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Research article

An inwardly focused cognitive style links mental imagery and mental health

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A B S T R A C T

Variations in mental imagery ability have been linked to emotional, cognitive, and personality traits, but a unifying framework connecting these associations to mental health has been lacking. We propose a model of mental imagery centered on an "inwardly focused" cognitive style, which integrates traits related to visual imagery. By examining the relationship between self-reported imagery vividness and various cognitive and personality measures, we found significant correlations with interoceptive awareness, mindful presence, and traits such as openness, conscientiousness, and extraversion. Canonical correlation analysis identified a singular latent variable reflecting this inward cognitive style, which was negatively associated with alexithymia (difficulty in identifying and expressing emotions) and positively linked to the frequency of involuntary autobiographical memories. A path analysis revealed that this inward focus mediates the relationship between imagery vividness and negative mental health outcomes, such as neuroticism, depression, and stress, via its effects on alexithymia and involuntary memories. These findings suggest that the inwardly focused cognitive style plays a critical role in shaping the relationship between mental imagery and mental health, highlighting its relevance for emotional regulation and well-being.

1. Introduction

Mental imagery is traditionally studied within a framework that emphasizes its similarities to external perception. For example, imagining an apple is thought to involve the same neural mechanisms as seeing an actual apple [1–4]. However, this view overlooks the nature of mental imagery as an internal experience. Unlike the perception of external stimuli, imagery is a process that requires significant self-monitoring as well as attention to internal states and representations, similar to the control exerted in mindfulness and hypnosis [5,6]. This aligns imagery with other processes that depend on internal signal processing, such as interoception (the perception of internal bodily sensations) and emotion processing. A recent theory proposes that individual differences in imagery experience may reflect a broader cognitive style characterized by a tendency to focus on internal states [7], which not only emphasizes introspection and self-monitoring but also links imagery to interoceptive awareness and emotion processing.

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The link between imagery and interoception, although not directly examined in previous research, can be hypothesized based on existing evidence. For instance, individuals with higher levels of mindfulness—a trait characterized by heightened awareness of internal experiences—tend to report more vivid mental imagery and greater interoceptive accuracy [8,9]. Moreover, emotion regulation predicts imagery vividness [10], and individuals with emotional dysregulation and psychopathological conditions tend to experience less vivid imagery [11]. Mindfulness mediated the link between imagery vividness and self-reported anxiety and depression, as more mindful individuals reported experiencing greater imagery and lower emotional dysregulation [12]. There is also evidence to show that interoception and emotional experience are closely linked (e.g., Ref. [13]).

Mental imagery vividness is also associated with various personality traits. Milton et al. (2021) found higher trait openness (characterized by greater openness to feelings and imagination) in individuals with hyperphantasia (very vivid imagery) compared to those with average levels of imagery. Openness is also positively correlated with attention to interoceptive processes [14]. Extraversion, which is linked to a greater need for stimulation and positive emotions [15], is lower in individuals with aphantasia (i.e., individuals who lack imagery) compared to controls [16] and is associated with higher interoceptive awareness [14,17]. Lastly, conscientiousness, a personality trait characterized by a high degree of organization and self-discipline, positively correlated with interoceptive awareness [14]. In our view, these associations reflect a tendency to prioritize introspection and self-awareness, forming a larger 'inwardly focused trait' or 'latent inward trait' explored extensively in a previous paper [7].

Moreover, the hypothesized inwardly focused trait may mediate the link between imagery and mental health conditions. Depression is often associated with intrusive negative imagery, reduced positive imagery, and overgeneralized memories [18–21]. Vivid imagery can exacerbate stress and anxiety through frequent imagery of threats [22,23]. In contrast, *voluntary* imagery might mitigate some negative effects of intrusive imagery and aid in self-regulation [24–26]. We propose that voluntary mental imagery has a beneficial effect on mental health through its association with effortful control and emotional regulation as part of the inwardly focused trait. Consistent with this view, alexithymia, as a condition characterized by difficulty in identifying and expressing emotions, is linked to both mental health conditions as well as disorders of imagery [27–29].

1.1. Present study

While mental imagery ability is linked to various measures of personality and self-perception, there is no comprehensive theoretical framework to account for these associations or their link to mental health. We hypothesized that these associations reflect a broader *inwardly focused cognitive style*—a latent trait characterized by heightened interoceptive awareness, emotional sensitivity, mindfulness, and personality factors such as openness and conscientiousness. We further hypothesized that this trait mediates the relationship between imagery vividness and mental health, such that the protective or detrimental impact of imagery depends on how it interacts with internal processing traits.

To test this, we conducted a comprehensive study across two independent data collection sites. First, we used correlation analyses to explore the link between imagery and a range of subjective traits related to inward focus, including interoceptive awareness, emotion processing, and personality dimensions (see Table 1). Second, we employed Canonical Correlation Analysis (CCA) to uncover multivariate relationships between these measures and to examine whether they are organized by a common latent dimension. Finally, we used Structural Equation Modelling (SEM) to assess whether this inward trait mediates the relationship between imagery vividness and negative mental health outcomes.

2. Methods

The data were collected in the context of EU COST Action CA18106 (The Neural Architecture of Consciousness) and are part of a

Table 1
Correlation analysis with vividness of visual imagery.

Domain	Variable	Combined Site R	Site 1 R (n = 298)	Site 2 R (n = 293)	Combined BF	Interpretation
Interoception	MAIA - Attention	25.6****	30****	19.9***	3.89E+07	Extreme evidence for
Personality	Openness	24****	24.3****	20.7***	3.24E+06	H1
Mindfulness	Mindful Presence	20.6****	24.7****	17.1**	3.09E+04	
Interoception	MAIA - Emotional Awareness	19****	13.8*	23.5****	4.49E+03	
Interoception	MAIA - Noticing	17.1****	12.7*	23****	5.49E+02	
Interoception	MAIA - Self-Regulation	16.8****	14.7*	22.3***	3.88E+02	
Personality	Conscientiousness	15.3***	13.3*	23.7****	9.58E+01	Very strong evidence
Interoception	MAIA - Body Listening	15.2***	14.7*	14.5*	8.96E+01	H1
Personality	Extraversion	12.5**	16.7**	12.3*	9.59	Moderate evidence H1
Interoception	MAIA - Trusting	11.9**	14.6*	12.9*	6.26	
Sensory Sensitivity	Hypersensitivity †	−12.6*	−19.9***	0.3	2.68	Anecdotal evidence H1
Mindfulness	Mindful Acceptance	8.6*	10.8	6.7	0.86	Anecdotal evidence H0
Sensory Sensitivity	Importance of Olfaction - Application	8.2*	14.6*	−6.9	0.7	
Personality	Neuroticism	−6.6	−13.5*	−2.6	0.35	

larger project that includes MRI and behavioral data collected from healthy participants drawn from the general population. The current article presents data collected at two sites during overlapping study periods: the Center of Functionally Integrative Neuroscience (Aarhus University, Denmark; site 1) where data collection occurred from 2019 to 2021, and the Consciousness Lab (Jagiellonian University, Kraków, Poland; site 2) where data collection took place from 2020 to 2022. Some data from the overall project already appear in other published or in preparation articles. Data on imagery has been published in a separate manuscript with the different aim of examining the neural correlates of imagery [30].

The local research ethics committee at the Institute of Psychology, Jagiellonian University, Poland, approved the study at site 1 (decision no: KE/03/042020). The regional ethics committee, De Videnskabsetiske Komitéer for Region Midtjylland, Denmark, approved the study at site 2 (Project ID: M-2016-69-16). The study adhered to the principles outlined in the Declaration of Helsinki. All participants gave written informed consent.

2.1. Participants

Site 1 (Jagiellonian University, Kraków, Poland): Approximately 360 individuals were initially screened for eligibility. Participants with MRI incompatibility or health-related counterindications were excluded during screening (estimated 10–15 %). Of those who passed initial screening, 315 participants were recruited and assigned study IDs. During the study period, 12 participants dropped out before commencing study procedures, leaving 303 participants who began the study. Of these, 298 participants completed all required assessments including the VVIQ questionnaire and were included in the final analysis. Site 2 (Aarhus University, Denmark): A total of 380 individuals self-screened and signed up for the study. One participant did not meet inclusion criteria and was excluded. Of the remaining 379 eligible participants, 74 did not sign up for the MRI component, leaving 305 participants for potential inclusion. Four participants dropped out before or during the MRI session, resulting in 301 participants who completed the MRI protocol. Of these, 293 participants completed all required assessments including the VVIQ questionnaire and were included in the final analysis.

At both sites, participants were recruited through a local participant database and local advertisement. They were compensated financially for participation. The following inclusion criteria were used: age between 18 and 50 years (40 for site 1), normal or corrected-to-normal vision, and normal hearing. Exclusion criteria were brain damage or brain surgery and standard MRI contraindications, the use of neuropharmacological or other medicines that may affect neural states, pregnancy, and skin diseases. Additional exclusion criteria at site 1 were cardiovascular conditions or chronic pain, as this site had additional pain experiments published elsewhere. Site 1 included 298 participants (186 females) aged between 18 and 41 years (mean = 23.94) who performed all tasks. Site 2 included 293 participants (168 females) aged between 18 and 47 years (mean = 24.48). Not all participants performed all subtests (see Results section). More details on sample size considerations can be found in Section 1.3.2 of the Technical Annex of the Action: https://e-services.cost.eu/files/domain_files/CA/Action_CA18106/mou/CA18106-e.pdf.

3. Materials

The following characteristics were examined using questionnaire tests at both sites (N = 591):

Mental imagery: Participants' ability to generate vivid mental images was assessed using the 32-item Vividness of Visual Imagery Questionnaire-2 (VVIQ). Participants are instructed to visualize for example; a "sun rising above the horizon into a hazy sky" and rate on a scale from 1 ("No image at all, you only know that you are thinking of the object") to 5 ("Perfectly clear and vivid as real life") how vivid their imagery is. Following previous approaches [31], we created summed VVIQ scores normalized to the unit interval.

Interoceptive awareness: Interoceptive awareness was measured using the 37-item Multidimensional Assessment of Interoceptive Awareness MAIA-2 [32]. The MAIA-2 includes eight subscales that assess different facets of interoceptive awareness. The "Noticing" subscale evaluates an individual's awareness of uncomfortable, comfortable, and neutral bodily sensations. The "Not-Distracting" subscale measures the tendency not to ignore or distract oneself from sensations of pain or discomfort. The "Not-Worrying" subscale assesses the tendency not to worry or experience emotional distress in response to sensations of pain or discomfort. The "Attention Regulation" subscale evaluates the ability to sustain and control attention focused on bodily sensations. The "Emotional Awareness" subscale measures the awareness of the connection between bodily sensations and emotional states. The "Self-Regulation" subscale assesses the ability to regulate distress by paying attention to bodily sensations. The "Body Listening" subscale measures the extent to which an individual actively listens to their body for insights. Finally, the "Trusting" subscale evaluates the experience of one's body as safe and trustworthy.

Mindfulness: Mindful acceptance and presence were measured with the 14-item Freiburg Mindfulness Scale (FMI) [33]. The mindful presence subscale assesses focused awareness on the present moment, while the mindful acceptance subscale evaluates a non-judgmental, accepting attitude toward experiences.

Personality: Personality (openness, conscientiousness, extraversion, agreeableness, and neuroticism) was measured with the 240-item Polish NEOPIR at site 1 [34,35] and NEOPI-3 [36] at site 2.

Sensory sensitivity: Sensory sensitivity was measured using the 21-item noise sensitivity questionnaire [37], the 20-item importance of olfaction questionnaire [38], and the 42-item Glasgow Sensory Questionnaire [39]. Hypersensitivity (Glasgow) was only available for 100 subjects at site 2 and thus only 398 from the combined dataset.

Mental health: Negative mental health was measured using the neuroticism trait from the previously mentioned NEOPI personality measure, the 10-item perceived stress scale [40], and the 20-item depression scale from the Center for Epidemiological Studies [41].

At site 1 only: The 20-item Involuntary Autobiographical Memory Inventory (IAMI) questionnaire [42], Polish adaptation by Barzykowski et al. [43]. At site 2 only: The 20-item Toronto Alexithymia Scale (TAS), measuring the inability to express emotions,

known as alexithymia [44].

Internal consistency was generally acceptable to excellent across all measures. The lowest Cronbach's alpha was observed for the MAIA Noticing subscale (α = .665). All other MAIA subscales demonstrated good to excellent reliability (αs = 0.798–0.869). All remaining scales (e.g., VVIQ, FMI, NEOPIR, OSS, CESD, PSS, TAS, IAMI) demonstrated excellent internal consistency (all αs ≥ 0.809). See Supplementary Table S7 for detailed values.

3.1. Procedure

Site 1: Tests were administered in two separate sessions. A computerized version of the Polish NEO-PI-R was completed in an undisturbed environment at the Jagiellonian University, Kraków. The test duration was around 25–30 min. Participants completed the remaining questionnaires from home in a subsequent online session, typically within one week. They were instructed to fill out the questionnaires in an undisturbed environment, and they were allowed to take breaks as necessary. This session included other questionnaires for different sub-studies that are not included here. The total duration of the session was approximately 90 min.

Site 2: All tests were administered online in two separate sessions. Participants were instructed to complete the sessions in an undisturbed environment and were allowed to take breaks as necessary. All questionnaires, except NEO-PI-3, were completed in one session. This session included other questionnaires for different sub-studies that are not included here. The total duration of the session was approximately 75 min. Typically, a few days later, NEO-PI-3 was completed in a separate online session. The duration of this session was around 25–30 min.

3.2. Statistical analysis

Our analyses proceeded in three main stages: (1) bivariate correlations, (2) Canonical Correlation Analysis (CCA), and (3) Structural Equation Modeling (SEM).

Correlation analyses: Using a Pearson correlation analysis, we explored the relationships between VVIQ scores and various other measures, which were hypothesized to be part of the inwardly focused cluster (see Table 1). The correlations were assessed using both frequentist (p-values) and Bayesian (Bayes Factors) approaches [45].

Canonical Correlation Analyses: To investigate the shared constructs between mental imagery and a range of overlapping psychological traits (e.g., interoception, mindfulness, and personality), we employed Canonical Correlation Analysis (CCA). CCA was chosen because it is well-suited for examining relationships between two sets of variables, even when there are many interrelated items within each set—for example, across multiple questionnaire subscales. This allowed us to determine whether a common underlying dimension could account for the variance shared between imagery vividness and these psychological traits.

Many of the included measures exhibit substantial overlap, both conceptually and statistically. Traits related to interoception, sensitivity, emotion, and personality often show strong intercorrelations, and only a subset of items may meaningfully reflect the latent construct of interest. Moreover, despite being drawn from theoretically distinct domains, these traits may in practice form a single coherent factor—such as the "inwardly focused" trait we previously hypothesized [7].

CCA addresses these challenges by identifying weighted combinations of items (canonical variates) from each variable set that are maximally correlated [46,47]. This approach not only reduces dimensionality but also highlights the specific items contributing most to the shared variance. To ensure generalizability and avoid overfitting, we used Pyrcca, an open-source Python package for regularized CCA [48]. We then tested the robustness of the identified latent dimension by evaluating how well it predicted imagery scores across two independent data collection sites. This allowed us to validate whether the inwardly focused trait is stable and consistent across populations.

*Structural Equation Modeling (*SEM), was subsequently used to test whether this latent "inwardly focused" trait mediates the relationship between imagery vividness and negative mental health outcomes. SEM is a powerful modeling framework that estimates how observed and latent variables relate to each other, allowing us to assess indirect effects and test theoretically grounded pathways while accounting for measurement error [49,50]. While SEM does not, on its own, establish causality, it enables researchers to evaluate whether the data are consistent with hypothesized causal pathways under specific assumptions, such as correct model specification and absence of unmeasured confounders [51–53]. In this study, we treat our SEM models as providing evidence for or against of theoretically motivated causal assumptions, rather than enabling definitive causal claims.

4. Results

4.1. Correlation analyses

We identified several correlations between VVIQ scores and various other measures, which were hypothesized to be part of the inwardly focused cluster (see Table 1). First, we focus on those correlations that were strongest and most reliable across both sites.

Several significant positive correlations with VVIQ emerged with extreme evidence in a Bayesian framework supporting the alternative hypothesis (H1), namely, that a true association exists between the variables. These included MAIA - Attention ($r = 0.26$, $p < .0001$), Openness ($r = 0.24$, $p < .0001$), Mindful Presence (Freiburg) ($r = 0.21$, $p < .0001$), MAIA - Emotional Awareness ($r = 0.19$, $p < .0001$), MAIA - Noticing ($r = 0.17$, $p < .0001$), and MAIA - Self-Regulation ($r = 0.17$, $p < .0001$). All the above correlations also remained significant at individual sites. Next, we observed very strong evidence for H1 for conscientiousness ($r = 0.15$, $p < .001$) and MAIA - Body Listening ($r = 0.15$, $p < .001$). Both correlations were significant at individual sites. Moderate evidence for H1 was found

for extraversion ($r = 0.13$, $p < .01$) and MAIA - Trusting ($r = 0.12$, $p < .05$), and these correlations were also significant at individual sites.

The table is sorted by descending Bayes Factor from combined datasets, thereby showing the most reliable and strongest correlations from top to bottom. E+01 means the BF is multiplied by 10, and E+02 is multiplied by 100. **** = correlation is significant at $p < .0001$, *** = correlation is significant at $p < .001$, ** = $p < .01$, * = $p < .05$. NEO PI-R is the NEO PI (neuroticism, extraversion, openness personality Inventory). The NEO PI-R was used in site 1 (Krakow), and NEO PI-3 was used in site 2 (Aarhus), which uses slightly different items (see methods). † Hypersensitivity (Glasgow) was only available for 100 subjects in site 2 and thus only 398 from the combined dataset. In total, data from 591 participants are available from other questionnaires. A detailed table is available in supplementary materials containing single-site correlations and correlations with other Bayes Factor interpretations (lower Bayes Factor scores).

Anecdotal evidence for H1 was found for hypersensitivity (Glasgow) ($r = -0.13$, $p < .05$), mindful acceptance (Freiburg) ($r = 0.09$, $p < .05$), and importance of olfaction-application ($r = 0.08$, $p < .05$). Hypersensitivity was significant only at site 1, and MAIA - Trusting was significant only at site 2.

Anecdotal evidence for H0 was found for neuroticism ($r = -0.07$, $p > .05$), importance of olfaction summary ($r = 0.06$, $p > .05$), and MAIA - not-worrying ($r = 0.03$, $p > .05$). Neuroticism and the importance of olfaction summary score were significant when combined and individually at site 1, but not significant at site 2. MAIA - not-worrying was not significant at either site.

In summary, the results of correlation analyses across combined sites support the notion that VVIQ is associated with varying degrees of evidence (as indicated by Bayes Factors) with several hypothesized inwardly focused traits. Most notably, the correlations with extreme and very strong evidence for H1 included the MAIA subscales of Attention, Emotional Awareness, Noticing, Self-Regulation, and Body Listening; Mindful Presence (Freiburg); and the personality traits from the NEO personality inventory of openness, extraversion, and conscientiousness.

We also examined the correlation between VVIQ and two questionnaires, which were available at single sites; the Involuntary Autobiographical Memory Inventory (IAMI) at site 1 showed a positive trend ($r = 0.146$, $p = .011$). The Toronto Alexithymia Scale (TAS), tested at site 2, showed a negative correlation ($r = -0.166$, $p = .004$). This provides further evidence of the link between imagery vividness and emotional awareness as well as involuntary memories. The full list of correlations can be found in the supplementary materials (S1).

4.2. Canonical Correlation Analysis

In line with recommendations for CCA analyses [48], we performed 100 iterations of training for each site. We found that a single component was consistently optimal, selected in 76 out of 100 iterations for site 1 and 86 out of 100 for site 2. This indicated that one shared pattern best captured the relationship between the two variable sets. For the VVIQ (imagery) items, all weights were positive, suggesting that the identified component reflects increased imagery vividness. For the other questionnaire items, the weights varied, with both positive and negative values observed (see Fig. 1 for weights).

To evaluate the generalizability of this component, we used site 1 data to predict imagery scores (VVIQ) in site 2, and vice versa. We looked at how well the model could predict individual VVIQ item scores as well as the overall VVIQ summary score. For the model trained on site 1 and tested on site 2, the correlation between observed and predicted VVIQ scores was $r = 0.26$ ($p < .001$) at the item level, and $r = 0.38$ ($p < .001$) for the summary score. When testing site 2 predictions on site 1, item-level correlations were $r = 0.29$ ($p < .001$) for training and $r = 0.18$ ($p < .001$) for testing. Summary score correlations were stronger: $r = 0.44$ ($p < .001$) for training and $r = 0.28$ ($p < .01$) for testing.

Combining all cross-site predictions, we found an overall correlation of $r = 0.27$ ($p < .001$) between observed and predicted VVIQ summary scores (Fig. 1). This shows that the CCA model reliably captures a shared dimension that relates psychological traits to imagery vividness across both samples. The prediction across different sites, provides evidence of the generalizability of the identified canonical covariates and the relationship between them.

It's important to clarify that CCA does not predict exact VVIQ scores, as noted by Dubois and colleagues [54,55]. Rather, it captures shared variance between the two variable sets. This means that our findings reflect how well the trait patterns align with imagery vividness, not individual score precision.

4.3. Defining a latent inward trait using CCA weights

We next examined how the CCA weights could be used to define a latent inward trait (LIT), a shared dimension capturing the psychological characteristics most strongly related to imagery vividness. All 32 VVIQ-2 items had positive weights across both sites, indicating that the imagery component identified by CCA consistently reflects increased vividness (see Supplementary S6). In contrast, the weights for the other psychological questionnaires (e.g., MAIA, FMI, and the personality traits) included both positive and negative values, suggesting that these traits contribute in different ways to this inward cognitive style.

To identify which items were consistently important across sites, we standardized the weights and considered items stable if the absolute difference between the sites was less than the average absolute difference. We then focused on items with high positive weights (above 0.5 standard deviations in both sites), as these represent the most influential contributors to the latent trait.

As predicted, and in line with the univariate correlations, we found that items from openness, conscientiousness, extraversion, interoceptive awareness (MAIA), and mindfulness (FMI) showed high and stable positive weights. In addition, items from agreeableness also contributed positively. Specifically, we observed consistent high weights for openness (13 items), conscientiousness (11),

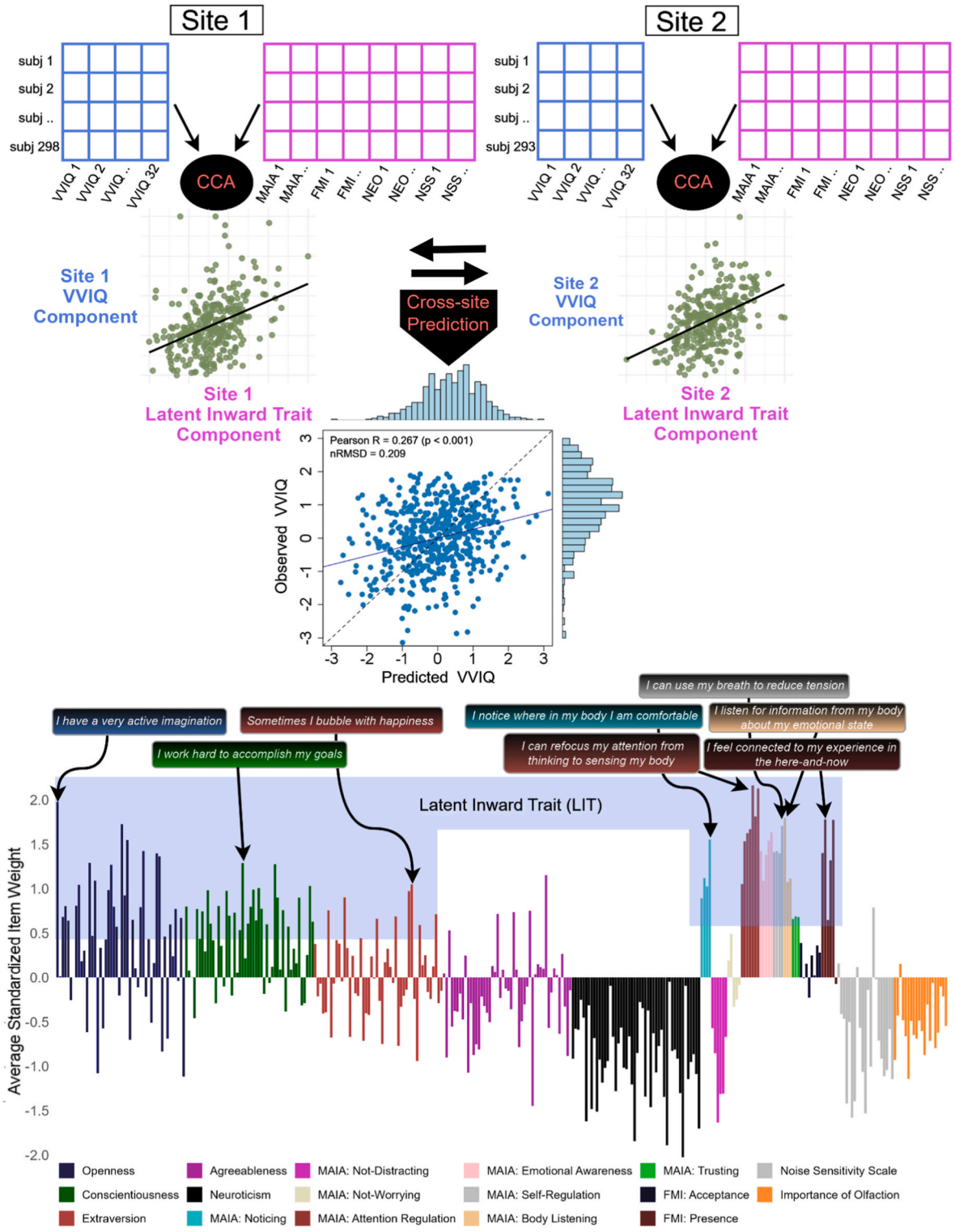

Fig. 1. Canonical Correlation Analysis (CCA). The process and results of (CCA) were used to predict visual imagery across two data collection sites. *Top*: data matrices for sites 1 and 2. Each site contains data from multiple participants across various measures. Matrices on the left include a set of VVIQ scores, while matrices on the right include items from cognitive and personality measures such as MAIA, FMI, and NEO, and sensory sensitivity items. CCA integrates these datasets to identify latent traits (canonical variables) that could predict the VVIQ scores across the two sites. *Middle*: Scatter plot of the correlation between observed and predicted VVIQ scores across both sites. The findings demonstrate the robustness and generalizability of the CCA model in predicting VVIQ scores across different sites. *Bottom*: CCA weights. All weights are shown descriptively as the

standardized within-site and average across sites. Blue-shaded regions overlapping certain positive weighted items indicate items used to construct the latent inward trait (see methods for details). Above the plot are depicted the item text with the highest weight for a subset of the summary scales used (see supplementary for a full list).

extraversion (5), MAIA (10), FMI (4), and agreeableness (4) (see Supplementary S5). These findings support the idea that individuals scoring higher on these traits tend to experience more vivid mental imagery.

In contrast, neuroticism items showed consistently high negative weights across both sites, suggesting that higher emotional instability is associated with less vivid imagery. Similarly, items related to noise sensitivity and the importance of olfaction also had stable negative weights, indicating that certain types of sensory sensitivity may dampen mental imagery.

In summary, the CCA analysis revealed that a latent inward trait (LIT), is shaped by both enhancing (e.g., openness, interoception) and opposing (e.g., neuroticism, sensory sensitivity) psychological factors. This multidimensional structure helps explain why imagery vividness varies across individuals, and supports the existence of a broader trait reflecting inward cognitive focus. A complete list of weighted items is provided in the supplementary materials.

4.4. Structural equation modelling

To further test the validity of the latent inward trait (LIT), we examined whether it helps explain the link between imagery vividness and mental health. We identified items from the CCA that had consistently positive and stable weights across both sites. These items were combined to form the latent inwardly focused trait, which was then used in Structural Equation Modeling (SEM) to explore its role in mediating the relationship between VVIQ and negative mental health outcomes [49,50]. Due to our theoretical foundation, we defined the latent trait using items from the personality traits of Openness, Conscientiousness, and Extraversion, as well as MAIA and FMI items, and thus excluded Agreeableness to remain aligned with our prior model [7]. The models were fitted using the lavaan package in R, and bootstrapping (n = 5000) was used to generate confidence intervals and test for indirect effects [56]. Similarly, a latent negative mental health (NMH) variable was constructed using items from three measures: depression (CESD), neuroticism (NEO-PI), and stress (Perceived Stress Scale).

In both site 1 and site 2, VVIQ was positively correlated with LIT, confirming the CCA findings (see Fig. 2). When LIT was not included, the direct relationship between VVIQ and NMH was not significant (site 1: $\beta = 0.003$, $p = .960$; site 2: $\beta = 0.048$, $p = .484$), which aligns with results from the previous univariate Pearson correlations. However, when LIT was included as a mediator, the indirect effect of VVIQ on NMH via LIT became significant (site 1: $\beta = -0.133$, $p = .002$; site 2: $\beta = -0.112$, $p = .002$), indicating that higher VVIQ scores are associated with lower NMH through LIT. These consistent findings across sites support the mediating role of LIT in the protective effect of vivid mental imagery on mental health.

To deepen our understanding of how LIT mediates this relationship, we incorporated two additional variables: the Involuntary Autobiographical Memory Inventory (IAMI) and the Toronto Alexithymia Scale (TAS). Previous correlations showed that IAMI was

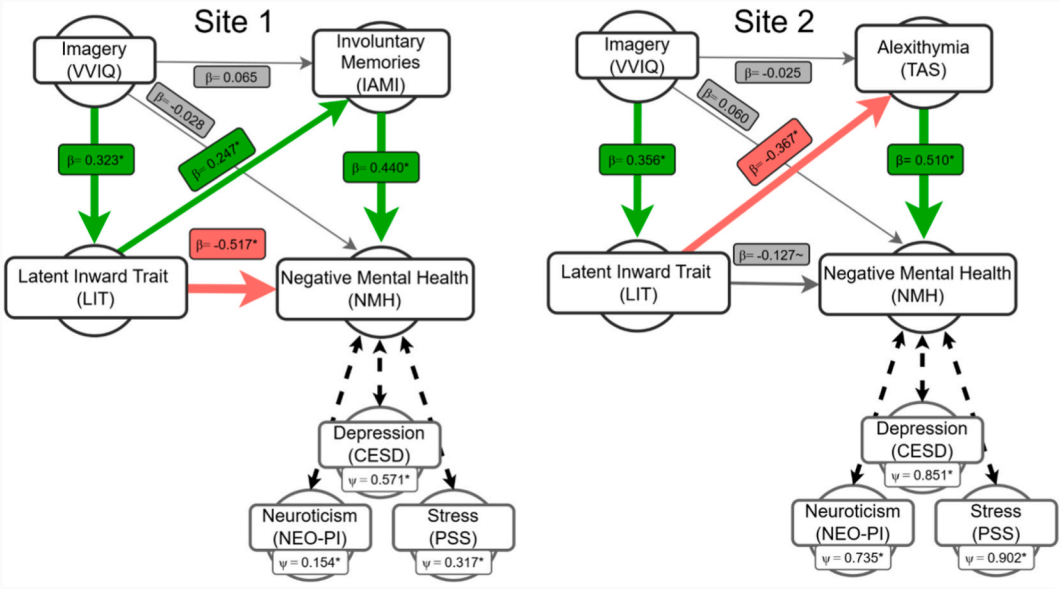

Fig. 2. Structural Equation Models depicting the relationship between imagery ability, latent inwardly trait (LIT), and negative mental health. Green, red, and grey arrows among latent variables indicate positive, negative, and insignificant coefficients. Black dashed arrows indicate covariances between individual mental health questionnaires and a latent negative mental health (NMH) component. Stars * indicate significance, $p < .05$, tilde ~ indicate borderline $p < .1$. beta β are standardized coefficient estimates, psi ψ are covariance estimates.

positively associated with VVIQ, while TAS was negatively associated with VVIQ. Separate models showed that VVIQ → LIT → IAMI, and VVIQ → LIT → TAS, provided slightly better fit, in terms of AIC and BIC compared to LIT - > VVIQ → IAMI, and LIT→ VVIQ → TAS (see Supplementary S8).

IAMI captures the frequency of spontaneous, often vivid autobiographical memories, which we theorized could be emotionally distressing—especially for individuals with high VVIQ—and therefore potentially detrimental to mental health. In contrast, TAS measures alexithymia, the difficulty in identifying and describing emotions. Lower TAS scores (i.e., reduced alexithymia) might be beneficial for emotional functioning and mental health.

We constructed two additional SEM models to explore these relationships in more detail: one including IAMI (tested at site 1), and another including TAS (tested at site 2). These models allowed us to examine how memory frequency and emotional awareness may further mediate the pathway between VVIQ, LIT, and negative mental health.

4.5. SEM: involuntary autobiographical memory mediation

Consistent with our initial predictions, despite introducing IAMI into the model, VVIQ did not have a direct effect on negative mental health (NMH) *($\beta = -0.028$, $p = .638$)* (see Fig. 2). Instead, VVIQ had a stronger and statistically significant indirect effect via the latent inwardly focused trait (LIT) *($\beta = -0.167$, $p = .001$)*.

The path analysis revealed that LIT significantly increased IAMI *($\beta = 0.247$, $p = .002$)*, and that the previous direct effect of VVIQ on IAMI was no longer significant *($\beta = 0.065$, $p = .301$)*. Since IAMI was strongly associated with higher NMH *($\beta = 0.440$, $p < .001$)*, this pattern suggests that LIT plays a dual role: it directly and strongly reduces negative mental health *($\beta = -0.517$, $p = .001$)*, while also increasing IAMI, which is associated with worse mental health outcomes.

These results provide evidence that higher levels of LIT are associated with increased NMH when accompanied by greater IAMI. This model suggests that LIT captures both the protective and detrimental pathways through which VVIQ relates to mental health. However, the direct protective pathway VVIQ → LIT → NMH ($\beta = -0.167$, $p = .001$) remained stronger than the indirect pathway through IAMI *($\beta = -0.041$, $p = .025$)*.

Interestingly, this longer indirect path, VVIQ → LIT → IAMI → NMH—was statistically significant but small in magnitude ($\beta = -0.041$, $p = .025$), and in the opposite direction than anticipated. While all component paths in this chain were positive, the overall indirect effect was negative, likely reflecting the dominant protective influence of LIT on NMH that offsets the small risk transmitted through IAMI. Given its small size and counterintuitive sign, this pathway should be interpreted with caution and may reflect model dynamics rather than a meaningful clinical mechanism.

When combining both pathways, the total effect of VVIQ on NMH remained negative and statistically significant *($\beta = -0.126$, $p = .016$)*. In summary, this model highlights the complex interplay between vivid mental imagery, inward cognitive traits, and involuntary autobiographical memories in shaping mental health outcomes.

4.6. SEM: alexithymia mediation

Consistent with our conceptualization of the latent inwardly focused trait (LIT), we predicted that some of its effects on mental health would be mediated by alexithymia, as measured by the Toronto Alexithymia Scale (TAS), which reflects an individual's ability to identify and express their bodily and emotional experiences [28]. The results supported this prediction, showing that TAS was significantly and negatively predicted by LIT *($\beta = -0.367$, $p = .020$)*. This finding aligns with the idea that individuals with higher levels of LIT tend to exhibit greater emotional and interoceptive awareness, which stands in contrast to the difficulties captured by TAS.

In line with our hypotheses, TAS had a significant positive effect on negative mental health (NMH) *($\beta = 0.510$, $p = .010$)*, indicating that higher levels of alexithymia were associated with poorer mental health outcomes. This pattern allowed for the emergence of a new significant indirect pathway: VVIQ → LIT → TAS → NMH *($\beta = -0.079$, $p = .027$)*. In this path, VVIQ increased LIT, which in turn reduced TAS scores, ultimately leading to lower NMH. These results suggest that one route through which LIT exerts its protective effect on mental health is by reducing alexithymia.

Importantly, after introducing TAS into the model, the previous indirect path from VVIQ to LIT to NMH was no longer significant *($\beta = -0.126$, $p = .093$)*. This suggests that the influence of LIT on mental health may be more accurately explained through its impact on alexithymia rather than through a direct path.

Additionally, the direct path from VVIQ to TAS was not significant *($\beta = -0.025$, $p = .702$)*, indicating that the entire effect of VVIQ on TAS was mediated through LIT. These findings underscore the central role of alexithymia in explaining how inwardly focused cognitive traits contribute to better mental health, and highlight emotional awareness as a key mechanism underlying the protective function of vivid mental imagery.

5. Discussion

Findings of the present study provide empirical evidence for the existence of a latent inwardly focused trait that mediates the impact of visual imagery on mental health. Significant positive correlations were found between VVIQ and the MAIA subscales of Attention, Emotional Awareness, Noticing, Self-Regulation, and Body Listening, as well as the Mindful Presence subscale of the Freiburg Mindfulness Inventory. For personality traits, openness, conscientiousness, and extraversion correlated significantly with VVIQ. Additionally, we found a negative correlation between VVIQ and alexithymia, further supporting the link between imagery

vividness and emotion processing.

CCA was used to analyze item-by-item relations in the questionnaires and to identify specific questions from the different data sets that cluster together. In line with our predictions, items from openness, conscientiousness, extraversion, MAIA, and FMI scales related to a singular canonical covariate component that had consistent and positive weights, which supported a prediction of increased vividness of VVIQ items.

Finally, the link between VVIQ and mental health was examined using structural equation modelling (SEM). A link between VVIQ and mental health was found, which was wholly accounted for by the aforementioned latent inward trait (LIT). In other words, once LIT was introduced to the model, VVIQ no longer, by itself, showed a significant link to negative mental health (NMH). Specifically, higher VVIQ scores correlated with better mental health (reduced NMH) through LIT. However, LIT also showed a dual role by increasing involuntary autobiographical memories (IAMI), which negatively impacted mental health (increasing NMH), although to a lesser extent. Additionally, models provided evidence that the influence of LIT on mental health was almost exclusively mediated by a reduction in alexithymia.

Our results also indicate that the relationship between VVIQ/LIT and mental health is not always positive, depending on other traits. Specifically, vivid imagery might be unfavourable for mental health when coupled with greater levels of involuntary autobiographical memories.

This finding aligns with discussions around involuntary imagery in aphantasia [57,58] and also underscores the relevance of measuring intrusive negative imagery in mental disorders [22,59]. It is important to note that while the pathway from VVIQ to LIT to IAMI indicates a significant negative impact on mental health via increased IAMI, the overall positive effects of LIT—primarily through enhanced emotional processing and reduced alexithymia—appear to outweigh this adverse influence. Our findings thus dovetail with previous studies [12] suggesting that higher imagery ability generally has positive effects on mental health. Our results thus suggest that the impact of vivid imagery on mental health depends on how it interacts with other traits—such as emotional awareness and memory processes.

5.1. How inward focus and imagery interact

Importantly, our use of SEM is intended to test theoretically motivated models and indirect pathways. While this approach allows us to evaluate whether the data are consistent with hypothesized causal relationships, the results should be interpreted as statistical associations—not as definitive evidence of cause-and-effect. This distinction is important for accurately interpreting the findings, as the validity of any causal inference depends on key assumptions, such as correct model specification and the absence of unmeasured confounding [51,56,60,61]. Stronger causal evidence would require complementary methodological approaches—most notably, longitudinal designs to establish temporal precedence, or experimental and interventional studies that directly manipulate key variables.

These findings are broadly consistent with existing frameworks of trait mindfulness and attentional style. For example, the Five Facet Mindfulness Questionnaire (FFMQ) conceptualizes mindfulness as involving awareness, non-reactivity, and attention to internal experience—dimensions which align closely with the MAIA subscales and FMI measures contributing to our inward trait [62,63]. Similarly, our findings resonate with the Attention-to-Body Model [32], which links interoceptive awareness with adaptive self-regulation and emotional processing. These models emphasize the benefits of internal attention for psychological health, which our results support. However, our work extends these theories by showing that vivid mental imagery plays a key role in shaping how inward focus impacts wellbeing [12].

At the same time, our findings diverge from these models by highlighting potential costs of an inward focus. Specifically, we found that higher scores on the inward trait were also associated with more frequent involuntary autobiographical memories, which in turn were linked to poorer mental health.

This suggests that inward attention, while generally adaptive, can also lead to emotionally intrusive content. This nuance is not well-captured by existing mindfulness or attentional style frameworks, which largely emphasize the regulatory benefits of inward focus [64–68]. Instead, these relationships offer support for the threshold model, which has been recently proposed to explain how autobiographical memories—especially involuntary ones—enter conscious awareness [69–72]. Briefly, this model posits that for a memory to reach awareness, it must first surpass a certain threshold. This threshold can be modulated by various factors. For instance, retrieval intentionality (i.e., deliberately trying to recall something) may lower the threshold. Similarly, directing attention inward—such as focusing on bodily sensations, as captured by interoceptive sensitivity—may not only reduce the threshold (increasing the chance that an involuntary memory is noticed amid the ongoing stream of awareness) but also increase the likelihood of an involuntary memory occurring in the first place. Moreover, the model assumes that a memory's accessibility—or its ability to cross the awareness threshold—can be influenced by intrinsic features of the memory itself. These may include emotional intensity, vividness, physiological arousal, or other phenomenological characteristics. According to the model, "phenomenologically rich" memories—those that are vivid, emotionally charged, and capable of eliciting strong bodily sensations—are more likely to exceed the threshold. Because such memories are inherently more attention-grabbing, they are more likely to disrupt ongoing thought processes and enter conscious awareness involuntarily. The current findings therefore call for a more refined understanding of how inward focus operates in both adaptive and maladaptive ways, depending on context and content.

5.2. Inward focus and personality traits

As predicted, Openness, Conscientiousness, and Extraversion correlated with VVIQ. In the CCA analyses, high and stable weights

were observed for items from subscales of the same subdomains, thus providing support for the hypothesis that they are part of the inward cluster associated with imagery. These traits may support a cognitive style that is attuned to introspection and processing internal experiences, which enhances imagery vividness and related cognitive functions. While neuroticism is associated with negative emotionality and stress and disorganization, conscientiousness is anti-correlated with neuroticism and reflects a stable and proactive approach to life's challenges. We speculate that for conscientious individuals, mental imagery strengthens their goal-oriented behavior by making future outcomes more tangible and emotionally salient [73,74]. Our results align with studies showing that imagery can act not only to aid in planning and strategizing but also to boost motivation by vividly imagining the rewards of completing a goal in the future [75]. Our SEM model slightly favored the pathway where imagery vividness precede LIT in explaining involuntary autobiographical memory (IAMI) and alexithymia (TAS), though the empirical evidence was nearly equivalent across competing models. We therefore remain cautious in drawing firm causal conclusions. Future longitudinal or intervention-based studies are needed to clarify whether inward focus enables imagery vividness or whether vivid imagery shapes internally oriented cognitive traits.

While Agreeableness did not correlate with VVIQ, 4 items from this subscale were stable across sites for predicting our canonical VVIQ covariate. Agreeableness reflects an individual's propensity to be kind, cooperative, empathetic, and considerate in their interactions with others (e.g., Ref. [76]). Agreeable individuals are more often accurate in recognizing and understanding others' emotions compared to those low in agreeableness [77]. It might thus relate to an inwardly focused trait due to its close link to emotion processing. However, this finding might also reflect a response bias. Agreeable individuals may be more inclined to respond positively on self-report questionnaires, including those assessing imagery vividness, possibly leading to inflated correlations with traits like emotional awareness and mindfulness.

5.3. Domain-general and domain-specific contributors to imagery

These results indicate that mental imagery, interoception, and emotion processing can be partly understood through a common underlying mechanism. This mechanism is proposed to relate to the propensity to focus on internal representations (see Ref. [7]). Mindful presence, which emphasizes maintaining attention on the present moment, similarly relies on a strong internal focus. However, it is important to note that imagery also involves domain-specific components (e.g., vision, hearing or touch) which reflect the contribution of specialised sensory systems (such as the visual cortex in case of visual imagery), as well as across-system interactions (such as the influence of visual imagery on pain perception, e.g., Ref. [78]). Consistent with this, Dance et al. found that individuals with aphantasia, who lack visual imagery, also exhibit lower sensory sensitivity and decreased visual discomfort in the pattern glare task [79]. In the present study, correlation analyses revealed a similar relationship between hypersensitivity and VVIQ, however, this was only seen for site 1. Further research employing a task-based approach is warranted to further investigate these links. In summary, it is proposed that imagery is best understood as having both domain-general and domain-specific contributors, the former of which is the focus of the present study and reflects the propensity to engage with internal signals.

5.4. Implications for clinical practice

The identification of an inwardly focused cognitive style—characterized by vivid mental imagery, interoceptive awareness, and emotional processing—has important implications for therapeutic interventions. Mindfulness-Based Cognitive Therapy (MBCT), which emphasizes nonjudgmental attention to internal experience, may be more effective for individuals high in LIT [80]. Likewise, clinical hypnosis, particularly when combined with imagery-enhancing suggestions, has demonstrated efficacy in promoting emotional regulation and reducing psychological distress by harnessing internally focused mental representations [6,81,82]. Our findings also align with research on Future-Oriented Episodic Specificity Training (FeST), a technique in which individuals simulate vivid, emotionally salient future events to improve mood, goal-setting, and psychological resilience [83–85]. However, the observation that involuntary autobiographical memories (IAMI) mediate negative effects in some individuals underscores the need to distinguish between deliberate, adaptive imagery and intrusive, distressing imagery. Involuntary imagery—often vivid and emotionally intense—has been implicated in various forms of psychopathology, including depression and PTSD [59,68], and contrasts with the regulated, intentional imagery cultivated in therapeutic settings. Consequently, interventions such as imagery rescripting [86], or treatments targeting emotional awareness and alexithymia may be particularly beneficial for individuals whose inward focus is coupled with intrusive imagery. Understanding how individuals differentially engage with voluntary and involuntary imagery and autobiographical memory can inform more personalized approaches to treatment, maximizing therapeutic benefit while mitigating potential emotional risks.

5.5. Limitations and future directions

Although the present findings provide novel insights into the psychological mechanisms linking imagery and mental health, several limitations warrant consideration. First, our sample consisted of individuals recruited from the general population. While this allowed for a focused investigation of individual differences in cognitive style, it limits the generalizability of findings to clinical populations or individuals with neurodevelopmental or neurological conditions. The extent to which an inwardly focused cognitive style is similarly structured—and similarly beneficial or detrimental—in clinical or neurodivergent groups remains unknown. Future research should replicate and extend these findings in more diverse populations, including individuals with mood and anxiety disorders, PTSD, or autism spectrum conditions, where the role of imagery and internal focus may differ. Moreover, although both sites used two sessions, the procedures differed: Site 1 included a longer home session (~90 min) with additional questionnaires, while Site 2 had a shorter

~75 min session. No formal attention checks were included, which may be a limitation [87].

A further limitation, is the exclusive reliance on self-report instruments. There is evidence that objective assessments of mental imagery might dissociate from imagery vividness [88–92]. Similarly, self-reported measures of interoception do not always align with objective accuracy in assessing interoception [3,93–95]. Future research should explore whether the present results also extend to psychophysical assessments of these domains [96,97]. An important limitation is that the cross-sectional nature of the data precludes strong inferences about directionality or causality. Finally, while the IAMI questionnaire provided valuable data on the frequency of involuntary autobiographical memories, it did not assess their valence (i.e., whether they are positively or negatively toned). This limits the interpretation of how such memories contribute to mental health outcomes. Future studies should consider incorporating valence-specific measures of intrusive memories to differentiate their potentially adaptive or maladaptive effects. Furthermore, our imagery measure (VVIQ) captures only volitional subjective imagery. Exploring both the valence and the volitional versus intrusive nature of imagery through additional questionnaires [98], may yield a more nuanced understanding of its role in emotion regulation and mental health.

5.6. Conclusion

This study provides evidence for a model of mental imagery centered on an "inwardly focused" cognitive style. It was found that self-reported imagery vividness is linked to interoceptive awareness, mindful presence, and the personality traits of openness, conscientiousness, and extraversion. Structural equation modelling demonstrated that the proposed latent inward trait fully mediates a crucial, albeit modest, relationship between variations in imagery vividness and mental health outcomes, markedly through its interactions with alexithymia and involuntary autobiographical memories. Collectively, the findings underscore the complexity of mental imagery as a multifaceted construct, whose influence on mental health is shaped by domain-general cognitive mechanisms. Further studies are needed to go beyond self-reported measures and further elucidate potential causal pathways between mental imagery, individual cognitive differences, and mental health.

CRediT authorship contribution statement

Timo L. Kvamme: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Renate Rutiku:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Data curation. **Michal Wierzchoń:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization. **Inga Griskova-Bulanova:** Methodology. **Francesca Fardo:** Writing – review & editing, Methodology. **Krystian Barzykowski:** Writing – review & editing, Methodology, Data curation. **Kristian Sandberg:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Juha Silvanto:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization.

Disclosures on use of AI

All other authors declare no conflicts of interest. During the preparation of this work, the author(s) used ChatGPT to generate draft text for a minor fraction of the manuscript text. It was further used interactively to improve the quality of writing of these and other parts of the text. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kristian Sandberg reports financial support was provided by European Cooperation in Science and Technology. Timo Kvamme reports financial support was provided by Carlsberg Foundation. Francesca Fardo reports financial support was provided by European Research Council. Krystian Barzykowski reports financial support was provided by National Science Centre in Poland. Michal Wierzchon reports financial support was provided by National Science Centre. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2025.e44433.

Data availability

Data from both sites cannot be shared publicly as they are part of an ongoing study, thus considered unanonymized under Danish law, even if pseudonymized. Researchers who wish to access the data may contact Dr Kristian Sandberg (kristian.sandberg@cfin.au.dk) at The Center of Functionally Integrative Neuroscience and/or The Technology Transfer Office (TTO@au.dk) at Aarhus University, Denmark, to establish a data sharing agreement. After permission has been given by the relevant ethics committee, data will be made available to the researchers for replication. As the project is ongoing, sharing requests for other purposes will be evaluated on a case-by-case basis.

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