evidence for this fact comes from observational and correlational findings demonstrating severe consequences when deprived, even temporarily, of social connection (Baumeister & Leary, 1995; Cacioppo & Cacioppo, 2014; Durkheim, 1951; MacDonald & Leary, 2005). Indeed, we strive for connection and as a consequence, thrive when socially fulfilled – the contented feeling of satisfaction arising when one’s desire for social connection is met. How we fulfill the need for social connection and, in particular, the neural mechanisms related to “social satiety” are unclear. The current studies, therefore, test whether recalling previous experiences of social connection with a close other fulfills the need for social connection and whether resulting feelings of satisfaction have implications for social interaction outside of the lab (Study 1). We also examine neural correlates that may relate to fulfilling the need for social connection via the recall of prior experiences with a single close other (Study 2).

According to need to belong theory, the need for social connection is fulfilled by (1) frequent, affectively pleasant interactions with an ongoing relationship partner, (2) in the context of concern for each other’s welfare (Baumeister & Leary, 1995). In other words, positive experiences with a close other might fulfill the need for social connection. By extension, experiences with someone less close, such as an acquaintance, would fail to fulfill the need. Despite the impact and general acceptance of hypotheses from the need to belong theory, few have tested the basic premise that positive experiences with a close other satisfies the need for social connection. Indeed, fulfilling any need involves an iterative process involving, at minimum, experiences of acceptance free from negativity.

Recalling prior experiences with a close other, where one vividly relives prior positive experiences, may contribute to this iterative process (i.e., potentially by increasing the frequency with which positive experiences with a close other are re-experienced or processed; Bluck & Alea, 2002). Given that recalling positive social experiences with a close other are subjectively more valuable than recalling positive non-social experiences (Speer & Delgado, 2020) coupled with suggestions that recalling prior autobiographical experiences (i.e., episodic simulation) can create novel current experiences (Mildner & Tamir, 2019) it is possible that recalling prior experiences of social connection with a close other contributes to fulfilling the need for social connection.

A useful analogy for understanding social satiety comes from the literature on loneliness – a state indicating that one’s “basic human need for connection is not being met” (Peplau, Russell, & Heim, 1978) – where the need for connection is likened to the need for food (Gardner, Pickett, & Brewer, 2000; Gewirtz & Baer, 1958; Gewirtz, Baer, & Roth, 1958). Just as one yearns for or craves palatable food when hungry and feels sated after consumption, so too might one hunger for social connection when lonely and feel satisfied after an experience with a close other, possibly even after recalling a prior experience. Despite many important differences between the need for food and the need for social connection, clues for understanding of the brain mechanisms that fulfill the need for social connection may come from the literature on satiety to palatable food.

Brain imaging findings consistently identify the ventral striatum (VS) and ventromedial prefrontal cortex (VMPFC) in satiety, key nodes of the brain’s valuation circuitry (Berridge, 2009; Knutson & Cooper, 2005; O’Doherty, 2004). Fasted states,

intended to induce hunger, are associated with an increase in VS activity to pictures of food (Fletcher et al., 2010; Goldstone et al., 2009) and a subsequent decrease in VS activity to the same stimuli once satiated (Thomas et al., 2015; Kringelbach, O'Doherty, Rolls, & Andrews, 2003). In Positron emission tomography (PET) scanning, VMPFC activity shows a sustained response over trials as participants consume to satiety and then a decrease once satiated (Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001). VMPFC activity to images of food is also correlated with the experience of the food stimuli (e.g., pleasantness, desirability) suggesting the VMPFC tracks the subjective experience of consumption (Goldstone et al., 2009; Kringelbach et al., 2003; Rolls & McCabe, 2007). Beyond findings from the food satiety literature, the VS and VMPFC have well-characterized functions in processing pleasant stimuli with the VS coding the motivating properties of a stimulus, and the VMPFC coding the attainment or fulfillment of the stimulus (Berridge, 2009; Berridge & Kringelbach, 2008; Knuston & Cooper, 2005). Both regions have long been hypothesized to contribute to social connection with close others (Aron et al., 2005; Eisenberger et al., 2011; Inagaki et al., 2015; Panksepp, 1998).

Returning to the brain's response to social connection, heightened VS activity in response to social stimuli in those with unfulfilled social connection needs mirror findings from the food satiety literature. Higher feelings of loneliness (Inagaki et al., 2016a), and yearning for a deceased loved one (O'Connor et al., 2008) have each separately been associated with higher VS activity in response to viewing images of close others. Such findings are mirrored in the addiction literature where higher reports of craving for alcohol and nicotine are correlated with higher VS activity to images of the

same stimuli (David et al., 2005; Schacht, Anton, & Myrick, 2013). On the other hand, longer relationship length and higher perceived support, two likely correlates of a satisfying social connection, are associated with greater VMPFC activity to images of the close other (Eisenberger et al., 2011). Taken together, VS activity as assessed over recalled experiences of social connection may signal craving for social connection whereas VMPFC activity may indicate fulfillment. An interaction pattern between time and the two regions may thus lead to social satiety (Groves & Thompson, 1970). However, whether recalling prior experiences with the same close other would produce such patterns of activity has not been tested.

The current studies assess whether recalling prior experiences with a close other temporarily fulfills the need for social connection. Study 1 assesses feelings of satisfaction in response to recalling four prior experiences of social connection with a close other or an individual who is known, but not close (i.e., an acquaintance). As a preliminary test of the implications of recalling prior experiences for future social interaction, Study 1 also assesses whether recalling prior experiences might alter the desire for continued social interaction with the same individual outside of the lab. Study 2 then examines the neural correlates of social satiety focusing on activity in the VS and VMPFC to recalling prior experiences with a single close other. To our knowledge this is the first set of studies of its kind, thus we borrowed from prior research on habituation and satiety in the lab (e.g., Fischer, Wright, Whalen, McInerney, Shin, & Rauch, 2002; Kringelbach et al., 2003; Small et al., 2001) and examined the dependent variables from Study 1 and 2 with a simple comparison of the first half compared to the second half of the tasks.

Following the current theoretical perspective, we hypothesized that recalling prior experiences of social connection with a close other would lead to greater feelings of satisfaction, as compared to recalling prior experiences with an acquaintance. Recalling prior experiences in the experimental setting may alter the desire for interaction with the same individual 48 hours later in one of two ways: reducing the desire for additional contact, perhaps indicating the need for social connection has been met for the time being; or alternatively, increasing the desire for additional contact, potentially indicating that satisfaction sensitizes us (i.e., renders us more responsive) to social contact. Based on previous neuroimaging findings (Inagaki et al., 2016a) and the existing literature on satiety to palatable food, we anticipated an interaction between brain region (VS and VMPFC) and time (first half vs. second half) such that VS activity in response to recalled experiences with a close other decrease from the first to second half of blocks, while VMPFC activity sustains.

Study 1

Method

Participants

One hundred and fifty-one participants (M age = 18.93, \pm 1.84 years, range 18-34, 64% female, $n = 76$ in close other condition) completed the current study in exchange for course credit. We report how we determined our sample size, all data exclusions, all manipulations, and all measures in Study 1 and 2 (see below for more about Study 2). Sample size was determined following a power analysis in GPower (Erdfelder, Franz, & Buchner, 1996) on the primary comparison of feelings of satisfaction between condition. With a desired medium effect size of .50, alpha of .05,

and 80% Power, 64 participants per condition was deemed sufficient. The authors note that approaches published well after the current power analysis was conducted suggest the current power analysis may have overestimated potential effects (Lakens & Caldwell, 2021). A sample of 151 total participants was ultimately collected in order to protect against data loss for the follow-up measure. Participants self-identified as 69% White, 16% Asian, 4% African-American, and 11% mixed or other. 2% of the sample identified as Hispanic/Latinx. Procedures were approved by the Institutional Review Board of the University of Pittsburgh, and all participants provided informed consent prior to study procedures. Participants received 1 research credit in exchange for their participation.

Lab task

In a 2 x 2 mixed design, participants were randomly assigned to one of two conditions – one in which they were asked to identify a close other or another condition in which they were asked to identify an acquaintance. Participants were then instructed to recall (i.e., relive) pleasant social experiences with the same individual for a total of four unique experiences. Reliving emotional experiences is a common manipulation in psychology and neuroscience studies (Anderson & Galinsky, 2006; Ayduk, Mischel, & Downey, 2002; Kahneman, Krueger, Schkade, Schwartz & Stone, 2004; Kross, Berman, Mischel, Smith, & Wager, 2011; Meyer, Williams, & Eisenberger, 2015) that also alters feelings of social connection (e.g., Inagaki & Eisenberger, 2016; Poerio, Totterdell, Emerson, & Miles, 2016; Speer & Delgado, 2020). The method also allows participants to imagine personally relevant, meaningful social experiences irrespective of challenges posed by physical distance.

The first instructions from each condition read as follows: *Take 5 minutes to imagine a time when you had a pleasant interaction with a [loved one or acquaintance] in your life. Try to really immerse yourself in the experience by remembering as many details as you can and reliving the experience. For example, what happened during this interaction?, What did you do together?, Was it a special occasion or a normal day?, How did you feel? Choose an interaction with [someone who you share a close, positive relationship with such as a friend, family member, or romantic partner/someone who you don't know well or who you know, but don't feel particularly close to such as a coworker or acquaintance]. This page will automatically advance after 5 minutes has passed.*

Instructions for the subsequent trials asked participants to “*take 5 minutes to imagine a different time you had a pleasant interaction with THE SAME [loved one or acquaintance] you previously wrote about.*” In order to standardize the amount of time participants spent reliving their experience, Qualtrics, the program used to present instructions, automatically advanced after 5 minutes had passed. Participants were then given an unlimited amount of time to write about their experience (“*Please write about the interaction that you just imagined using the space below. In order to protect the privacy of the person you are writing about, please do not use names.*”).

Writing samples from the close other condition include (note that samples are heavily revised to remove personal and identifying information): “*...my friend and I had decided to go downtown for a day. We both like art, so we went to the [art museum]. We walked around for hours looking at paintings, making jokes, and generally just spending some quality time together. When we were done, we walked around downtown and saw*

the city Christmas tree (it was December), then got sushi, which was kind of our "thing" we always did together." and "The first thing that comes to mind is a recent trip I took ...with my girlfriend. I hadn't seen her since I moved into college, and she was...visiting for the week. I remember the feeling of excitement I had in anticipation of showing her parts of [the city] neither of us had seen before... Before her visit, I was worried about possibly falling out of touch with her, and I remember a feeling of relief as I was able to reconnect with her and realize our love was not tarnished by the distance and time apart. It was a really nice experience, and one of my favorite moments with her."

Writing samples from the acquaintance condition include: *"My friend brought [the acquaintance] with us when we decided to go out to dinner. We had put our work out clothes on but decided last minute that we weren't in the mood to run. We were walking down the hill and laughing at ourselves and the fact that we had gone through so much trouble to get ready to exercise but instead were going to eat food. Throughout dinner we all talked about our experiences over the last week and if we had high hopes for the year. I felt like I had made a new friend and that making friends wasn't as hard as I thought it would be."* and *". . .I was a mentor for the younger riders and I was there to assist them in whatever ways they needed me. When I arrived at the competition, I was partnered up with another girl my age who I had seen many times before, but never talked to. We realized that we were the same age and we spent the whole day working together. We had a really fun day and realized that we are actually super similar. I just remember laughing really hard with her and having a ton of fun, even though we had just officially met."*

After writing, feelings of satisfaction were collected with the item: *to what extent do you feel satisfied with your relationship with this person?* (1 – not at all, 4 – moderately, 7 – very much so). The item was selected from the Relationship Assessment Scale (Hendrick, 1988) and re-worded to be relationship-specific. The simplest analytical approach to assess habituation and sensitization in the brain imaging and psychophysiology literature is to divide responding into two equal sections and compare activity across time (e.g., Fischer et al., 2002). Following this approach, satisfaction following the first two recalled experiences were averaged to compare to the second two recollections (i.e., first half vs. second half). This analysis approach also matches the approach taken for the imaging analyses in Study 2.

Feeling outside of the lab: Follow-up survey

It is possible that the effects of recalling prior experiences of social connection persist beyond the lab setting. That is, reliving experiences might temporarily decrease the desire for continued interaction. Another hypothesis is that reliving sensitizes, or increases the desire for interaction. Therefore, approximately 48 hours after the lab session, participants were emailed a follow-up survey to report on their desire for additional social interaction. We reasoned that 48 hours away from the lab would be a sufficient break after the task, and would also be a short enough time period to keep participants engaged in the study. Indeed, the majority of participants (99%) completed the follow-up survey. Instructions asked participants to report on their current desire for additional social interaction with the individual they wrote about since leaving the lab: *I want to spend time with this person* and *I want to contact this person* ($r = .924$).

To assess the specificity of the findings to the individual chosen for the lab task, participants also reported on their general desire for additional social interaction with others. Thus, participants were asked to think about their general feelings toward other people in their life since leaving the lab prior to responding to the same questions as outlined above ($r = .815$). Responses to the 2 items for the individual participants wrote about and general others were averaged separately. Two participants failed to respond to the follow-up survey, leaving a sample of 149 for analyses with the follow-up questions ($n = 75$ from close other condition, $n = 74$ from acquaintance condition). We note that this sample size is still above the predetermined cutoff from the power analysis.

Data analyses

Data were analyzed in SPSS (v. 28.0). Repeated measures ANOVA tested the interaction between condition (close other vs. acquaintance) and time of the task (first half vs. second half). The interaction was further interrogated with paired samples t-tests to assess feelings of satisfaction across time in each condition separately.

For the follow-up survey that measured desire for additional social interaction, repeated measures ANOVA tested for an interaction between condition (close other vs. acquaintance) and social target (the individual participants wrote about during the lab session vs. other people). Significant interactions were further interrogated with independent samples t-tests to assess differences between condition and paired samples t-tests to assess differences between social target. Significance was determined at a $p < .05$, two tailed, Bonferroni corrected for multiple comparisons and a bias corrected and accelerated 95% confidence interval excluding 0. Data can be found

on the Open Science Framework:

https://osf.io/nue32/?view_only=4c63091eb51340c89abe5749cf477835

Results

Satisfaction to the lab task

To assess whether reliving prior experiences with a close other temporarily fulfills the need for social connection, an interaction between condition (close other vs. acquaintance) and time (first half vs. second half of the task) was run. There was no main effect of time ($F(1, 149) = .003, p = .956$). Instead, the main effect was qualified by an interaction ($F(1, 149) = 5.543, p = .020$) which was further evaluated to compare feelings of satisfaction from the first half of the task to the second half of the task in each condition separately.

Simple effects were not significant, but given the primary hypothesis, we describe the pattern of results for interested readers. Feelings of satisfaction with the close other *increased* after reliving prior experiences (M first half = 6.026, $SD = 1.508$; M second half = 6.138, $SD = 1.493$; $t(75) = 1.898, p = .062$, BCa 95% CI = [-.236, 0.000], Cohen's $d = .217$). Feelings of satisfaction with the acquaintance, however, did not change after recalling prior experiences (M first half = 5.013, $SD = 1.346$; M second half = 4.907, $SD = 1.552$; $t(74) = 1.485, p = .142$, BCa 95% CI = [-.034, .243], Cohen's $d = .171$).

Desire for social interaction outside of the lab

Recalling prior experiences of social connection in the lab may have implications for feelings outside of the lab. Therefore, the interaction between condition and social target (the individual participants wrote about during the lab session vs. other people) was run to assess whether condition preferentially influenced the desire for additional

social interaction (i.e., a potential consequence of sating the need to connect). There was a main effect of social target such that desire for additional social interaction was higher for interacting with others (vs. the individual participants wrote about during the lab session; $F(1, 147) = 7.900, p = .006$), but the main effect was qualified by an interaction ($F(1, 147) = 38.261, p < .001$; Fig. 1).

For those in the close other condition, the desire for additional social interaction with the individual they wrote about was higher ($M = 6.247, SD = 1.422$) than the desire to interact with others ($M = 5.760, SD = 1.220, t(74) = 2.662, p = .010, \text{BCa } 95\% \text{ CI} = [.135, .843], \text{Cohen's } d = .307$). However, the opposite pattern emerged for those in the acquaintance condition. The desire for additional social interaction with the acquaintance was lower ($M = 4.223, SD = 1.856$) than the desire for additional social interaction with others ($M = 5.520, SD = 1.136, t(73) = 5.803, p < .001, \text{BCa } 95\% \text{ CI} = [1.717, .874], \text{Cohen's } d = .675$).

As further evidence for the specificity of the findings to a close other, and as expected, the desire for additional social interaction was greater for the close other compared to the acquaintance ($t(147) = 7.476, p < .001, \text{BCa } 95\% \text{ CI} = [1.483, 2.565], \text{Cohen's } d = .487$). However, there was no difference between conditions for the desire to interact with others, suggesting that the current pattern of results are not attributable to participants in the acquaintance condition having a lower desire to interact with or socialize with other people in general ($t(147) = 1.241, p = .217, \text{BCa } 95\% \text{ CI} = [-.136, .601], \text{Cohen's } d = .274$).

Study 1 - Discussion

Close social connection is necessary for optimal functioning throughout the lifespan (Bowlby, 1988; Hofer, 1973; Harlow, 1958; Gunnar, 2017; Baumeister & Leary, 1995; Reis, Collins & Berscheid, 2000). Prior findings also suggest feelings of satisfaction are important for maintaining relationships over time (Le, Dove, Agnew, Korn, & Mutso, 2010). Results from Study 1 further clarify which social targets might best fulfill social connection needs. Thus, recalling experiences with a close other increased feelings of satisfaction over time, whereas recalling experiences with an acquaintance did not; and recalling prior experiences with a close other increased, rather than decreased, the desire for additional social interaction with the same individual, but not with others more generally. Together, the results of Study 1 suggest that recalling prior experiences with a close other may fuel both satisfaction and socializing with the same person even in a relationship in which satisfaction is already high. Future research aimed at clarifying the moderating role of closeness to the target of social connection will be important for understanding who best fulfills the need to connect.

Study 1 successfully increased social satisfaction with the use of the recall of past experiences. Thus Study 1 informed the design and analyses for Study 2. Specifically, the lab paradigm from Study 1 was optimized for the neuroimaging environment in order to assess neural mechanisms related to fulfilling the need for social connection with a self-identified close other.

Study 2

Participants

Forty-two participants were recruited through a voluntary research registry (University of Pittsburgh's Pitt + Me). Prior to enrollment, participants were screened for current physical or mental illness, medication other than birth control, and contraindications for MRI or the MR environment (non-removable metal, claustrophobia, weight above 400 pounds, pregnancy). Sample size was determined by a power analysis in fMRIpower (Mumford & Nichols, 2008) using results from our previous research with a similar imaging task (Inagaki et al., 2016a; Inagaki et al., 2016b). Using mean parameter estimates from the same VS ROI as used in the present analyses in response to a similar task in which participants view images of a close other, we determined that with between 35 and 40 participants, we would have at least 80% power to detect a medium effect (Cohen's $d = .40$) in the VS at a $p < .05$, one-tailed. Data collection ended once 40 participants with complete data (imaging scans and post-scan self-report) had been obtained.

Two participants were excluded for technical difficulties during scanning leaving a final sample of 40 participants (M age = 26.43, $SD = 5.611$, range 19 – 40, 21 females). Participants self-identified as 60% White, 15% Asian, 20% Black, and 2% mixed race or other races. 17.5% of the sample identified as Hispanic/Latinx. Procedures were run in accordance with the University of Pittsburgh and Carnegie Mellon University's Institutional Review Boards, and all participants provided informed consent before completing procedures. Participants were paid \$35 USD for their participation.

Method

Scanner task

Following previously established procedures (Inagaki et al., 2015; Inagaki et al., 2016a; Inagaki et al., 2016b), participants were instructed to send the experimenters two digital photographs of a close other. Two photographs were requested to keep participants engaged in the task. To guide the selection of close others, instructions asked participants to send photographs of family members, very close friends, or a significant other who they would rate a 9 or 10 on a scale of 1 (not very close) to 10 (very close).

Once in the scanner, participants completed a similar task to that used in Study 1, but optimized for imaging analyses. In particular, we modified a commonly used imaging paradigm to assess the neural correlates of close relationships (Aron et al., 2005; Acevedo, Aron, Fisher, & Brown, 2012 ; Inagaki et al., 2015; Inagaki et al., 2016a; 2016b) and previous tasks used to assess satiety and habituation over the course of a study (Fischer et al., 2003; Kringelbach et al., 2003; Small et al., 2001; Tataranni et al., 1999). Based on results from Study 1, the imaging study focused on reliving experiences with a close other only (i.e., a high-quality social target). In a block design, participants were instructed to “*Think of a pleasant memory you have had with [first name of participant’s close other]. Try to remember in as much detail as possible*” prior to each block (7-s). They then viewed one of two images of the close other for 15-s followed by 10-s of fixation crosshair. A 12-s attention-orienting block of mental serial subtraction followed each reliving experience in order to stop continued thoughts about the close other, as is standard in this task (Aron et al., 2005). During serial subtraction blocks, participants calculated easy mental math silently in their heads (e.g., 10-5).

There were twelve blocks per run (6 close other, 6 serial subtraction) and a total of four runs.

At the beginning and end of the entire scanning session, participants also reported on their feelings of satisfaction with the same item from Study 1 (*“how satisfied are you with your relationship?”*). Participants used the scanner-compatible button box with 1 indicating ‘not at all’ and 5 indicating ‘very much’ in order to make their responses.

Post-scan measures

After exiting the scanner, and as a manipulation check on the intended task experience, participants were asked ‘how able were you to immerse yourself in your memories?’ with the anchors of 1 (not at all), 4 (moderately), and 7 (very much). In addition, descriptive measures about the close other were collected including relationship type, relationship length (in years), and frequency of contact (*“how often do you spend time or interact with this person?”* 1 – daily, 2 – weekly, 3 – monthly, 4 – yearly).

fMRI data acquisition

Scanning took place at Carnegie Mellon University’s Scientific Imaging and Brain Research (SIBR) Center on a Siemens Verio 3T MRI Scanner. A Magnetization Prepared Rapid Gradient Echo scan (MP-RAGE; TR/TE = 2300/1.97 milliseconds, flip angle = 9°, 256 × 256 matrix, 176 sagittal slices, FOV = 256; 1-mm thick) was acquired before functional scans to assist data registration. Participants then completed four runs of the task (T₂*-weighted gradient-echo covering 51 axial slices, TR/TE = 2000/25 milliseconds; flip angle = 79°; 70 × 70 matrix; FOV = 210 mm; 2-mm thick). Runs 2 and

3 lasted 4:34 each and runs 1 and 4 lasted 5:50 each, to accommodate the feelings of satisfaction question. A resting state scan and a temperature perception task were collected following the satiation task to test separate theoretical questions. Results from the temperature perception task have been reported in separate publication (Inagaki & Ross, 2020).

Data Analyses

Imaging data were preprocessed in SPM12 (Wellcome Department of Imaging Neuroscience, London) using the DARTEL procedure. Images were realigned, normalized to the MP-RAGE, warped into Montreal Neurologic Institute space, and smoothed with a 6-mm Gaussian kernel, full width at half maximum. Following the analytical approach from Study 1, linear contrasts comparing activity in response to the first vs. second set half of blocks for each condition were computed for each participant before group level analysis. The main comparison of interest is first vs. second half of the blocks, averaged across the four runs.

Region-of-interest (ROI) Analysis

The primary aim of Study 2 is to assess whether regions previously associated with satiety, the VS and VMPFC, change over recollections of prior experiences of social connection with a close other. Therefore, structural ROIs of the VS and VMPFC were determined a priori and examined for current analyses. The VS ROI was structurally defined by combining the caudate and putamen from the Automated Anatomical Labeling (AAL) Atlas (Tzourio-Mazoyer et al., 2002) in the Wake Forest University Pickatlas (Maldjian, Laurienti, Kraft, & Burdette, 2003) and then constraining the ROI at $-24 < x < 24$, $4 < y < 18$, $-12 < z < 0$ (Inagaki et al., 2016a). The VMPFC

ROI was generated from the Harvard-Oxford probabilistic cortical atlas (Desikan et al., 2006).

Following the analysis approach from Study 1, mean parameter estimates from the first and second set of blocks (i.e., first 3 blocks vs. second 3 blocks of each condition) were pulled using the MarsBar toolbox in SPM (Brett, Anton, Valabregue, & Poline, 2002) and entered into a 2 (condition: recalling experiences with a close other vs. serial subtraction) \times 2 (time: first half vs. second half) \times 2 (region: VMPFC vs. VS) repeated measures ANOVA. Significant interactions were further interrogated for two-way interactions, first between time and region in each condition separately, then between condition and time for each region separately, and finally, with paired samples t-tests. Significance was determined as $p < .05$, one tailed, Bonferroni corrected for multiple comparisons, following directional hypotheses and the power analysis, and a BCa 95% CI excluding 0.

Feelings of satisfaction collected at the end of the scan and mean parameter estimates from the independently defined structural ROIs were entered into Pearson correlation analyses to assess subjective experience-brain relationships. Significance of the difference between correlations with feelings of satisfaction and each of the two regions (VS, VMPFC) were assessed by Fisher r-to-z transformations of the correlation coefficients.

Results

Post-scan self-reports

As evidence that participants were able to engage in the task, reports of ability to immerse themselves in the memories were relatively high ($M = 5.340$, $SD = 1.21$).

Participants' chosen close others included 40% family members, 40% partners or spouses, and 20% friends. Relationship type was not a significant covariate (p 's > .326). The close others were indeed rated as close ($M = 9.713$, $SD = .451$ on a scale of 1-10). Relationship length for the majority of participants was 6 or more years (65%), followed by 2 (12.5%), 3, 4, or 5 years (7.5% each). Thus, participants were able to recall experiences with a high-quality, established close other. The majority of participants also reported spending time or interacting with their close other on a daily basis (55%) followed by weekly (32.5%), monthly (10%), and yearly (2.5%), suggesting participants were engaged in continual interaction with their close others.

Pre-post scan feelings of satisfaction with the close other did not show change. Thus, feelings of satisfaction from the beginning ($M = 4.750$, $SD = .439$) to end of the scan ($M = 4.780$, $SD = .480$) remained high ($t(39) = .330$, $p = .372$, BCa 95% CI = [- .175, .132]).

Imaging results

A three-way interaction among condition, time, and region appeared ($F(1, 39) = 7.919$, $p = .004$), which was broken down, first by assessing the pattern of activity in each condition separately. For the condition in which participants recalled prior experiences with a close other, the time (first half vs. second half) x region (VS, VMPFC) analysis revealed no main effect of time ($F(1, 39) = .011$, $p = .459$) or region ($F(1, 39) = .244$, $p = .312$). However, the hypothesized interaction emerged ($F(1, 39) = 8.283$, $p = .003$; Fig. 2). The interaction was, therefore, further interrogated to assess the direction of the effects over time.

VMPFC activity to reliving prior positive experiences with a close other remained stable over the two halves of the runs (M first half = $-.119$, $SD = .598$; M second half = $.096$, $SD = 1.103$; $t(39) = 1.260$, $p = .108$, BCa 95% CI = $[-.510, .083]$, Cohen's $d = .199$). VS activity, on the other hand, showed a decrease over time (M first half = $.053$, $SD = .556$; M second half = $-.189$, $SD = .992$; $t(39) = 1.829$, $p = .038$, BCa 95% CI = $[-.007, .466]$, Cohen's $d = .289$). The same interaction did not emerge for the serial subtraction blocks ($F(1, 39) = .003$, $p = .480$).

Based on these results alone, it is not clear whether the pattern of activity is due to the recall of prior experiences or whether VS activity, for example, is merely decreasing over time. Therefore, interactions between condition and time were also evaluated for each region separately. A condition x time interaction emerged for the VS ($F(1, 39) = 4.113$, $p = .025$) such that VS activity decreased from the first to second half of the runs to recalled experiences with a close other (as reported above). VS activity did not, however, change in response to the serial subtraction blocks (M first half = $-.076$, $SD = .143$; M second half = $-.038$, $SD = .168$; $t(39) = 1.077$, $p = .144$, BCa 95% CI = $[-.104, .026]$). The same interaction did not emerge for the VMPFC ($F(1, 39) = 1.056$, $p = .155$).

Associations between VMPFC and VS activity to close others and feelings of satisfaction

As evidence for the relevance of the current pattern of brain activity to the subjective experience of social satiety, VMPFC activity in response to the second halves of recollections and feelings of satisfaction were positively correlated. Thus, greater VMPFC activity to the second half of the runs was associated with greater

feelings of satisfaction at the end of the task (vs. first half: $r = .482$, $p = .001$, BCa 95% CI = [.107, .709]; vs. serial subtraction during the second half of the runs: $r = .391$, $p = .007$, BCa 95% CI = [.059, .623]). The association remained after adjusting for pre-scan feelings of satisfaction (vs. first half: $r = .406$, $p = .005$, BCa 95% CI = [.061, .633]; vs. serial subtraction from the second half of the runs: $r = .316$, $p = .025$, BCa 95% CI = [.015, .560]).

VS activity to the second half of the runs, however, was not associated with feelings of satisfaction (vs. first half: $r = -.036$, $p = .412$, BCa 95% CI = [-.374, .234]; vs. serial subtraction from second half of the runs: $r = .086$, $p = .300$, BCa 95% CI = [-.378, .433]). Further, the association between VMPFC activity and feelings of satisfaction was significantly different from the association between VS activity and feelings of satisfaction, suggesting a unique role for the VMPFC in fulfilling the need for social connection (vs. first half: $z = 3.35$, $p < .001$; vs. serial subtraction from second half of the runs: $z = 1.946$, $p = .026$). Thus, there was a preferential association between VMPFC activity to recalling prior positive experiences with a close other and feelings of satisfaction with the same close other.

General Discussion

Humans need close social connection, but how humans fulfill their need for social connection and the neural mechanisms related to this process are open questions. Over two studies, we tested the premise that recalling prior positive experiences with a close other might temporarily fulfill the need for social connection. In Study 1, vividly reliving experiences with a close other (vs. an acquaintance) increased feelings of satisfaction and the desire to spend time with the same close other (compared to other individuals)

outside of the lab. Study 2 demonstrated potential neural correlates of fulfilling the need for connection, showing an interaction between time and brain regions previously known to contribute to satiety. VMPFC activity in response to recalling prior experiences with a close other remained stable, whereas activity in the VS decreased over time. Together, results are consistent with hypotheses suggesting that repeated social interaction with high-quality interaction partners fulfills the need for social connection, and the current theoretical perspective that the need for social connection may be fulfilled similarly to other needs (Baumeister & Leary, 1995).

In Study 1, recalling prior experiences with a close other increased the desire for future social interaction with the same individual, but not with others in general. In this way, experiencing social connection may beget wanting social connection (Vohs & Baumeister, 2008), which may contribute to the maintenance of the relationship. There are likely individual and relationship-specific differences in the threshold or setpoint with which one is socially fulfilled (Pickett, Gardner, & Knowles, 2004). Additional research that directly measures individual differences in the threshold for satisfying social connection needs, as well as future social behavior, will be particularly informative for understanding the longer-term effects of fulfilling social connection needs on actual social behavior.

Study 2 began to probe neural correlates linking the recall of prior experiences of social connection with feelings of satisfaction. Pulling from the extensive neuroimaging literature on viewing positive stimuli, including food and drugs, VMPFC and VS activity were expected to differ as participants relived their social connection experiences (Groves & Thompson, 1970; Haber, Kim, Mailly, & Calzavara, 2006). And indeed, an

interaction between time (first vs. second half) and brain region emerged such that VMPFC activity remained stable over recollections, but VS activity decreased. Further, greater VMPFC activity to the second half of recollections (vs. first half and vs. the serial subtraction blocks from the second half of the runs) was uniquely associated with higher feelings of satisfaction at the end of the scan suggesting VMPFC activity may indeed contribute to the subjective experience of satisfying the need for social connection.

Whereas VS activity to recalling prior experiences with a close other showed a pattern consistent with habituation, where one would observe a drop or decrease in responding (Thompson & Spencer, 1966), the VMPFC showed a pattern more consistent with sensitization (i.e., an increase or a stabilizing of responses over time; Kringelbach & Berridge, 2009). Such a pattern of sustained, rather than decreased, activity is consistent with prior research showing sustained activity in reward-related regions to positive images is associated with well-being (VS: Heller, et al., 2013). The pattern with the VMPFC, however, departs from other theories suggesting that repeated hedonic experience reduces enjoyment (hedonic adaptation; for review see Frederick & Loewenstein, 1999). Instead, the current results suggest that in the context of connecting with a close other, simulating prior experiences might sustain 'enjoyment.' Whether VMPFC activity is truly stable over time may benefit from more sophisticated statistical modeling of brain dynamics over time, but could be tested in future work (e.g., Satpute, Hanington, & Barrett, 2016). Nonetheless, an additional implication of the current results is that the opposite pattern of activity, with sustained VS but a decrease in VMPFC to prior experiences of social connection, may be a neural correlate of

unfulfilled social connection (loneliness, disconnection, illness characterized by social disconnection).

Consistent with this hypothesis, heightened VS activity to images of close others or other desirable stimuli has previously been related to unfulfilled social connection, yearning for the same close other, and craving (David et al., 2005; Inagaki et al., 2016a; O'Connor et al., 2008; Schacht et al., 2013). Experimentally increasing VS activity to images of a close other via pharmacological manipulation (endotoxin vs. placebo) also causes an increase in craving for the close other suggesting a causal role of the VS in the craving side of social satiety (Inagaki et al., 2015). Results from Study 2 further suggest that the VMPFC, along with the VS, jointly relate to fulfilling the need for social connection – though in a more sophisticated, interaction pattern (Groves & Thompson, 1970). Additional research using pharmacological manipulations of VS and VMPFC activity to experiences of social connection (e.g., Eisenberger, Moieni, Inagaki, Muscatell, & Irwin, 2017; Manninen et al., 2017) or other experimental manipulations of brain activity, will clarify the causal contribution of these two regions to fulfilling the need for social connection.

Although the current framing attributes VMPFC activity to social-connection related processing, the VMPFC is also well-known for its relationship to self-processing and autobiographical memory (Buckner & DiNicola, 2019; Mildner & Tamir, 2019; Spreng, Mar, & Kim, 2009). The VMPFC is a key node within the default mode network (specifically the medial temporal lobe subsystem) due its role in these processes (Squire & Zola-Morgan, 1991) suggesting such functions might be inherent to VMPFC function. While self-processing and memory functions seem at odds with the current

framing, previous theoretical perspectives from the field of social psychology propose that people process the self in relation to others, especially close others (Aron, Aron & Smollan, 1992). Similarly, self-processing and social connection, including the maintenance of close relationships over time, are some of the proposed primary functions of autobiographical recall (Bluck & Alea, 2002; Kensinger & Ford, 2020). Recent neuroimaging evidence further supports a shared function account: MPFC activity (encompassing portions of the VMPFC) when thinking of close others is similar to activity when thinking about the self (Courtney & Meyer, 2020). Further, the amygdala, hippocampus and insula, regions that traditionally appear in studies of autobiographical recall (Kensinger & Ford, 2020; Svoboda, McKinnon, & Levine, 2006) sometimes also appear in studies manipulating experiences of social connection (e.g., Inagaki & Ross, 2020). Thus, understanding the self, recalling social memories, and social connection may share overlapping processes. Future research can further clarify these regions' roles in the need to connect by including additional conditions where people relive experiences that only involve themselves or non-social recall conditions (e.g., remember non-social details from the past such as the weather) to compare VMPFC activity to the current social satiety condition over time.

The need to belong theory suggests that frequent interactions are important for fulfilling the need to connect, but a concrete definition of frequency remains unclear. The current studies used the recollection of prior experiences (Study 1: recall four unique experiences, Study 2: recall 24 unique experiences) as a proxy for frequent experiences with the same close other. However, feelings of satisfaction toward the close other did not change in either study. This could be due to ceiling effects on the

chosen outcome, the fact that participants did not engage in novel, in-person interactions with their chosen close others, or because the study designs did not manipulate the number of prior experiences recalled. A related point is that the human capacity for social connection is likely immense. People are highly sensitive to even subtle signs of rejection (Eisenberger, 2015; MacDonald & Leary, 2005), but can experience multiple, powerful experiences of social connection with (seemingly) insatiable appetite. It makes sense that the brain would be built this way – with sensitivity biased toward detecting and protecting against rejection. If even modest signs of rejection can threaten social connection, maintaining social connection needs becomes all the more important. Indeed, recurring social connection, potentially via recall, might positively relate to social well-being in the same way that recurring stressors negatively relate to health. In other words, acute stressors of limited duration do not affect an organism's health until they are reimagined and reexperienced (Etkin & Wager, 2007; Rauch, Shin, & Phelps, 2006). Likewise, acute experiences of social connection might be insufficient for maintaining one's need for social connection (Baumeister & Leary, 1995), perhaps until they are reexperienced either via recall or via repeated in-person interaction. Future research that induces varying numbers of in-person social connection experiences in the lab, or measures naturalistic connection experiences outside of the lab will help clarify how frequent interaction needs to be in order to fulfill the need to connect.

Limitations of the current studies include (1) the use of recall to manipulate social experience, (2) the choice to constrain the recalled experiences to positive experiences, (3) the lack of behavioral measures, (4) the comparison condition in Study 2. Regarding

the use of recalled experiences, humans are able to vividly re-experience events from their past (Tulving, 1983). Indeed, recall is a widely used method to induce emotional experience, including social connection (Inagaki & Eisenberger, 2016; Poerio et al., 2016; Speer & Delgado, 2020; Wildschut, Sedikides, Arndt & Routledge, 2006) and is especially useful when inducing personalized, meaningful experiences (e.g., Kross et al., 2011; Meyer et al., 2015). Recalling previous experiences is not a replacement for in-person social interaction, but the current results suggest that such an approach is potentially useful for maintaining feelings of connection and temporarily fulfilling the need to connect. This is especially important when real or imagined barriers to in-person interaction threaten such needs (e.g., long-distance romantic and familial relationships, feelings of loneliness, physical barriers such as social distancing to curb the COVID-19 pandemic, or even the death of a primary close other).

Although the need to belong theory suggests that positive experiences with a close other fulfill the need for social connection, whether positivity is necessary to fulfill social needs requires additional research. Indeed, many social experiences are not positive. Might neutral, mundane (e.g., sitting together on the couch; Lakey & Orehek, 2011), or negative experiences (e.g., helping someone through a difficult situation; Inagaki & Orehek, 2017) still fulfill the need for social connection? Memory research suggests the valence of the emotions one is experiencing at the time of encoding and at the time of recall can influence the memory for that event (Kensinger & Ford, 2020). Whether the valence of the social connection experience differentially affects how effective the recalled experience is in fulfilling the need to connect remains an open question. In addition, the implications of the follow-up results from Study 1 are that

reliving positive experiences with a close other might prompt more socializing (sensitize) with this individual, but behavior was not measured in the current study. Future research could remedy this issue by recording naturalistic social behavior. Finally, the comparison condition in Study 2 was mental serial subtraction, but the recall of prior experiences and serial subtraction are not well-matched on psychological experience and thus, results of Study 2 should be interpreted with caution until replication.

Across two studies and spanning feelings collected in the experimental setting in response to personalized tasks, naturally occurring feelings outside of the lab, and the brain, recalling experiences of social connection with a close other fulfilled the need for social connection. Results are consistent with previous theories suggesting that social connection needs might be fulfilled in ways similar to other basic needs (Baumeister & Leary, 1995; Bowlby, 1988; Gardner et al., 2005; Leary & Downs, 1995).

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Fig. 1

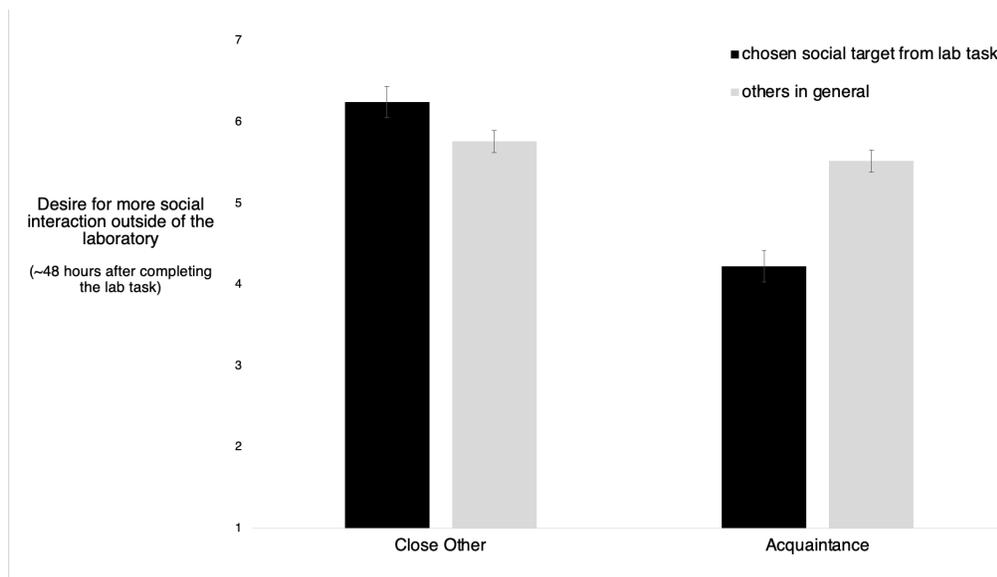


Figure 1. Study 1, Desire for social interaction collected outside of the lab. The close other condition produced a unique increase in the desire for additional social interaction with the same individual. Within a participant, the desire for additional social interaction with the close other was greater than others in general. The opposite pattern emerged for those in the acquaintance condition. Between participants, desire for additional social interaction with the close other was also greater than the desire for interaction with an acquaintance (darker bars). However, there was no difference between conditions on the desire to interact with others in general (lighter bars), suggesting the pattern of results are not attributable to participants in the acquaintance condition having a lower desire to interact with or socialize with other people in general.

Fig. 2

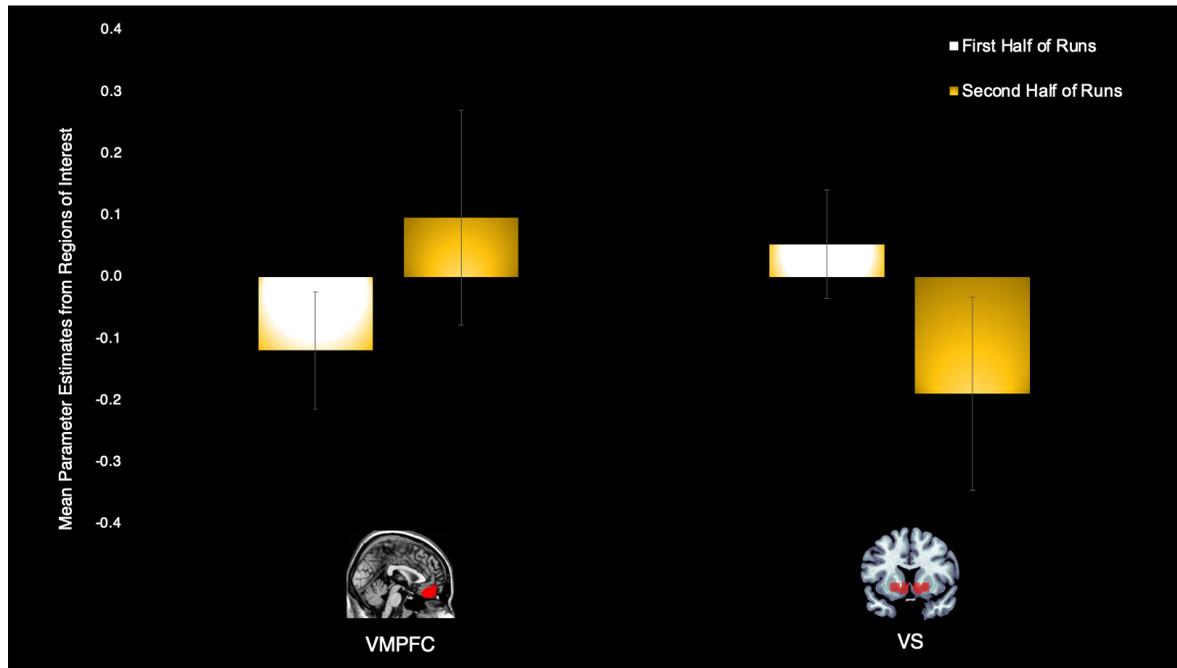


Figure 2. Study 2, Interaction between brain region (VS, VMPFC) and recalling prior experiences of social connection with a close other (first half vs. second half of runs). VMPFC activity remained stable over time whereas VS activity decreased. The same decrease in VS activity did not appear in response to mental serial subtraction.

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