The influence of generativity on purpose in life is mediated by social support and moderated by prefrontal connectivity between the VMPFC and DLPFC in older adults at risk for Alzheimer's disease

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Abstract

Objectives

Generativity is the desire and actions to improve the well-being of younger generations. Generativity is associated with purpose in life, with both being shown to independently improve cognition in older adults. Our aims were to identify the neural substrates supporting generativity and determine the mechanism underlying the relationship between generativity and purpose in life in older adults.

Method

Forty-three older adults (M_{age} = 70.33, 79.1% female) at risk for Alzheimer's disease underwent resting-state functional magnetic resonance imaging and completed questionnaires assessing generativity, social support, and purpose in life. Seed-to-voxel analyses examined if resting-state functional connectivity (rsFC) of the ventromedial prefrontal cortex (vmPFC) and ventral striatum, key nodes at the intersection of subjective valuation and self-transcendence, were associated with generativity. Moderated mediation models examined if social support or rsFC mediated or moderated the association between generativity and purpose in life, respectively.

Results

Generative desire was associated with enhanced rsFC between the vmPFC and right dorsolateral prefrontal cortex (rdlPFC). Affectionate social support fully mediated the relationship between generative desire and purpose in life, and rsFC between the vmPFC and rdlPFC significantly moderated this association.

Discussion

This study is the first to examine the rsFC underlying generativity and provides mechanistic insight into how purpose in life is enhanced through generative desire. Generative desire is

supported by rsFC implicated in value-based social decision making and is associated with purpose in life through enhanced love and affection from others. This knowledge contributes to future developments of personalized interventions that promote resilience in at-risk aging.

Keywords: Self-transcendence, altruism, MRI, ventromedial prefrontal cortex, dorsolateral prefrontal cortex

Introduction

Alzheimer's disease (AD) is a progressive neurodegenerative disease that is characterized by a decline in cognitive abilities, including memory, learning, and reasoning (DeTure & Dickson, 2019). AD has significant emotional, social, and economic impacts for the individual, their family, and society (Grabher, 2018). Thus, it is crucial to identify disease prevention strategies that delay the onset and progression given that delaying the onset of AD by 5 years would reduce its prevalence by 50% (Brookmeyer et al., 1998). Social isolation is one risk factor that is associated with a 1.26x increased risk of dementia (Shen et al., 2022). In contrast, high levels of perceived social support predict higher cognitive abilities and a reduced risk of dementia in older adults, including in those with preclinical AD or mild cognitive impairment (Marioni et al., 2015; Oh et al., 2021). Social support is hypothesized to prevent dementia through a combination of behavioural (e.g., engagement in health behaviours, decreased stress and depression) and neurobiological mechanisms (e.g., changes in brain structure and function, increased neurogenesis, reduced brain atrophy; Hsiao et al., 2018).

Social support is an important modifiable risk factor in AD prevention since older adults appear to display enhanced social motivation relative to younger adults (Gutchess & Samanez-Larkin, 2019; Lockwood et al., 2021). There is growing evidence that older adults experience a 'prosocial goal shift' where behaviours benefitting the well-being of others become increasingly rewarding with age (Isaacowitz, 2021; Sparrow, 2021). Generativity is a type of social motivation that involves the desire to contribute to the well-being of younger generations (referred to as generative *desire*) and actions directed towards increasing the well-being of younger generations (referred to as generative *achievement;* Gruenewald et al., 2016). Erikson (1950) originally defined generativity in his psychosocial development theory as a stage at

midlife that arises from a desire to be needed. He suggested that generativity at midlife evolves into “grand-generativity” in older adulthood that is characterized by an evaluation of how one has left a legacy. The literature suggests that generativity remains stable or even increases in older adulthood (Isaacowitz, 2021). Importantly, generativity is associated with life satisfaction, well-being, participation in productive activities, self-efficacy, and physical health (Doerwald et al., 2021; Gruenewald et al, 2012; Pinazo-Hernandis et al., 2023; Wiktorowicz et al., 2022).

The relationship between generativity and well-being in older adulthood is congruent with the predictions of Socioemotional Selectivity Theory (SST). SST posits that an individual’s perception of their time horizons determines how they prioritize their social goals (Carstensen, 2006). When time is perceived as open-ended in young adulthood, future-oriented goals involving knowledge acquisition are prioritized. In contrast, when time is perceived as limited in older adulthood, goals that enhance socioemotional well-being in the present are prioritized. By promoting the well-being of future generations, generativity may provide a means for older adults to maximize their socioemotional well-being. There is evidence that SST applies to older adults in the preclinical and early stages of AD when emotion regulation, positive affect, and attention to social information are preserved or even enhanced compared to age-matched controls (Chow et al., 2023; Sturm et al., 2004; Zhang et al., 2015). Individuals with pre-clinical AD also show enhanced empathic concern, “an other-oriented form of emotional empathy that promotes pro-social actions” early in the disease process (Chow et al., 2023).

Generativity can be enhanced in older adulthood through positive relationships with one’s family and community. Parenting and grandparenting is one means of behaving generatively since it involves passing on family values to younger generations (Villar et al., 2021). Hebblethwaite and Norris (2011) found that grandparent-grandchild dyads who

participated in recreational activities together (e.g., family vacations, holiday celebrations, cooking, gardening) developed strong intergenerational bonds that increased grandparents' generative goals. Generativity can also be enhanced in older adulthood through volunteer work that establishes intergenerational bonds. For example, the Baltimore Experience Corps Trial (BECT) is an intergenerational social program where older adults volunteer to help elementary school students with reading. Compared to a control group that participated in other volunteer work, older adults who participated in this program demonstrated increased generative desire and achievement following the intervention that was sustained at 24 months (Gruenewald et al., 2016). In addition, older adults who participated in the program have demonstrated increased physical, social, and cognitive functioning compared to controls (Carlson et al., 2009; Tan et al., 2006). The subgroup in this study at the greatest risk of cognitive impairment (i.e., Mini-Mental State Examination score < 24 or diminished executive function at baseline) showed the greatest improvement in memory, executive function and prefrontal activation following the intervention (Carlson et al., 2009; Carlson et al., 2008), suggesting that intergenerational programs might be particularly effective for older adults at risk of cognitive decline.

Generativity is associated with enhanced purpose in life in older adults (de St, Aubin, 2013). Purpose in life is conceptualized as having goals, directedness, and feelings that give one's life meaning (Boyle et al., 2009). It is associated with many facets of successful aging, including increased physical health, greater engagement in health behaviours, and a reduced risk of AD, dementia, and mortality (Boyle et al., 2009; Boyle et al., 2010; Pinquart, 2002). When asked what roles are most meaningful to them, older adults with AD or dementia report that their family role (i.e., as a parent or grandparent) and relationships as most valuable to them (Cohen-Mansfield et al., 2006; Cotrell & Hooker, 2005). Social relationships are thought to motivate

older adults to engage in more activities and interests that enhance their purpose in life (Pinquart, 2002).

McAdams and de St. Aubin's (1992) generativity model further elucidates how generativity contributes to purpose in life in older adulthood. According to the model, older adults have an intrinsic motivation to behave generatively that arises from a need to be needed, to have meaningful relations with others, and to invest resources into activities that will leave a legacy on future generations. Additionally, there are cultural demands (i.e., normative expectations of older adults) that serve as a source of extrinsic motivation to engage in such behaviours. These converging sources of extrinsic and intrinsic motivation lead to a concern for the next generation. Individuals with high concern for the next generation develop generative commitments, or goals to behave generatively, that then result in generative behaviours. The last stage of the model is the "narration" stage where older adults define their purpose in life by considering how they have integrated generativity in their lives. The narration stage allows older adults to develop an identity and life story that provides their life with purpose (Kruse & Schmitt, 2012).

To date, no studies have yet examined the neural substrates of generativity. Understanding the neural correlates of generativity is crucial to understand and modify the cognitive processes that support this behaviour and for developing future circuit-based interventions that promote health and resilient aging. Resting-state functional connectivity (rsFC) is a powerful method that is easily acquired in a task-free environment. This method can provide insight into the functional organization of the brain and the networks supporting internal mental processes and behaviour (Misic & Sporns, 2016). It is possible that generativity relies on brain systems implicated at the intersection of subjective value, decision-making and self-transcendent processing. Self-transcendence refers to a shift in mindset from focusing on self-interests to the well-being of

others and humanity (Kang et al., 2018). Self-transcendence is tightly linked with generativity as they both involve introspecting about one's values and life story to create a sense of purpose that extends beyond the self. Prior research in younger adults showed that self-transcendence is associated with activity in nodes of the reward network, particularly the ventromedial prefrontal cortex (vmPFC) and ventral striatum (VS) (Kang et al., 2018). Therefore, it is possible that individuals with differential connectivity of the reward network supports the relationship between generativity and purpose in life. This may be particularly true in older adults at risk of AD given that regions of the reward network are relatively spared in aging and AD (Cassidy et al., 2014; Fjell et al., 2009; Sturm et al., 2023).

For this study, we recruited a well-characterized subsample of participants from the longitudinal aging cohort at McGill University, Pre-Symptomatic Evaluation of Experimental or Novel Treatments for Alzheimer's Disease (PREVENT-AD) for the current study. First, this study aims to identify the functional neuroanatomy underlying generativity in older adults at risk of AD. To our knowledge, the brain regions supporting generativity in older adults are entirely unknown. It is hypothesized that enhanced generativity is associated with differential rsFC to the vmPFC and VS, central nodes at the intersection of the reward valuation and self-transcendence. In addition, we tested whether any significant differences in rsFC moderate the influence of generativity on purpose in life. To test this hypothesis, combined seed-to-voxel rsFC and moderation analyses were employed. The second aim of this study is to identify the neurobehavioral mechanisms underlying the relationship between generativity and purpose in life. We hypothesized that generativity is positively associated with purpose in life and sought to replicate this finding based on prior literature. We sought to critically extend this finding by testing the extent to which social support mediates the effect of generativity on purpose in life.

Methods

Participants

Participants consisted of 43 cognitively normal older adults (M_{age} = 70.33, 79.1% female) from the Pre-Symptomatic Evaluation of Experimental or Novel Treatments for Alzheimer's Disease (PREVENT-AD) cohort at McGill University (Tremblay-Mercier et al., 2021). A Monte Carlo power analysis (Schoemann et al., 2017) determined that a sample size of $N = 43$ was required for detecting an indirect effect with power of 80%, correlations of .65 for the *a* and *b* paths, and a correlation of .60 for the *c'* path. In addition, G*Power version 3.1 (Faul et al., 2007) was used to conduct a power analysis for the moderation analysis. The analysis showed that a sample size of $N = 42$ was required for detecting the interaction with an effect size of 0.2 and power of 80%.

The PREVENT-AD cohort consists of adults 55 years and older who are cognitively normal at the time of enrollment and have a first-degree family history of AD. Participants were considered *APOE ε4* carriers if they had at least one E4 allele. Exclusion criteria included history of a major psychiatric illness (e.g., schizophrenia), current treatment for cancer (excluding non-melanoma skin cancer), diagnosis of a neurological disorder or brain injury, current alcohol or substance abuse, a cardiac event that occurred in the past six months (e.g., myocardial infarction, coronary artery bypass grafting, angioplasty), and any change in an antipsychotic, anti-depressant, anti-anxiety, or attention deficit disorder / attention deficit hyperactivity disorder medication in the past six months. All participants in this study come from a subsample of the cohort who participated in the Healthy Aging Brain Study, a behavioural intervention designed to enhance physical activity behaviour. The behavioural and MRI data used in this study were

collected during the baseline phase of the trial. Participants' demographic characteristics are shown in Table 1.

Procedure

All study procedures were approved by the McGill University Research Ethics Board. Participants from the PREVENT-AD cohort were recruited for the intervention by contacting them by phone and email and by sending flyers in the mail. All eligible participants then attended a videoconferenced meeting with a member of the research team where they were provided with detailed information about study procedures and were given the opportunity to ask any questions. All participants provided written informed consent in accordance with the Declaration of Helsinki. Thereafter, all participants completed an online battery of questionnaires, described below.

Behavioral Inventories

The BECT Generativity Questionnaire (Gruenewald et al., 2016). This measure was used to assess generative desire and achievement. Participants rated the extent to which they agree with seven generative desire statements (e.g., "I want to make a difference in the lives of others.") and six generative achievement statements (e.g., "I feel like I make a difference in my community.") on a 6-point scale ranging from *strongly disagree* to *strongly agree*. Scores for the generative desire subscale ranged between 7 and 42, with higher scores indicating greater generative desire. Scores for the generative achievement subscale ranged between 6 and 36, with higher scores indicating greater generative achievement.

The Medical Outcomes Study Social Support Survey (Sherbourne & Stewart, 1991). This measure consists of 19 items that assess the availability of four types of social support. The emotional and informational support subscale consists of eight items that measure how often individuals have someone to listen to them, confide in, and provide them with advice and

information. The tangible support subscale consists of four items that measure the frequency of support in daily tasks such as chores and preparing meals. The affectionate support subscale consists of three items that measure how often individuals have someone to show them love and affection. Finally, the positive social interaction subscale consists of three items that measure how often individuals have someone to spend time with and do enjoyable things with. Each item is scored on a Likert scale of 1 to 5 where 1 = *none of the time* and 5 = *all the time*. Scores for each subscale are obtained by calculating the mean score across its items. All scores range between 1 and 5, with higher scores indicating a higher availability of social support.

The Psychological Well-Being Purpose in Life subscale (Ryff et al., 2007). This inventory consists of seven items that measure the extent to which individuals have goals, a sense of directedness, and beliefs that give life meaning (e.g., "Some people wander aimlessly through life, but I am not one of them."). Each item is scored using a Likert scale from 1 and 7 where 1 = *strongly disagree* and 7 = *strongly agree*. Negatively worded items are reverse coded, then scores on all items are summed to create a total score. Total scores range between 7 and 49, with higher scores indicating greater purpose in life.

The TestMyBrain (TMB) Digital Neuropsychology Toolkit (Singh et al., 2021)

The TMB Digital Neuropsychology Toolkit is a reliable and valid tool used for remotely administered neuropsychological evaluations. It includes a variety of computerized tests that assess working memory, attention, processing speed, memory, executive functioning, and reasoning. The tests used in the current study are described below:

Simple Reaction Time (Rutter et al., 2020). This test measures basic psychomotor response speed. Participants are presented with red squares that say "STOP!" and green squares that say

"GO!" and are instructed to press a key on their keyboard (or tap the screen) whenever a green square appears. Scores for each participant reflect their median reaction time.

Choice Reaction Time (Rutter et al., 2020). This test measures the speed of response selection and attention. On each trial, participants are presented with 3 arrows, with one arrow having a different colour from the rest. Participants are asked to indicate the direction of the arrow that is a different colour from the rest by pressing the "x" key (to indicate left) or the "m" key (to indicate right). Scores for each participant reflect their median reaction time on correctly answered trials.

Gradual Onset Continuous Performance Test (Fortenbaugh et al., 2015). This test measures sustained attention, response inhibition, and cognitive control. The participant is presented with images of cities that rapidly transition into other images or cities or images of mountains. Images of mountains appear 10-20% of the time. The participant is instructed to press a key when a city image appears and to not press anything when a mountain image appears. Discrimination scores reflect how accurately the participant was able to respond to mountains and cities, with higher scores indicating greater accuracy. The impulsivity score reflects how quickly and impulsively the participant responded, with higher scores indicating greater impulsivity.

Matrix Reasoning (Chaytor et al., 2021; D'Ardenne et al., 2020). This test is a measure of perceptual reasoning. On each trial, participants view a matrix of images with one image missing. They are asked to select the image (out of five response options) that best completes the pattern, based on a logical rule. Trials gradually increase in difficulty. Scores reflect the number of correct responses out of 36.

Digit Span (Forward and Backward; Chaytor et al., 2021; Germine et al., 2012; Hartshorne & Germine, 2015). This test measures working memory and attention. Participants are

presented with a series of digits for 1000 milliseconds each. In forward digit span, participants are asked to recall the sequence in the same order by typing the number series on the keyboard. In backward digit span, participants are asked to recall the sequence in the reverse order by typing the sequence on their keyboard. In both tests, the number series begins with two numbers and increases to a maximum of 11 numbers. Participants complete two trials at each span length and if at least one trial is answered successfully, the span length is increased by one number. If both trials with the same span length are answered incorrectly, the task is discontinued. Scores on both tests are the longest span length where at least one trial was answered successfully.

Visual Paired Associates (Passell et al, 2019). This test measures episodic memory. Participants are presented with 24 pairs of images and are told that they will later be tested on which images were paired together. After all image pairs are presented, there is a delay of approximately 2.5 minutes where participants complete the Choice Reaction Time test. Then, participants are presented with one image from each of the pairs that were previously presented and are asked to select which image was presented with it. Participants are presented with five response options. Scores reflect the number of images that were correctly identified, out of 24.

Digit Symbol Matching (Chaytor et al., 2021; D'Ardenne et al., 2020; Hartshorne & Germine, 2015). This test is a measure of processing speed. On all trials, participants are presented with nine symbols that are paired with the digits 1, 2, or 3. On each trial, one symbol is presented above these pairings and participants are asked to press the key of the corresponding digit as quickly as possible. Scores reflect the total number of correct responses in 90 seconds.

MRI Data Acquisition and Preprocessing

Participants were scanned in a Siemens TIM Trio 3 Tesla MRI scanner using a standard Siemens 32-channel head coil (Siemens Medical Solutions, Erlangen, Germany). T1-weighted

structural images were acquired using an MPRAGE (Magnetization Prepared Rapid Gradient Echo Imaging) sequence. The parameters included a repetition time (TR) of 2300 milliseconds (ms), echo time (TE) of 2.98 ms, inversion time (TI) of 900 ms, flip angle of 9°, Field of View (FOV) of 256 x 240 x 176 millimeters, phase encode A-P, a GRAPPA acceleration factor of 2, and a Bandwidth (BW) of 240 Hz/px. Multi-echo T2*-weighted anatomical images were acquired using a multi-echo gradient echo (GRE) sequence. The parameters were as follows: TR = 44 ms, TE = [2.84, 6.2, 9.56, 12.92, 16.28, 19.64, 23, 26.36, 29.72, 33.08, 36.44, 39.8] ms, flip angle = 15°, FOV = 350 x 263 x 350 mm, a phase encode R-L, and BW = 500 Hz/px. The resting-state functional MRI data were acquired by an echo-planar imaging (EPI) sequence. The scanning duration for each run was 5.04 minutes and two sessions were performed continuously. The parameters were as follows: TR = 2000 ms, TE = 30 ms, flip angle = 9°, FOV = 256 x 256 x 252 mm, phase encode A-P, BW = 2442/px. Thirty-two slices were collected in each run.

The preprocessing of both functional and structural data was performed using the fMRIprep pipeline (Esteban et al., 2019). First, the structural images underwent skull stripping using a Nipype implementation of the antsBrainExtraction.sh tool (ANTs), an atlas-based brain extraction workflow. Next, brain tissue was segmented with FSL fast and normalized to Montreal Neurological Institute (MNI) space using ANT's antsRegistration. Preprocessing for the resting-state functional images included head motion correction, realignment, slice timing correction, susceptibility distortion correction, co-registration to reconstructed structural images, and spatial normalization to standard space. For each BOLD run, the BOLD time-series was averaged to generate a reference volume. The BOLD reference was co-registered to the T1W reference using bbregister, implementing a boundary-based registration with six degrees of freedom. Head motion parameters with respect to the BOLD reference (one rigid-body transformation, three rotations,

and three translations) were estimated with FSL's mcflirt. Then, the rigid-body transformation was applied to re-sample the BOLD time series onto their original, native space. Transformations were concatenated to map the BOLD image to MNI standard space. Potential confounds were estimated, including the mean global signal, mean tissue signal class, tCompCor, aCompCor, Framewise Displacement, and DVARS. Volumes with framewise displacement above 0.9 mm and/or global blood-oxygen-level-dependent (BOLD) signal changes above 3 standard deviations were flagged as motion outliers. All dummy scans were removed prior to any additional analyses.

Denoising was performed on the fMRIprep outputs using Tedana (DuPre et al., 2021). The signal across echoes were combined using a weighted average, and then normalized across echoes. A time series for the optimally combined echoes was then extracted. Principal component analysis was applied to the optimally combined data to separate the BOLD signal from thermal noise. Then, independent component analysis denoising was performed. This step uses a TE-dependence model to classify principal component analysis components as BOLD or non-BOLD while removing motion and physiological noise. Finally, the functional data were smoothed using a full-width half-maximum kernel of 6 mm in the CONN toolbox (Whitfield-Gabrieli & Nieto-Castanon, 2012).

Analyses

Functional Brain Imaging Analyses

Seed-to-voxel rsFC analyses were performed using the CONN toolbox (Whitfield-Gabrieli & Nieto-Castanon, 2012). Regions of interest (ROIs) were functionally defined based on a meta-analytic conjunction analysis to define the neural correlates of subjective value (Bartra et al., 2013). The average time series in both ROIs were extracted. First-level correlation maps were obtained by extracting Pearson's correlation coefficients between the average time series in each ROI and the time series of all other voxels. Correlation coefficients were then Fisher transformed

to z-scores to increase normality prior to the second-level general linear models. Two general linear models were computed for each ROI, with generative desire and generative achievement included as the covariates of interest. Age, sex, mean framewise displacement, and *APOE ε4* carrier status were included as nuisance variables in the general linear models. All analyses were performed with voxel level $p < .001$ and a cluster-size $p < .05$ family wise error (FWE) corrected cluster-extent threshold to correct for multiple comparisons.

Behavioral Analyses

Moderated mediation models were tested using Model 5 of the PROCESS macro for SPSS, version 4.0 (Hayes, 2022). Generative desire and generative achievement were entered as predictor variables in separate models, with purpose in life included as the outcome variable in each. Sex, age, and *APOE ε4* carrier status were included as covariates in all models. Affectionate social support and positive social interactions scores were significantly correlated with generative desire, generative achievement, and purpose in life (ps $< .05$). Therefore, four separate models were computed with affectionate social support and positive social interactions included as mediators and generative desire and generative achievement included as predictors of purpose in life. The indirect effects were tested using a percentile bootstrapping method with 5000 samples. Because four separate mediation models were computed, we applied a Bonferroni correction and used 99% confidence intervals. In all models, Fisher-transformed z-scores were extracted and seed-based rsFC associated with generativity was included as a moderator variable.

Results

Functional Brain Imaging

As shown in Figure 1, greater generative desire scores were associated with enhanced rsFC between the vmPFC seed and a cluster in the right dorsolateral prefrontal cortex (rdlPFC; $t(37) =$

3.57, voxel $p < 0.001$ uncorrected, cluster p-FWE < 0.05, peak voxel MNI coordinates = [28, 36, 34], k = 316. Seed-to-voxel analyses with the VS included as the seed or generative achievement included as the covariate of interest were not statistically significant.

Moderated Mediation Models

Separate linear regression models controlling for age, sex, and *APOE ε4* carrier status revealed that generative desire (β = 0.34, SE = 0.16, 99% CI [0.12, 0.67], $p = .043$, $R^2 = 0.24$) and generative achievement (β = 0.38, SE = 0.17, 99% CI [0.05, 0.72], $p = .027$, $R^2 = 0.26$), were significant predictors of purpose in life. The model with affectionate social support included as the mediator between generative desire and purpose in life was statistically significant (see Figure 2). In particular, the direct effect of generative desire on purpose in life was no longer statistically significant after controlling for the effect of affectionate social support (β = 0.15, SE = 0.15, 99% CI [-0.26, 0.56], $p = .329$). The indirect effect, however, was statistically significant (β = 0.18, SE = 0.09, bootstrapped 99% CI [0.001, 0.47]). This suggests that affectionate social support fully mediated the effect of generative desire on purpose in life. The interaction between generative desire and rsFC between the vmPFC and rdlPFC on purpose in life was also statistically significant (β = 1.72, SE = 0.62, 99% CI [0.03, 3.42], $p = .009$). Simple slopes for the association between generative desire and purpose in life at low (-1 standard deviation (SD) below the mean), moderate (mean), and high (+1 SD above the mean) levels of rsFC are shown in Figure 3. The mediation models with generative achievement as the predictor or positive social interactions as the mediator variables did not reveal statistically significant indirect effects.

Discussion

The purpose of the current study was to identify the neural correlates of generativity as well as the neurobehavioral mechanisms underlying the relationship between generativity and

purpose in life in cognitively normal older adults at risk of AD. The findings revealed that greater generative desire was associated with enhanced rsFC between the ventromedial prefrontal cortex (vmPFC) and right dorsolateral prefrontal cortex (rdlPFC) and this rsFC moderated the relationship between generative desire and purpose in life. Moreover, affectionate social support fully mediated the association between generative desire and purpose in life.

The finding that resting-state functional connectivity between vmPFC to dlPFC increased with elevated generative desire can be understood in light of prior anatomical, neurostimulation and functional neuroimaging studies. A medial-lateral axis of the PFC has been proposed where medial areas are involved in affective and motivational processing whereas lateral areas are involved in higher-order cognitive processing (Petrides, 2005). In particular, the vmPFC is a region at the intersection of reward valuation and self-transcendent processing (Bartra et al., 2013; Kang et al., 2018) while the dlPFC is largely involved in cognitive processes such as planning and working memory (Petrides, 2005). The vmPFC and dlPFC have been shown support prosocial value-based decision-making (Zhang & Glascher, 2020). Namely, the vmPFC is thought to encode the subjective value of decision options and the rdlPFC may modulate the subjective value of choices as a function of context. One study that examined prosocial decision making found that participants who underwent transcranial magnetic stimulation (TMS) to the rdlPFC (but not the left) rejected selfish options in favour of costly options that benefited others more than those who received TMS (Baumgartner et al., 2011). This shift in decision-making benefitting others rather than the self was associated with altered connectivity between vmPFC to rdlPFC. The authors concluded that the rdlPFC might exert top-down executive control over the vmPFC, thus preventing the impulse to act selfishly and allowing behaviour to align with social norms.

Neurostimulation studies implicating dlPFC in social decision making have shown seemingly divergent results with both excitation and inhibition of this region increasing prosociality (Yuan et al., 2022). Gross et al. (2018) attempted to explain these discrepant findings. The authors suggested that the lateral PFC is involved in making social decisions that reflect one's internal goals and values rather than decisions that are based solely on external rules or norms. They showed that excitatory stimulation of the right lateral PFC caused participants to make more decisions that aligned with their internal goals when a rule was in place that conflicted with this goal (i.e., participants who freely made more prosocial than selfish decisions were more likely to make prosocial decisions when a selfish rule was imposed). In contrast, inhibitory stimulation of the right lateral PFC caused participants to make more decisions that aligned with external rules regardless of whether they conflicted with their internal goals. Taken together, these results highlight how generative desire in older adulthood is supported by brain regions involved in value-based prosocial decision making. Compared to younger adults, older adults find prosocial behaviours particularly valuable and rewarding (Carstensen et al., 2006; Lockwood et al., 2011), in line with the vmPFC's role in reward valuation. Thus, the enhanced vmPFC to dlPFC rsFC in those with higher generative desire might support older adults' ability to align their social behaviour with internal goals that are subjectively valuable (e.g., to leave a legacy and to improve the world for future generations).

Connectivity between the vmPFC and dlPFC was also found to moderate the association between generative desire and purpose in life, with the effect being the highest for those with high rsFC (+1 SD above the mean). This supports the idea, described above, that vmPFC to dlPFC rsFC supports value-based decision making. Older adults who make social decisions that align with their generative goals and values might make more decisions and pursue more

behaviours that that contribute to their life purpose. The finding that those with low vmPFC to dlPFC connectivity (-1 SD below the mean) show a negative association between generative desire and purpose. Specifically, these older adults might not be intrinsically motivated by generative behaviours and instead derive purpose in life from other activities and interests in-line with their values. These findings highlight the need for consideration of individual difference using precision methods to develop the right interventions that enhance generativity for the right individual at the right time.

We observed that affectionate social support mediated the relationship between generative desire and purpose in life. A possible explanation for this finding is that older adults who experience more generative desire have a greater motivation to pursue relationships that contribute to others' well-being and this is reciprocated through an increased availability of love and affection from others. Prior research has demonstrated that the effect of generativity on well-being is mediated by respect received from younger generations (Cheng, 2009), suggesting that older adults' well-being does not only depend on the contributions they make to others, but also how others behave towards them. The finding that affectionate social support fully mediated the association between generative desire and purpose in life is in line with the predictions of motivational life span theories such as SST that suggest that older adults prioritize goals that maximize their socioemotional well-being. Our results indicate that generative desire provides a means for older adults to enhance their socioemotional well-being (i.e., by increasing the perceived availability of love and affection from others). In turn, this allows older adults to experience greater directedness and life purpose.

The current study has several limitations. One limitation is that brain imaging data was acquired two years prior to the collection of the behavioural data. Given that generativity and

resting-state functional connectivity are impacted by age-related processes, this presents a putative temporal confound. Furthermore, this study is limited by the over-representation of women in the current sample. Thus, these findings should be replicated in diverse samples in order to strengthen the generalizability of the findings. While all participants in this study are at risk of AD due to a first-degree family history, no participants in this study were diagnosed with mild cognitive impairment (MCI) or early dementia. The potential impact of early AD on generativity is a future direction of this research.

In conclusion, this study examined the neural correlates of generative desire and the neurobehavioural underpinnings that support the influence of generative desire on purpose in life in at-risk older adults. Enhanced generative desire was associated with greater rsFC between the vmPFC and rdlPFC, regions implicated in value-based social decision making. Moreover, rsFC and affectionate social support were found to moderate and mediate the relationship between generative desire and purpose in life, respectively. The results of the current study have implications for promoting the health and well-being of at-risk older adults. Therefore, interventions designed to enhance generativity may be effective to increase purpose in life in older adults at risk for cognitive impairment (Gruenewald et al., 2016). Future interventions might increase their efficacy by implementing familial intergenerational interventions that enhance feelings of love, appreciation, and affection in older adults. Prior research has demonstrated that older adults in early stages of AD experience preserved socioemotional functioning (Sturm et al., 2004; Zhang et al., 2015), suggesting that such interventions might also be effective for those with early functional impairment (i.e., mild cognitive impairment or mild dementia). Shedding light on this question might provide insight into how to improve the quality of life in individuals at risk for AD. Finally, a deeper understanding of the neural correlates of

generativity is also crucial to understand the cognitive processes and brain mechanisms that support healthy aging. These findings may guide the development of personalized interventions and circuit-based strategies to promote resilient aging.

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Tables

Table 1. Demographics, neurobehavioral inventory scores, and computerized cognitive assessment scores for the full sample ($N = 43$).

Demographic Variable	
Sex, *n* (%)	
Male	9 (20.9%)
Female	34 (79.1%)
Age (years), *M* (*SD*)	70.33 (5.19)
Education (years), *M (SD)*	15.93 (2.94)
***APOE ε4* Carrier Status, *n* (%)**	
Carrier	14 (32.6%)
Non-carrier	29 (67.4%)
Social Support, *M* (*SD*)	
Total	4.20 (0.61)
Emotional / Informational	4.23 (0.76)
Tangible	4.12 (0.95)
Affectionate	4.20 (0.76)
Positive interactions	4.21 (0.70)
Generativity, *M (SD)*	
Generative desire	31.05 (6.36)
Generative achievement	23.05 (6.12)
Purpose in Life, *M (SD)*	35.66 (7.08)
TMB Digital Neuropsychology Toolkit, *M* (*SD*)	
Simple Reaction Time	385.76 (85.58)
Choice Reaction Time	1188.32 (347.62)
Gradual Onset Continuous Performance (Discrimination)	2.71 (0.83)
Gradual Onset Continuous Performance (Impulsivity)	0.43 (0.43)
Matrix Reasoning	22.62 (6.01)
Forward Digit Span	6.46 (1.94)
Backward Digit Span	5.23 (1.98)
Visual Paired Associates	14.92 (4.26)
Digit Symbol Matching	36.26 (7.64)

Note. Social support scores come from The Medical Outcomes Study Social Support Survey (Sherbourne & Stewart, 1991). Generativity scores come from the Generativity Questionnaire

(Gruenewald et al., 2016). Purpose in life scores come from The Psychological Well-Being Purpose in Life subscale (Ryff et al., 2007). TMB refers to TestMyBrain Digital Neuropsychology Toolkit (Singh et al., 2021).

Figures

Figure 1. Resting-state functional connectivity associated with generative desire. Generative desire is positively associated with resting-state functional connectivity between the ventromedial prefrontal cortex (vmPFC) region of interest (Panel A) and a cluster in the right dorsolateral prefrontal cortex (Panel B). Results are corrected for multiple comparisons and overlaid on a standard template.

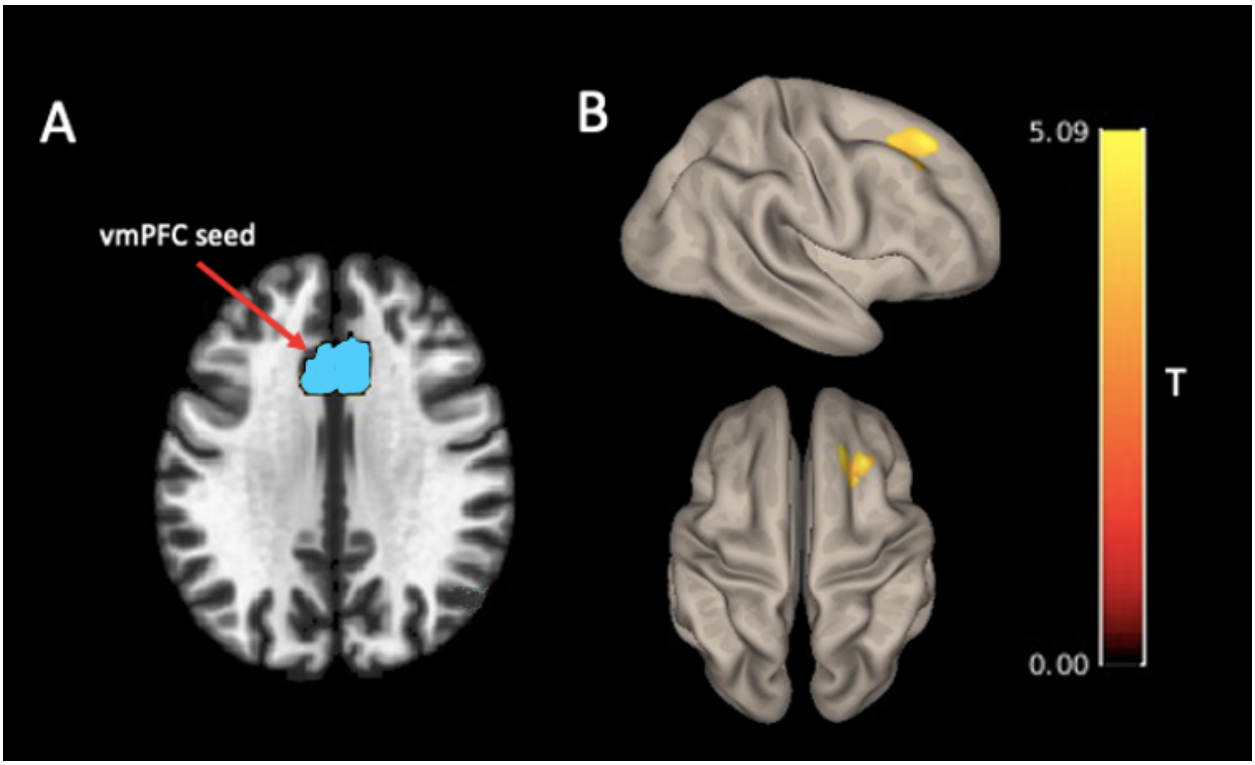


Figure 2. Diagram of the moderated mediation model results between generative desire and purpose in life. The dashed line between generative desire and purpose in life represents the indirect effect. The solid line between generative desire and purpose in life represents the direct effect after controlling for affectionate social support. vmPFC = ventromedial prefrontal cortex and dlPFC = dorsolateral prefrontal cortex. *$p < .05$, **$p < .01$.

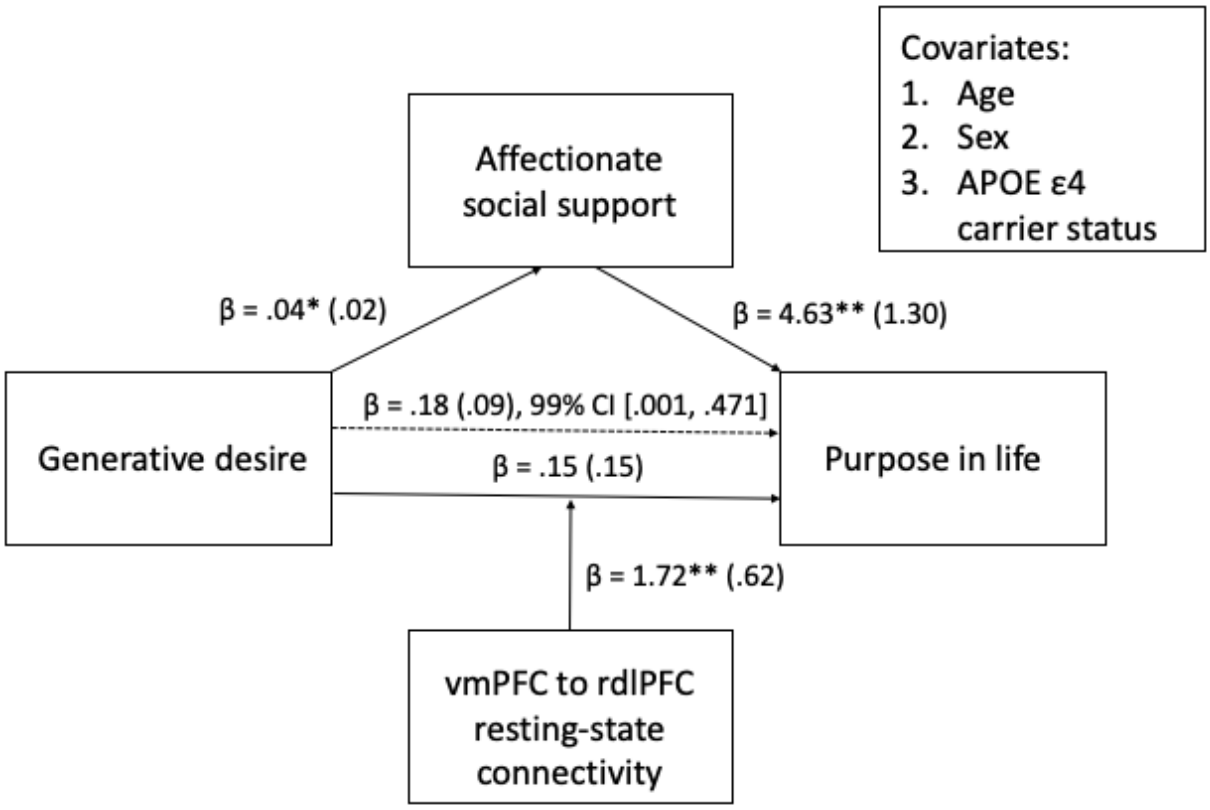
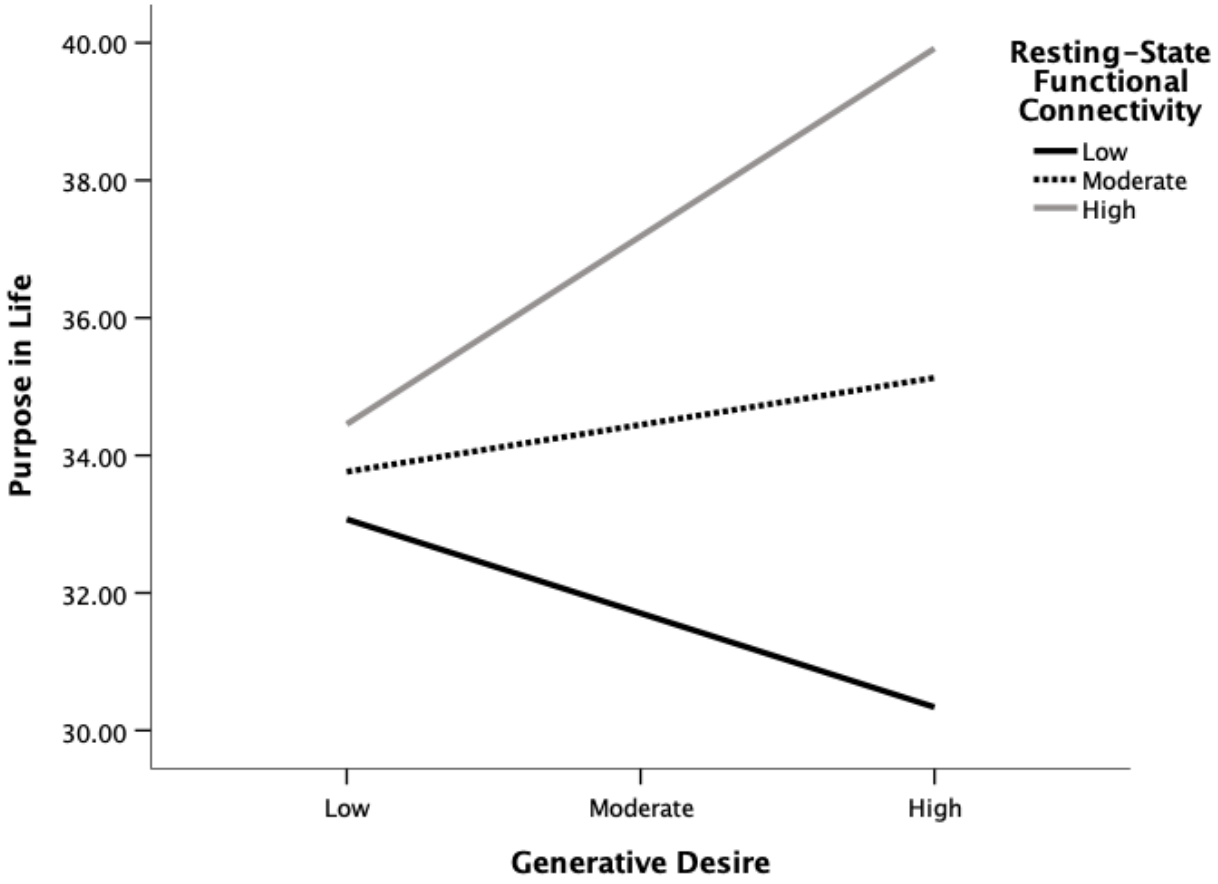


Figure 3. Simple slopes between generative desire and purpose in life at different levels of resting-state functional connectivity between the ventromedial prefrontal cortex and right dorsolateral prefrontal cortex. Generative desire and resting-state connectivity values were centered to their means. Purpose in life was regressed on generative desire at low (-1 standard deviations), moderate (mean), and high (+1 standard deviations) levels of resting-state functional connectivity.



Conflict of Interest

The authors have no conflicts of interest to disclose.

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