The Orthographic Mind:

Orthographic Imagery Propensity Correlates with Semantic Structures and Sensory Sensitivity

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Supplemental Data and Materials

Supplemental data and materials for peer review—including datasets, supplementary figures/tables, and analysis code—are available on the OSF (https://osf.io/x3an5/?view_only=6974a468ba304606a5aeb313d762cb61)

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Abstract

Individuals differ in their intrinsic modes of internal representation, exhibiting varying degrees of visual imagery, inner speech, and orthographic imagery. Yet the potential cognitive functions of these internal representation modes remain underexplored. Through three studies (N = 1,399), we demonstrate that individual differences in orthographic imagery propensity, measured by the Internal Representations Questionnaire (IRQ), systematically associate with internal semantic architecture and external sensory engagement. Study 1 (n = 1099) revealed that stronger orthographic imagery correlates with heightened between-cluster semantic associations and reduced semantic conformity to group norms, suggesting a role in generating novel conceptual links. Study 2 (n = 875) linked orthographic imagery to lower sensory processing sensitivity, suggesting its function as a top-down sensory filter. Unexpectedly, Study 3 (n = 487) found that visual imagery—not orthographic—predicted reduced engagement with reading apps, suggesting a cognitive-mismatch effect. These results position orthographic imagery as a unique mechanism that expands semantic networks while attenuating sensory influx, with implications for creativity research and clinical interventions for sensory hypersensitivity.

Keywords: orthographic imagery, internal representational propensity, individual difference, semantic representation

Public Significance Statement

This research shows that people differ in terms of thinking styles—in imagining words, pictures, or inner speech—and that these differences are linked to how concepts are organized in the mind. In particular, individuals who often visualize written words ("orthographic imagery") tend to connect concepts across categories that are typically more distantly related and show less conformity to others. They also report being less sensitive to overwhelming sensory experiences.

These findings suggest that intrinsic internal processing mode differences associate with both how people internally organize information and how they are affected by external experience.

Introduction

Human cognition operates through a variety of internal representation modes. While visual imagery has long been recognized and extensively studied (Galton, 1880; Marks, 1973; Pearson et al., 2015), other internal modes—such as inner speech or internal verbalization—have recently gained growing empirical support (Alderson-Day & Fernyhough, 2015). Adding to this diversity, orthographic imagery—a recently identified internal mode (Roebuck & Lupyan, 2020)—represents a hybrid of linguistic and visual cognition, characterized by the tendency to mentally visualize written text forms, as if "seeing the words in one's mind." Substantial individual differences have been observed: for visual imagery, 1% of the population has been identified as having little mental visual imagery experiences, compare to many have vivid ones (Zeman et al., 2015; Zeman, 2024); for inner speech, around 40% of people report frequently thinking in words or verbal sentences (internal verbalization score higher than 4.25/5) and 16% report rarely or never experiencing inner speech (internal verbalization score lower than 3.5/5; Nedergaard & Lupyan, 2024). While orthographic imagery has been less studied, the original report of this mode showed variations spanning from 1 to ~4.7 in a sample of 222 (5-point scale; see Figure 1 in Roebuck & Lupyan, 2020). These internal "cognitive mode phenotypes" raise a fundamental question: Do such variations in internal representational modes shape the architecture of how information is structured internally and bias how individuals engage with corresponding external information channels, affecting what information contents are gained?

To investigate this question, we first turn to the internal structure of semantic knowledge. Current neurocognitive models conceptualize semantic memory—our store of facts, beliefs, and conceptual knowledge—as a high-dimensional system abstracted from multiple modalities of sensorimotor experience (Binder et al., 2009; Lambon Ralph et al., 2017). Beyond sensory-based input, recent findings suggest that language-derived and inference-based representations also contribute, as evidenced by how congenitally blind individuals develop rich visual semantic knowledge without visual experience (Bi, 2021; Bottini et al., 2020; Kim et al., 2019; Wang et al., 2020). These modality-specific systems encode largely overlapping but also potentially modality-specific information structures (Fu et al., 2023), implying that individuals who rely more heavily on different internal modes may construct semantic representations with subtly different architectures. One way to probe these representational differences is by examining how meanings of individual words are structured and related across people.

What predictions can be made about internal representational modes and semantic structures? Drawing on the functional roles of language, we propose three non-mutually-exclusive hypotheses about how verbal and orthographic imagery propensities might shape semantic representations, relative to visual ones: 1) Category expansion hypothesis: Inspired by language's capacity for generating novel concepts (e.g., “chairdrobe”, “Babel fish”), individuals with stronger internal verbalization or orthographic imagery may show greater cross-category semantic associations. 2) Category cohesion hypothesis: Based on evidence that verbal labels encourage categorization (Lupyan, 2008; Waxman & Markow, 1995), those with stronger inner speech (and orthographic imagery) might exhibit tighter within-category semantic clustering. 3) Semantic norm alignment hypothesis: Language facilitates conceptual alignment across individuals (Lupyan & Bergen, 2016; Suffill et al., 2024), suggesting that those with stronger linguistic-based modes may show greater convergence with group-level semantic structures. These hypotheses guide our examination of how individual differences in internal cognitive style shape semantic organization.

For external information intake, the internal representation mode phenotypes may also be bias toward their preferred modes. Individuals may preferentially attend to or seek information in formats that align with their dominant internal processing styles (e.g., visual, verbal, or orthographic). Regarding sensitivity to external input, individual differences in sensory processing sensitivity have been systematically measured using the Highly Sensitive Person (HSP) scale (Aron & Aron, 1997), with robust empirical support (Greven et al., 2019; Jagiellowicz et al., 2011). Meanwhile, modality-based preferences in information engagement have been observed: in eye-tracking studies, visualizers attend more to graphical content, while verbalizers focus more on text

(Mehigan et al., 2011; Tsianos et al., 2009). These imagery preferences manifest functionally consistently across development, correlating with educational choices (e.g., object imagery with visual art classes, spatial imagery with physics classes, verbal imagery with writing classes) and culminating in professional specialization, where visual artists excel in object imagery, scientists in spatial imagery, and humanities professionals in verbal imagery (Blazhenkova & Kozhevnikov, 2009). However, orthographic imagery remains underexplored in this context. The proliferation of smartphones and multimodal digital platforms presents a novel, ecologically valid opportunity to study these preferences, comparing usage patterns across modalities such as text-based apps versus audio platforms.

We conducted three studies to examine how internal representational modes, especially orthographic imagery, influence both semantic structure and external sensory engagement (Figure 1). Study 1 (N = 1,109) included nine semantic rating experiments assessing how scores on the Internal Representations Questionnaire (IRQ; Roebuck & Lupyan, 2020) relate to three aspects of semantic structure: (1) global semantic association patterns, (2) clustering within and across categories, and (3) alignment with group-level semantic norms. A meta-analytic approach quantified cross-task consistency. Study 2 (N = 875) investigated how representational propensities relate to sensory processing sensitivity using the HSP scale. Study 3 (N = 487) examined how these propensities predict real-world information format preferences, measured by individuals' smartphone app usage, focusing on modality-specific engagement. Together, the three studies reveal how orthographic imagery—a hybrid of linguistic and visual internalization—can shape both the architecture of internal semantic cognition and external behavioral signatures of sensory engagement, advancing our understanding of how "thinking styles" influence cognition at multiple levels.

—Figure 1 here—

Methods

Quantifying internal representational propensities using IRQ

We collected IRQ data from 1,399 participants (596 males; mean age = 30 years, range = 18–58), with subsequent questionnaire subsamples drawn from this cohort. All participants completed the Chinese-translated IRQ (Appendix A) using a 5-point scale (1 = strongly disagree, 5 = strongly agree). The questionnaire contained two reverse-scored items and three attention-check questions (i.e., common-knowledge items) to detect inattentive responding. All participants correctly answered the attention checks, and all items were presented in a randomized order. The IRQ assesses four factors: Orthographic Imagery, Internal Verbalization, Visual Imagery, and Representational Manipulation. We excluded Representational Manipulation from analysis because it measures multimodal information-processing ability rather than cognitive propensity, which was outside the scope of our research. Scores for each of the remaining factors (hereafter referred to as Orthographic, Verbal, and Visual) were computed as the mean of their respective items. Internal consistency was acceptable for each factor: Orthographic Imagery (Cronbach's $\alpha = 0.789$), Internal Verbalization ($\alpha = 0.852$), and Visual Imagery ($\alpha = 0.826$).

Demographic variables (age, sex, education level) were recorded: sex was coded dichotomously (1 = male, 0 = female), and education level was coded on a 1–7 scale (1: primary school or below; 2: junior high school; 3: high school/vocational/technical school; 4: associate degree; 5: bachelor's degree; 6: master's degree; 7: doctoral degree). Data collection was conducted via the Credamo platform, with informed consent obtained and compensation provided. The research was approved by the Institutional Review Board of the State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University.

Study 1: Correlation between IRQ scores and semantic association patterns

In this study, we examined the relationship between individual differences in internal representational propensities (measured by the IRQ) and the structure of internal semantic representations. Through three analytical components, we assessed how IRQ scores correlate with distinct dimensions of semantic association patterns: (1) overall semantic association pattern, (2) within- and between-cluster semantic association strength, and (3) individual alignment with group-level semantic association patterns. These analyses examined whether internal representation styles are systematically associated with the organization of semantic knowledge.

Semantic association ratings.

To comprehensively map intrinsic semantic representations, four independent participant groups (total N = 1,109) completed nine rating experiments using six word sets spanning fundamental life concepts—including vegetables, fruits, objects, scenes, occupations, emotions, and abstract terms (Table 1). Group 1 (n = 291) conducted two semantic relatedness experiments: one involving visual-related words, emotions, and verbal-related abstract words and another focus on objects, scenes, and occupations. Group 2 (n = 343) performed four experiments—rating both semantic relatedness and emotional similarity for each of two distinct moral dilemma lexicon sets. Group 3 (n = 206) completed one semantic similarity experiment on emotional words. Group 4 (n = 269) executed two sensory experiments assessing color and flavor similarity within a fruit and vegetable set. All participants used a 7-point scale (1 = completely dissimilar/unrelated, 7 = highly similar/related), following dimension-specific instructions: they evaluated semantic associations by judging how closely two words were related or similar in meaning; they evaluated emotional similarity by judging the extent to which the words evoked congruent emotions; they evaluated sensory similarity by judging the similarity of color or flavor between words. This multi-dimensional design addresses the high variability and low effect sizes typically associated with subjective semantic ratings by enabling meta-analytic integration across experiments. The inclusion of diverse word sets and rating dimensions enhances ecological validity, supporting a systematic examination of stable cross-experiment relationships between internal representational propensities and semantic knowledge organization.

—Table 1 here—

Analysis 1.1: Predicting IRQ scores from overall semantic association patterns.

We utilized Relevance Vector Regression (RVR; Cui & Gong, 2018; Cui et al., 2018; Cui et al., 2016) to predict each IRQ factor score based on semantic association patterns from each semantic rating experiment (Figure 3A, Table 1). Semantic association patterns (i.e., semantic similarity/relatedness ratings for each word pair) served as input features, while IRQ factor scores were the outcome variables. Prior to modeling, semantic features were normalized within each training fold. To isolate unique relationships between overall semantic structure and specific IRQ factors, we implemented a rigorous covariate adjustment procedure during cross-validation: within each fold, demographic variables and the other two IRQ factors were regressed out from the training set scores, and the resulting coefficients were applied to both training and test sets to compute residuals for the target IRQ factor. RVR model was then trained on preprocessed semantic features to predict these residualized scores, with performance evaluated via Pearson's correlation between predicted and observed residualized values in the test set. We employed 5-fold cross-validation for robust evaluation: participants were randomly partitioned into five subsets (with remaining samples included in the final fold when sample size was not divisible by 5), and this entire process was repeated 50 times with new random partitions. The final performance metric was defined as the average correlations across all 250 folds (5 folds × 50 repetitions), providing a stable estimate of model generalizability. Significance was assessed using permutation testing (5,000 iterations), in which IRQ scores were randomly shuffled within each fold to establish null distributions.

To synthesize findings across nine semantic rating experiments regarding the relationship between internal representational propensities and semantic association patterns, we conducted multilevel meta-analyses using R. Correlation coefficients served as effect sizes. Because some semantic assessments included overlap participants, the effect sizes were statistically non-independent. Following established guidelines (Harrer et al., 2021;

https://bookdown.org/MathiasHarrer/Doing_Meta_Analysis_in_R/), we fitted a Correlated and Hierarchical Effects (CHE; Pustejovsky & Tipton, 2022) model with robust variance estimation (Hedges et al., 2010; Tipton, 2015; Tipton & Pustejovsky, 2015). We set the within-sample effect size correlation coefficient to $\rho = 0.8$. As this value was arbitrary, we conducted sensitivity analyses with alternative ρ values (0.4 and 0.6), and the main results showed robust consistency (Table S1). Confidence intervals and p-values for meta-regression coefficients were calculated using the "CR2" adjustment for small sample sizes, in accordance with recommended methodological practices.

Analysis 1.2: Correlation between IRQ scores and semantic cluster structure.

We examined the relationship between internal representational propensities and semantic cluster organization using two indices: within-cluster and between-cluster semantic association strength (Figure 4A). For each of the nine semantic rating experiments, we first constructed a group-level semantic distance matrix by transforming the mean semantic association ratings (7-point scale) into distances (distance = 7 - rating). To determine the optimal number of clusters (*k*), we evaluated k-means clustering solutions with *k* ranging from 2 to 8 and selected the one that maximized the average silhouette width, as implemented in the fviz_nbclust function in R (Version 4.3.3; R Core Team, 2016). K-means clustering was then performed separately for each experiment's distance matrix using the optimal *k*, with 25 random initializations, a maximum of 1,000 iterations, and a fixed random seed to ensure reproducibility. Following cluster assignment for each rating experiment (Figure S1), we computed two individual-level indices from each participant's semantic association rating matrix: (a) Within-cluster association strength – the mean semantic association rating for word pairs assigned to the same cluster; (b) Between-cluster association strength – the mean semantic association rating for word pairs assigned to different clusters. We then assessed the relationship between each IRQ factor score and these cluster-based indices using partial Pearson correlations, controlling for demographic variables and the other two IRQ factors. Meta-analyses followed the same procedure as described in Analysis 1.1.

Analysis 1.3: Correlation between IRQ scores and semantic conformity.

We examined relationships between IRQ factor scores and semantic conformity, defined as the degree to which a participant's semantic association pattern aligned with the group-level consensus pattern (i.e., the mean pattern of all other participants; Figure 5A). For each semantic rating experiment, we calculated Spearman's ρ between individual semantic association ratings and the group consensus pattern, applied Fisher's Z transformation to ρ values, and conducted partial Pearson correlations between each IRQ factor score and semantic conformity index, controlling for demographic variables and the other two IRQ factor scores. Meta-analyses followed the same procedure as in Analysis 1.1.

Study 2: Correlation between IRQ scores and HSP scale scores

Highly Sensitive Person Scale.

We administered the Chinese-translated HSP scale (Aron & Aron, 1997; Appendix B) to 875 participants (344 males; mean age = 30 years) to quantify sensory processing sensitivity. To improve engagement and validity, all items were changed from interrogative to first-person declarative form. The scale demonstrated good internal consistency in the current sample (Cronbach's $\alpha = 0.838$). The 27 questions were organized into three randomized blocks of nine statements each. Participants responded "yes" (scored 1) or "no" (scored 0) to each statement, and the total score was used as the index of sensory processing sensitivity. We adopted this binary format for ease of administration, and because the HSP scale is traditionally rated on a Likert scale, we validated the results in a separate sample of 150 participants using the standard format (see Results).

Partial correlation and regression analyses.

To examine the relationship between internal representational propensities and sensory processing sensitivity, we first conducted partial correlations between each IRQ factor score and the total HSP scale score. These analyses controlled for demographic variables (age, sex, education level) and the other two IRQ factor scores. For convergent evidence, we also performed a multiple linear regression analysis using the total HSP scale score as the dependent variable. All IRQ factors (orthographic, verbal, and visual) and the same demographic variables were entered simultaneously as predictors.

Study 3: Correlation between IRQ scores and media-specific app usage time.

Mobile App Usage Time Questionnaire.

A questionnaire assessing real-world information preferences was administered to 487 participants (197 males; mean age = 29 years). This instrument quantified daily usage time across three primary app categories, each selected for its direct correspondence to cognitive modalities assessed by the IRQ: (1) Reading apps (e.g., WeRead, including a variety of books; associated with orthographic imagery); (2) Spoken language audio apps (e.g., Himalaya, including podcasts, radio, audiobooks; associated with internal verbalization); (3) Video apps (e.g., TikTok; associated with visual imagery). Figure S2 presents the subcategories within each primary app category and corresponding user counts. Additionally, usage times for gaming, music, and news apps (featuring multimodal content) were recorded exclusively for calculating total mobile app usage time, which served as a covariate in subsequent analyses. Participants reported daily usage time for each app category by selecting from predefined intervals: never, < 30 minutes, 30 minutes–1 hour, 1–2 hours, 2–3 hours, 3–4 hours, or > 4 hours. Responses were numerically recoded as 0, 0.25, 0.5, 1, 2, 3, 4, respectively, for analysis.

Partial correlation and regression analyses.

To examine associations between internal representational propensities and media-specific app usage, we replicated Study 2's analytical framework. First, we conducted partial correlations between each IRQ factor score and time spent in each app category, controlling for demographic variables (age, sex, education level), the other two IRQ factor scores, and total mobile app usage time (aggregated across all categories: reading, audio, video, music, game, news). Including total usage time as a covariate controlled for its statistical dependence with category-specific usage. For convergent evidence, we also performed multiple linear regression analyses using time spent in each primary app category as the dependent variable. All models included the IRQ factors (orthographic, verbal, visual), demographic variables (age, sex, education level), and total mobile app usage time as predictors to estimate each factor's unique contribution.

Correlation and regression analyses in this research were conducted using JASP (Version 0.18.3.0; JASP Team, 2024).

The data and analysis code associated with this study are available at OSF (https://osf.io/x3an5/?view_only=6974a468ba304606a5aeb313d762cb61).

Results

Group profile and individual differences in IRQ across three studies

We collected IRQ data from a total of 1399 participants across three studies. Mean scores for each IRQ factor were as follows, on scales 1-5: orthographic = 3.69, verbal = 3.84, visual = 4.08. Intercorrelations among IRQ factors and their demographic associations are presented in Table 2. Orthographic scores correlated strongly with verbal scores ($r = 0.677$, $p < 0.001$), moderately with visual scores ($r = 0.406$, $p < 0.001$), while visual-verbal correlations were relatively weaker ($r = 0.296$, $p < 0.001$). Among demographic variables, age showed a small but statistically significant association with orthographic scores ($r = 0.078$, $p = 0.004$). Sex did not exhibit any significant relationship with IRQ factors (ps > 0.056), whereas education level was significantly correlated with all IRQ factors (rs > 0.067, ps < 0.012). Partial correlation analyses controlling for the other two IRQ factors revealed that age was specifically positively associated with orthographic scores (partial r = 0.088, $p < 0.001$) and negatively associated with verbal scores (partial $r = -0.057$, $p = 0.033$). Sex significantly correlated with orthographic scores (partial $r = 0.071$, $p = 0.008$; female set to 0, indicating that males scored higher). Education level no longer showed significant specific associations with any of the IRQ factors. Given these interrelationships, all subsequent analyses examining associations between a specific IRQ factor and either semantic representations or external information processing statistically controlled for the other two IRQ factors and demographic variables (age, sex, education level).

Figure 2 displays the distributions of individual scores for each IRQ factor. To quantify within-participant score dispersion across the three IRQ factors, coefficients of variation (*CV*) were computed for each individual, with gradient shading (light gray to black) representing *CV* magnitude. Participants with low variability ($CV < 10\%$; n = 826, 59% of the sample) primarily exhibited uniformly high scores across factors. Specifically, 663 individuals (80% of this subgroup) had all three factor scores ≥ 3.5. Conversely, uniformly low scores (all factors < 3.5) were rare (n = 22; 2.7% of the subgroup), suggesting that most participants engaged at least one self-report internal representation modality. This pattern is consistent with the findings reported by Roebuck and Lupyan (2020).

Inter-individual variability was also observed within each factor: orthographic exhibited the greatest variability ($CV = 0.210$), followed by verbal ($CV = 0.160$) and visual ($CV = 0.137$).

Having characterized these individual differences, we next examine their relationships with internal semantic representations and external information processing through the following three studies. When relationships between specific IRQ scores and univariate variables are examined (e.g., HSP scale score) partial correlation analyses were used, with multiple regression model results also reported for convergence when applicable; when relationships between specific IRQ scores and representation patterns are examined (i.e., overall semantic association pattern), multivariate analyses—Relevance Vector Regression (RVR)—were used.

—Figure 2 & Table 2 here—

Study 1: Correlation between IRQ scores and semantic association patterns

This study examined the relationship between internal representational propensities and semantic representations using a multidimensional semantic rating paradigm. We conducted nine rating experiments across four independent participant groups (*N* = 1,109), evaluating six word sets spanning diverse conceptual categories—vegetables, fruits, concrete objects, scenes, occupations, emotions, abstract terms—along four semantic dimensions: overall conceptual meaning, emotional experiences, color attributes, and flavor properties (Table 1). This design enables meta-analytic synthesis across experiments, allowing the discovery of subtle yet robust effects. It also enhances ecological validity by incorporating stimulus diversity, thereby facilitating the reliable detection of associations that are not confounded by semantic category or rating dimension.

To assess whether individuals with varying levels of internal representational propensity exhibit distinct semantic structures, we first applied RVR to predict IRQ scores from *overall semantic association patterns*. Building on theoretical assumptions outlined in the Introduction, we further examined the relationship between IRQ scores and two specific dimensions of semantic structure: *semantic clustering*, assessed via within- and between-cluster association strength, and *semantic conformity*, operationalized as individual-to-group semantic alignment. Given that both semantic representations and internal representational propensities reflect latent cognitive traits whose causal direction remains unclear—and considering that correlation coefficients are more appropriate than regression weights for meta-analytic synthesis—we adopted correlational analyses, rather than predictive modeling, to characterize the strength and consistency of these relationships across semantic rating experiments.

Overall semantic association patterns significantly associate with orthographic imagery scores.

We applied RVR to predict IRQ factor scores from semantic association ratings (Figure 3A). Ratings for each word pair served as input features, with IRQ factor scores as outcome variables. To isolate the unique contribution of each IRQ factor, we regressed out covariates including demographic variables and the other two IRQ factors. Prediction performance was evaluated as Pearson's correlation between predicted and observed residual scores, with robustness ensured through 5-fold cross-validation (see details in Methods). Significance was assessed via permutation testing (5,000 iterations), in which IRQ scores were randomly shuffled within each fold to generate a null distribution. Significance thresholds were set at $p < 0.05$.

As shown in Table 3 and Figure 3B, orthographic scores showed positive predictive-observed correlations in 8 out of 9 experiments. To quantify the overall predictive strength of semantic association patterns for each IRQ factor (Table 4, Figure 3B), we conducted meta-analyses across experiments. Results confirmed a significant overall effect for orthographic scores (Fisher *Z*-transformed $r = 0.093$; 95% *CI* [0.036, 0.150]; $p = 0.015$), whereas effects for the other two IRQ factors were non-significant (*p*s > 0.113). To assess potential publication bias, we performed Egger's test (t = 0.488, $p = 0.640$) and the rank correlation test (Kendall's tau = 0, $p = 1$), both indicating no evidence of bias. These findings demonstrate small but reliable correlations between overall semantic association patterns and orthographic imagery propensity across varied word sets.

—Figure 3, Table 3&4 here—

Correlation between IRQ scores and between- vs. within- semantic clusters.

To investigate the relationship between internal representation propensity and the structural characteristics of semantic association patterns, we examined two indices: within-cluster association strength and between-cluster association strength. To compute these metrics, we first performed hierarchical clustering on each experiment's group-level semantic distance matrix to identify underlying cluster structures. Based on the resulting cluster assignments (Figure S1), individual-level metrics were computed from each participant's ratings: within-cluster association strength was defined as the average association for word pairs within the same cluster, and between-cluster association strength as the average for those spanning different clusters. We then computed partial correlations between scores for each IRQ factor and the cluster structure metrics (Figure 4A), controlling for age, sex, education level, and the other two IRQ factors.

As summarized in Table 3 and Figures 4B and 4C, analyses revealed distinct patterns across IRQ factors: (1) Between-cluster association strength consistently exhibited positive correlations with orthographic scores across all nine experiments (9/9); (2) Within-cluster association strength frequently exhibited positive correlations with verbal scores (8/9). Meta-analyses for each IRQ factor across the nine experiments confirmed a significant and consistent positive correlation between orthographic scores and between-cluster association strength (Figure 4B and Table 4; Fisher Z-transformed $r = 0.098$; 95% *CI* [0.057, 0.140]; $p = 0.006$), whereas correlations for verbal and visual scores were non-significant (*p*s > 0.122). For within-cluster association strength, a consistent positive correlation was observed for verbal scores (Figure 4C and Table 4; Fisher *Z*-transformed $r = 0.072$; 95% *CI* [0.031, 0.113]; $p = 0.012$), whereas correlations for orthographic and visual scores were non-significant (*p*s > 0.172). Collectively, these findings indicate that orthographic and verbal representational propensities are differently associated with semantic structure: individuals with stronger orthographic imagery propensity exhibit stronger associations between conceptually distant words (i.e., across semantic clusters), whereas individuals with stronger internal verbalization exhibit stronger associations among conceptually related words within the same semantic cluster.

—Figure 4 here—

Correlation between IRQ scores and semantic conformity.

To assess the relationship between internal representational propensities and semantic conformity (Figure 5A)—operationalized as Fisher's *Z*-transformed Spearman correlations between each individual's semantic association ratings and the leave-one-out group mean pattern—we computed partial correlations between each IRQ factor and the conformity metric, controlling for age, sex, education level, and the other two IRQ factors.

As shown in Table 3 and Figure 5B, the analyses revealed distinct patterns across IRQ factors. Orthographic scores consistently exhibited negative correlations with semantic conformity in all nine experiments (9/9). The meta-analysis confirmed a significant negative correlation between orthographic scores and semantic conformity (r = -0.065, 95% CI [-0.121, -0.009], p = 0.035), while correlations for verbal and visual factors were non-significant (ps > 0.235). These findings suggest that individuals with stronger orthographic imagery propensity form semantic associations in idiosyncratic patterns, diverging from group-level norms.

Given that orthographic scores correlated with both between-cluster association strength and semantic conformity, we further examined the relationship between these two semantic variables. This analysis revealed a consistent negative correlation between semantic conformity and between-cluster association strength across all experiments (Table S2; Fisher Z-transformed r = -0.178; 95% CI [-0.292, -0.064]; p = 0.018). We then performed partial correlation analyses to disentangle the contributions of between-cluster association and semantic conformity. When controlling for semantic conformity, the correlation between orthographic scores and between-cluster association strength remained statistically significant (Fisher Z-transformed r = 0.089; 95% CI [0.037, 0.140]; p = 0.013). In contrast, the correlation between orthographic scores and semantic conformity was no longer statistically significant when controlling for between-cluster association strength (Fisher Z-transformed r = -0.051; 95% CI [-0.112, 0.010]; p = 0.073). These results indicate that the link between orthographic scores and semantic conformity is primarily explained by between-cluster association strength, not the reverse.

—Figure 5 here—

Study 2: Correlation between IRQ scores and HSP scale scores

This study examined the relationship between internal representational propensities (IRQ factor scores) and sensory-processing sensitivity (HSP scale scores). Partial correlation (Figure 6A, left panel) between individual IRQ scores and HSP scale scores, controlling for the other two IRQ score and demographic variables (age, sex, and education level), showed that orthographic scores were significantly associated with HSP scale scores (partial $r = -0.210$, $p < 0.001$), and not visual (partial $r = 0.051$, $p = 0.136$) and verbal (partial $r = 0.042$, $p = 0.221$) scores. Multiple linear regression analysis using HSP scale scores as the dependent variable and the three IRQ factors along with demographic variables (age, sex, and education level) as predictors confirmed the same results: The regression model was statistically significant (see Figure 6A, right panel and Table 5), $F_{(6, 868)} = 18.725$, $p < 0.001$, accounting for 10.8% of the variance in HSP scale scores. The contribution of orthographic scores was significant, in the negative direction ($b = -1.917$, $t = -6.330$, $p < 0.001$), while the verbal and visual factors did not reach significance (*p*s > 0.136). Age ($b = -0.138$, $t = -5.846$, $p < 0.001$) and education level ($b = -0.507$, $t = -2.023$, $p = 0.043$) negatively predicted HSP scale scores. The regression coefficient of sex also significant ($b = -0.740$, $t = -2.139$, $p = 0.033$; female set to 0, indicating that males reported lower HSP scores than females).

To address potential measurement effects from the use of binary (yes/no) response options instead of the conventional 7-point Likert scale for HSP assessment, we conducted a supplementary replication study with an independent sample of 151 participants using the standard format. The replication yielded convergent results: The regression model remained statistically significant ($F_{(6, 144)} = 6.883$, $p < 0.001$), accounting for 19.0% of variance in HSP scale scores. Orthographic scores again significantly and negatively predicted HSP scale scores ($b = -0.341$, $t = -2.518$, $p = 0.013$), while verbal and visual factors remained non-significant (*p*s > 0.414). Among demographic variables, only age retained a significant negative effect ($b = -0.037$, $t = -3.197$, $p = 0.002$), whereas education level showed a marginal trend toward significant ($b = -0.205$, $t = -1.852$, $p = 0.066$) and sex was no longer significant ($p = 0.839$). Taken together, these findings demonstrate a robust negative association between IRQ orthographic imagery scores and HSP scale scores, suggesting that individuals with stronger orthographic imagery propensity exhibit lower sensory-processing sensitivity.

—Figure 6 and Table 5 here—

Study 3: Correlation between IRQ scores and media-specific app usage time

This study examined the relationship between internal representational propensities and real-world media engagement across three widely used apps with different types of media: reading apps (e.g., WeRead, including a variety of books), audio apps (e.g., Himalaya, including podcasts, radio, audiobooks), and video apps (e.g., TikTok). We modeled self-reported time spent on each category as the dependent variable. Predictors included the three IRQ factor scores, demographic variables (age, sex, and education level), and total app usage time (controlling for its mathematical dependency on specific app usage time).

After controlling for the other two IRQ factors, total app usage, and demographics (age, sex, education), partial correlations (Figure 6B, left panel) showed that only visual scores were significantly associated with reading app usage time (r = -0.117, p = 0.010), with all other IRQ factor-app correlations non-significant (ps > 0.100). Including all variables in multiple regression models showed convergent results: All regression models were significant (ps < 0.001), with reading: $F_{(7, 479)}$ = 18.385, adjusted R^2 = 0.200; audio: $F_{(7, 479)}$ = 37.530, adjusted R^2 = 0.345, and video: $F_{(7, 479)}$ = 67.574, adjusted R^2 = 0.490. Total usage time positively predicted engagement across all app categories (ps < 0.001). Visual scores negatively predicted reading app usage time (b = -0.114, t = -2.585, p = 0.010; Figure 6B, right panel and Table 6). Orthographic and verbal scores were non-significant predictors across all app categories (ps > 0.100). Among demographics, female participants spent more time on reading apps (b = -0.125, t = -2.657, p = 0.008; female set to 0), older participants consumed more audio content (b = 0.015, t = 6.259, p < 0.001), and younger age (b = -0.013, t = -2.867, p = 0.004) combined with lower education level (b = -0.099, t = -2.096, p = 0.037) predicted longer video usage. Taken together, these results suggest that individuals with stronger visual imagery propensity engage less with text-based content.

—Table 6 here—

Relationships between effects across studies

Summarizing across studies, we found that stronger orthographic imagery propensity is significantly positively associated with between-cluster semantic association strength (leading to lower semantic conformity; Study 1) and significantly negatively associated with sensory-processing sensitivity (Study 2). To investigate potential links between these effects—specifically, whether sensory-processing sensitivity correlates with between-cluster semantic associations—we analyzed data from 630 participants who completed both the semantic rating tasks and HSP scale (Table S3). Meta-analysis results revealed a nonsignificant correlation between HSP scale scores and between-cluster association strength (Fisher Z-transformed r = -0.062; 95% *CI*: [-0.240, 0.116]; p = 0.337). Furthermore, with this reduced overlapping sample size, mutually controlled associations were significant without CR2 correction (ps < 0.031), and were marginally significant with CR2 correction (orthographic score and between-cluster association strength: Fisher Z-transformed r = 0.144; 95% *CI*: [-0.036, 0.324]; p = 0.082; orthographic score and HSP scale score: Fisher Z-transformed r = -0.218; 95% *CI*: [-0.469, 0.032]; p = 0.069). That is, the effects of IRQ orthographic imagery with semantic associations and with HSP scale cannot be readily attributed to one source.

To intuitively illustrate our core findings, we present a demonstrative example characterized by high orthographic imagery propensity (score = 4.67, z = 1.26). This participant assigned unusually elevated ratings to cross-cluster semantic word pairs (e.g., *moon–shy*: 5, group mean = 2.91; *baton–chalk*: 5, group mean = 2.07), exhibiting low sensory-processing sensitivity (HSP scale score = 10, z = -1.27)—a profile suggestive of diminished reactivity to intense stimuli such as pain, bright lights, and coarse fabrics.

Discussion

This study examined how three internal representational modes—orthographic imagery, visual imagery, and internal verbalization—influence semantic architecture and external information processing. Orthographic imagery, newly defined mode as “the mental simulation of written words”, showed the strongest effects (Figure 7): For internal semantic representations, it was related to between-cluster semantic associations, leading to reduced semantic conformity; For external inputs, individuals with higher orthographic imagery scores exhibited reduced sensitivity to intense sensory stimuli, which did not explain the internal semantic variations. Contrary to expectations, orthographic imagery did not predict real-world reading app engagement; instead, stronger visual imagery was associated with reduced reading app use. Finally, individuals with higher internal verbalization scores showed greater within-cluster semantic associations (stronger categorization).

—Figure 7 here—

First, it is important to note that the observed effect sizes linking internal representational propensity and semantic architecture were rather modest (*r*s ≈ 0.10). Gignac and Szodorai (2016) reported that the 25th percentile of observed correlations across 708 meta-analyses in psychological individual-differences research (e.g., personality and intelligence) was approximately r = 0.11, suggesting that the effect sizes we observed are close to falling within the expected range.Even small effects can accumulate into meaningful outcomes (Funder & Ozer, 2019). Moreover, as presented in the Introduction, for our measure of interest—semantic representation—only quite subtle effects are predicted. The internal semantic architecture behaviorally probed results from a fairly high-dimensional space (Hebart et al., 2020). Different representational modes (visual or language-derived) share some relational structures, with *cat* and *dog* related in both the visual and language spaces. Variations would only come from those relational structures that are potentially different across representation modes, which can be a very small fraction of the high-dimensional semantic space. Importantly, meta-analytic integration across nine experiments (*N* = 1,109) confirms robust statistical reliability, especially for orthographic imagery, despite small effect magnitudes. Another methodological note is that the results are correlational in nature, and in the discussion below we specifically avoid drawing causal conclusions.

Is orthographic imagery simply a byproduct of education – people with more reading experience and/or proficiency? Measured by six items in the IRQ (Roebuck & Lupyan, 2020), it assesses text visualization during thinking, remembering, and conversing. While education level showed subtle but significant positive correlations with all three representational modes (visual, verbal, and orthographic), no specific association persisted between education and orthographic imagery after controlling for the other two IRQ factors. This indicates orthographic imagery is not a simple reflection of literacy. Conversely, after controlling for the other two IRQ factors, orthographic imagery uniquely increased with age, while internal verbalization declined. This verbalization-age negative correlation contrasts with established childhood developmental patterns (where inner speech emerges from self-directed speech; Alderson-Day & Fernyhough, 2015). Although future research should investigate lifespan trajectories of these internal representational modes, in our key analyses the effects of age were controlled for along with other demographic variables.

Our key finding suggests a structured relationship between internal representational propensities and semantic architecture, partially consistent with the initial hypotheses. We observed a functional dissociation between orthographic imagery and internal verbalization despite their inter-correlation: orthographic imagery was positively associated with between-cluster associations (category expansion), while internal verbalization was linked to within-cluster associations (category cohesion). This intriguing difference was not directly predicted by any established theory of IRQ. Two issues are worth considering regarding this difference. First, we tested speakers of Mandarin Chinese, which is a well-known logographic language, characterized by opaque mappings between phonology and orthography. We do not know whether such functional dissociation is also robustly present in speakers of transparent languages such as Indo-European ones. There are also more general differences in terms of the contents and/or cognitive aspects of written vs spoken languages. Previous studies have discussed that written language is grammatically more complex, less context-dependent and exhibits greater lexical diversity (Schallert et al., 1977), and may be associated with more abstract and creative thought, as it externalizes memory, reduces temporal constraints, and enables symbolic reorganization (Olson, 1996; Ong & Hartley, 2013). It is thus possible that spoken language (underpinning internal verbalization) operates under temporal and auditory constraints, privileging local semantic integration; written language (supporting orthographic imagery) relies on visual-syntactic encoding with fewer temporal demands, which may allow structural reorganization that may support more distant associations. These speculations await further testing.

Notably, orthographic imagery negatively correlated with semantic conformity, a relationship that was largely explained by its link to between-cluster associations. This pattern may point to a cognitive trade-off in which orthographic processing is more aligned with conceptual innovation than adherence to consensus. Because between-cluster linking has been identified as a key mechanism of creative thinking (Mednick, 1962) and prior evidence connects semantic distance with creative potential (Green, 2016; Kenett, 2018), heightened orthographic imagery might facilitate such creative semantic structures. Future research should also examine whether orthographic training could influence creative cognition through changes in between-cluster associations.

Does rich orthographic imagery IRQ mode drive tendency of more reading, or the result of more reading experience? We did not observe any correlation with reading app usage. In general, the IRQ modes and the app use habits did not show transparent correspondence—visual/verbal propensities showed no modality-specific alignment with video/audio app engagement. This pattern diverges from previous claims of congruence between internal-style and behavioral patterns (Blazhenkova & Kozhevnikov, 2009; Mehigan et al., 2011; Tsianos et al., 2009). This divergence may be related to methodological distinctions—prior instruments measured internal representational abilities, whereas the IRQ assesses propensity—correlated but theoretically distinct constructs (Roebuck & Lupyan, 2020). Importantly, visual imagery propensity negatively predicted reading app engagement, suggesting individuals with strong visual imagery avoid text, possibly due to cognitive mismatch—where orthographic decoding might impose disproportionate effort relative to visual processing. Collectively, these findings reveal that propensities for distinct representational modes show only limited predictive power for information engagement. The neurocognitive origins of such individual differences and their behavioral manifestations require further investigation.

We also examined sensory-processing sensitivity (measured by the HSP scale) as another external information-processing indicator potentially linked to internal representational propensities. Guided by the correspondence between internal representational modes and external information intake, we anticipated that visual imagery—a sensory-based representational propensity—would show a positive association with HSP scale scores. Contrary to this expectation, our data revealed a robust inverse relationship between orthographic imagery propensity and HSP scale scores. This finding suggests that orthographic processing, characterized by symbolic abstraction, may contribute to attenuated environmental sensitivity. The observed negative correlation carries potential clinical significance. Given the well-established connections between heightened sensory-processing sensitivity and increased vulnerability to anxiety and depression (Bordarie et al., 2022; Lionetti et al., 2023; Liss et al., 2005), this pattern indicates that orthographic processing mechanisms could inform novel intervention approaches. Future research should investigate whether targeted orthographic training might benefit individuals with heightened sensory-processing sensitivity.

Conclusion

This investigation revealed distinct cognitive impacts of three internal representational modes. Orthographic imagery emerged as particularly influential, simultaneously strengthened between-cluster semantic associations, reduced semantic conformity (primarily explained by between-cluster strength), and attenuated sensory-processing sensitivity. These findings position orthography imagery not merely as perceptual processing but as a potential top-down modulator of cognition and affect, suggesting relevance for creativity research, clinical interventions, and education. Future work should explore orthography imagery's neural substrates, developmental trajectory, and cross-linguistic variability to unlock its full theoretical and applied potential.

Constraints on Generality

The present findings are expected to generalize, at minimum, to literate adult Mandarin speakers, as this was the population from which our 1,399 online participants were drawn. Because the study employed Chinese-language materials and involved a logographic writing system, generalization to speakers of alphabetic languages rests on theoretical assumptions about the origins of the effects. Nevertheless, the constructs examined (e.g., orthographic imagery, internal verbalization, visual imagery, and semantic structures) capture general cognitive components rather than language-specific skills, suggesting that similar patterns may extend beyond Chinese speakers. Replication in other linguistic and cultural contexts will be important for assessing the broader generality of these results.

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Supplemental data and materials are available on the OSF

https://osf.io/x3an5/?view_only=6974a468ba304606a5aeb313d762cb61

Figure 1

Overview of the present research. Study 1 explored how individual differences in internal representational propensities relate to semantic representation by correlating IRQ scores with different semantic metrics: (1) overall semantic association patterns; (2) Semantic cluster structure, including within-cluster association (the mean association strength among items within the same semantic cluster) and between-cluster association (the mean association strength among items from different semantic clusters); (3)Semantic conformity, defined as the similarity between each individual's association pattern and the leave-one-out group mean. Study 2 examined the relationship between internal representational propensities and sensitivity to external sensory input, using the Highly Sensitive Person Scale (Appendix B). Study 3 investigated how internal representational propensities align with real-world information preferences, assessed via self-reported mobile app usage time. IRQ = Internal Representations Questionnaire.

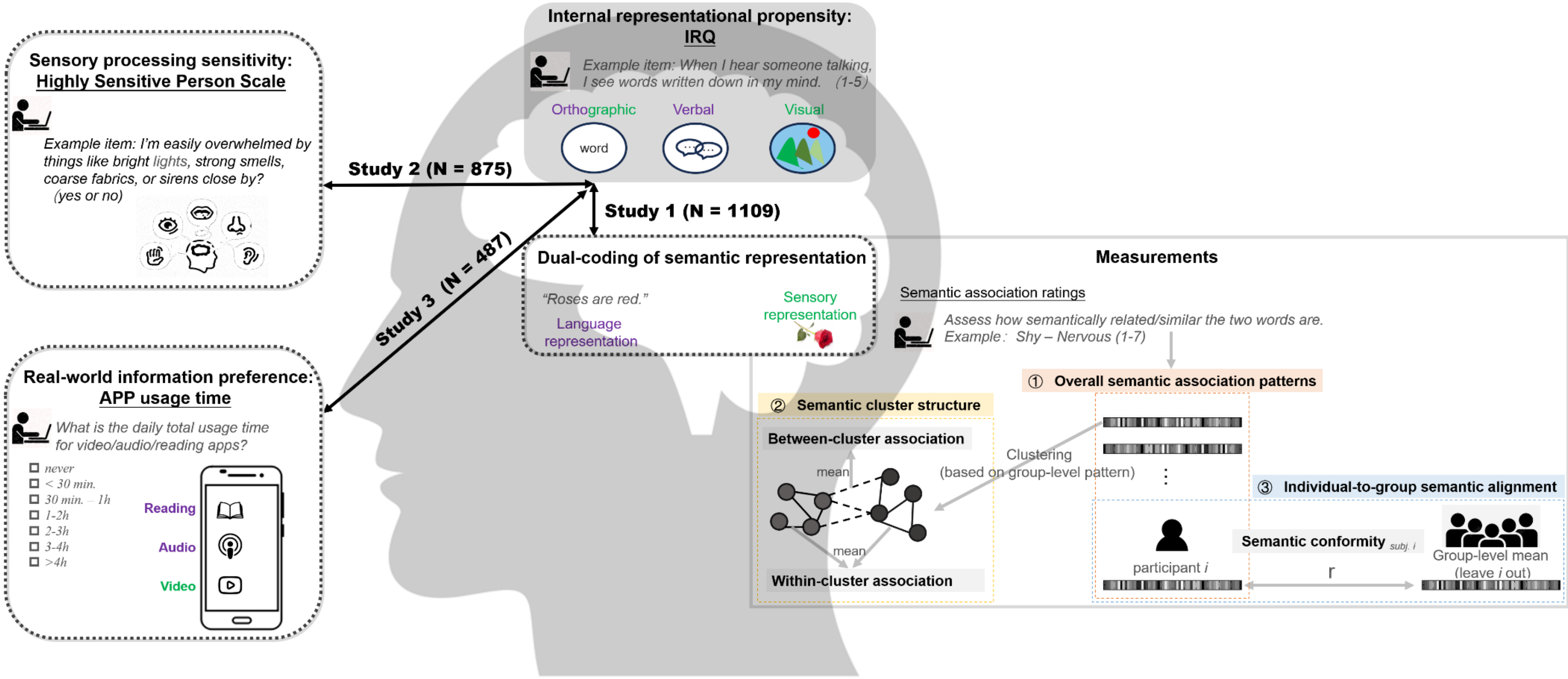

Sensory processing sensitivity:
Highly Sensitive Person Scale
Example item: I'm easily overwhelmed by things like bright lights, strong smells, coarse fabrics, or sirens close by?
(yes or no)
Internal representational propensity:
IRQ
Example item: When I hear someone talking, I see words written down in my mind. (1-5)
Orthographic
Verbal
Visual
word
Study 2 (N = 875)
Study 1 (N = 1109)
Study 3 (N = 487)
Dual-coding of semantic representation
"Roses are red."
Language representation
Sensory representation
Real-world information preference:
APP usage time
What is the daily total usage time for video/audio/reading apps?
never
< 30 min.
30 min. – 1h
1-2h
2-3h
3-4h
>4h
Reading
Audio
Video
Measurements
Semantic association ratings
Assess how semantically related/similar the two words are.
Example: Shy – Nervous (1-7)
① Overall semantic association patterns
② Semantic cluster structure
Between-cluster association
mean
Clustering
(based on group-level pattern)
Within-cluster association
③ Individual-to-group semantic alignment
Semantic conformity subj. i
participant i
r
Group-level mean
(leave i out)

Figure 2

Distribution of individual scores on each IRQ factor. Mean scores range from 1 to 5, corresponding to responses from "strongly disagree" to "strongly agree." Each participant's mean score is connected by a line and color-coded with a gradient from light gray to black, reflecting the magnitude of variation (measured by the coefficient of variation across the three factors). Maroon diamond markers represent the group mean for each factor. Error bars denote the mean ± standard deviation. A black horizontal line above indicates a significant group mean difference between two compared factors (*p*s < 0.001). CV = coefficient of variation.

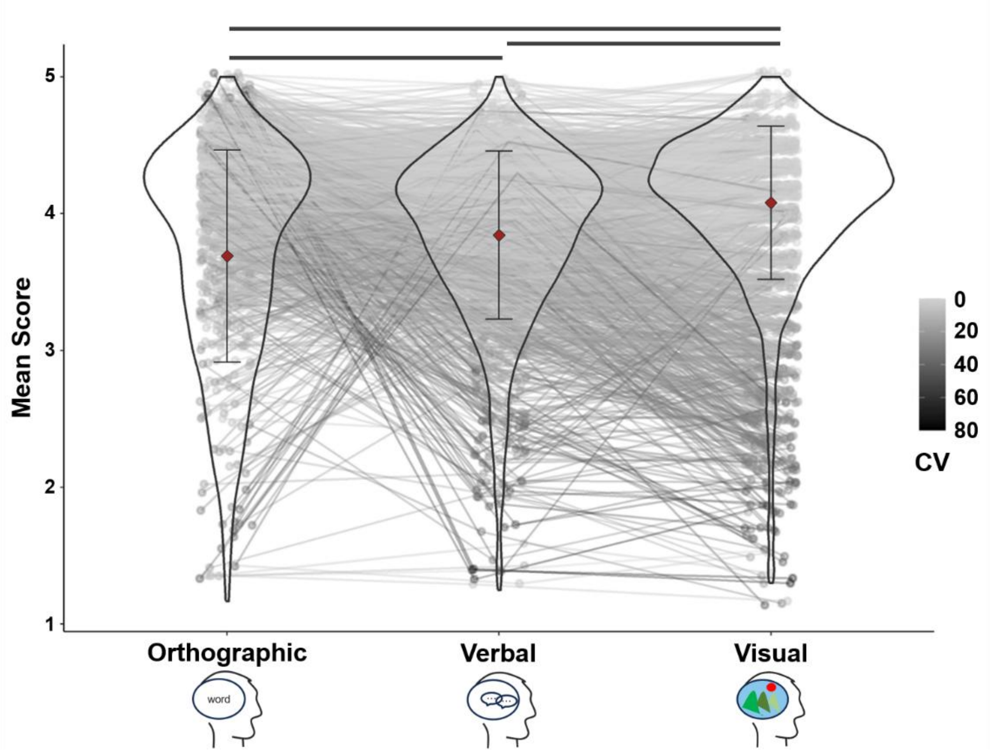


Figure 3

Analysis 1.1: Predicting IRQ scores from overall semantic association patterns. **A.** Flowchart illustrating the use of Relevance Vector Regression (RVR) to predict IRQ factor scores from semantic association patterns. Semantic similarity/relatedness ratings between word pairs served as input features, with one of the three IRQ factor scores as the outcome variable. A 5-fold cross-validation procedure was employed to ensure model robustness. Correlations between predicted and observed IRQ residual scores were averaged across folds. RSM = representation similarity matrix; IRQ = Internal Representations Questionnaire. **B.** Forest plot of meta-analysis results across nine semantic rating experiments predicting each IRQ factor score using semantic association patterns. Dot color (light to dark) reflects sample size (small to large samples). Error bars represent the 95% confidence interval of the Fisher Z-transformed correlation coefficient. Note that significance levels of the RVR-derived correlations were obtained via permutation testing (see Table 5); the confidence intervals shown here do not reflect statistical significance of the predictive effect. Red squares denote significant meta-analytic results. Experiment labels indicate participant counts, stimulus sets, and semantic assessment type (Sem = semantic similarity/relatedness; Emo = emotional similarity), corresponding to Table 1. CHE = correlated and hierarchical effects.

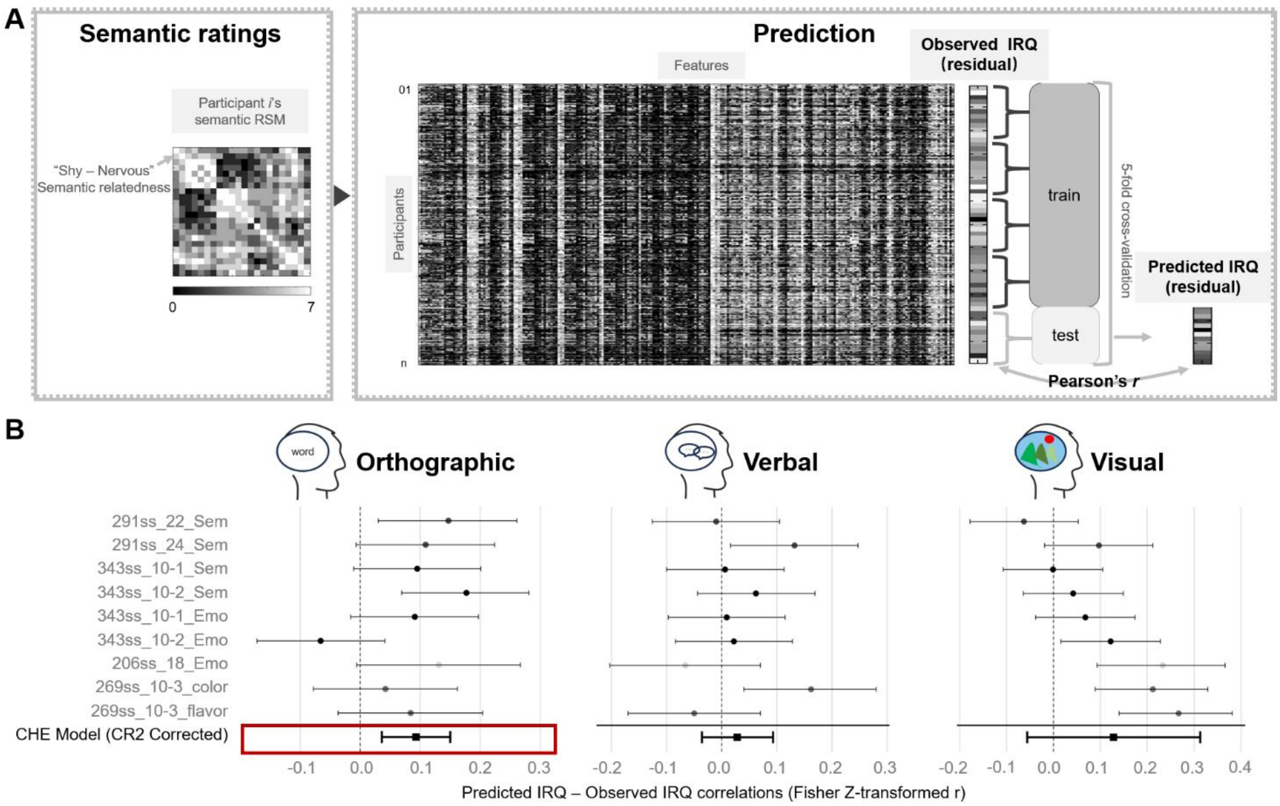

A
Semantic ratings
Participant i's semantic RSM
"Shy – Nervous" Semantic relatedness
0
7
Prediction
Features
Participants
01
n
Observed IRQ (residual)
train
test
5-fold cross-validation
Predicted IRQ (residual)
Pearson's r
B
Orthographic
Verbal
Visual
291ss_22_Sem
291ss_24_Sem
343ss_10-1_Sem
343ss_10-2_Sem
343ss_10-1_Emo
343ss_10-2_Emo
206ss_18_Emo
269ss_10-3_color
269ss_10-3_flavor
CHE Model (CR2 Corrected)
Predicted IRQ – Observed IRQ correlations (Fisher Z-transformed r)

Figure 4

Analysis 1.2: Correlation between internal representational propensities and semantic cluster structure—within- and between-cluster semantic association strength. A. Flowchart illustrating the procedure for correlating IRQ scores with semantic associations within or across clusters. Hierarchical clustering was applied on each experiment's group-level RDM to identify underlying cluster structures. Based on the resulting cluster assignments, individual-level metrics were extracted from each participant's RSM: within-cluster association was defined as the average association for word pairs within the same cluster, and between-cluster association as the average for those spanning different clusters. Finally, we calculated Pearson correlations between IRQ scores and these two indices across participants. RDM = representation distance matrix; RSM = representation similarity matrix; IRQ = Internal Representations Questionnaire. B. Forest plot of meta-analysis results across nine semantic rating experiments showing correlations between each IRQ factor score and between-cluster association. C. Forest plot of meta-analysis results across the same experiments showing correlations with within-cluster association. Dot color (light to dark) reflects sample size (small to large samples). Error bars represent the 95% confidence interval of the Fisher Z-transformed correlation coefficient. Red squares denote significant meta-analytic results. Experiment labels indicate participant counts, stimulus sets, and semantic assessment type (Sem = semantic similarity/relatedness; Emo = emotional similarity), corresponding to Table 1. CHE = correlated and hierarchical effects.

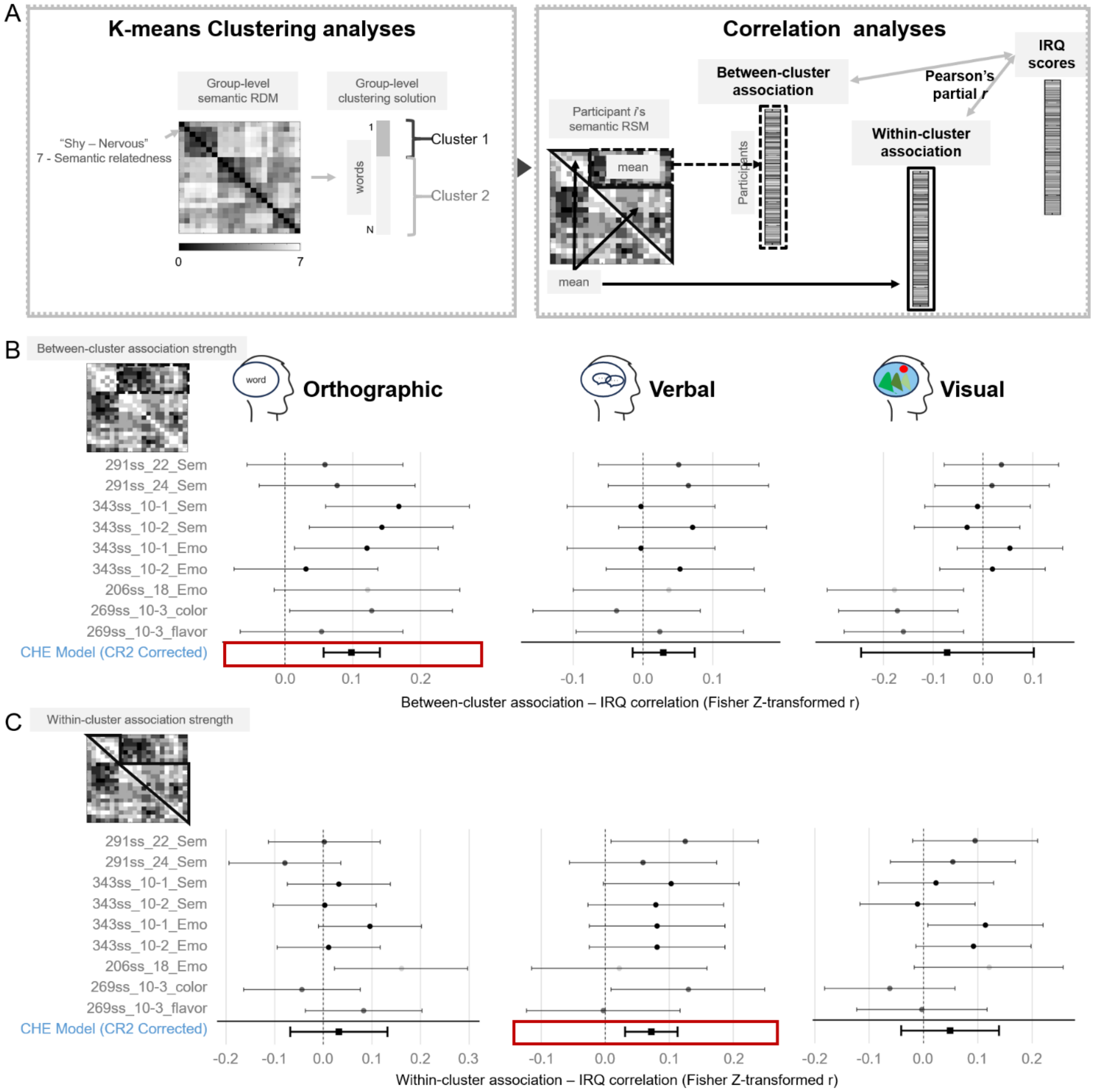

A
K-means Clustering analyses
Group-level semantic RDM
Group-level clustering solution
"Shy – Nervous"
7 - Semantic relatedness
words
Cluster 1
Cluster 2
0
7
Correlation analyses
IRQ scores
Between-cluster association
Pearson's partial r
Participant i's semantic RSM
Within-cluster association
mean
Participants
mean
B
Between-cluster association strength
Orthographic
Verbal
Visual
291ss_22_Sem
291ss_24_Sem
343ss_10-1_Sem
343ss_10-2_Sem
343ss_10-1_Emo
343ss_10-2_Emo
206ss_18_Emo
269ss_10-3_color
269ss_10-3_flavor
CHE Model (CR2 Corrected)
Between-cluster association – IRQ correlation (Fisher Z-transformed r)
C
Within-cluster association strength
Within-cluster association – IRQ correlation (Fisher Z-transformed r)

Figure 5. Analysis 1.3: Correlation between internal representational propensities and semantic conformity. A. Flowchart illustrating the procedure for correlating IRQ scores with semantic conformity. For each participant, we computed semantic conformity as the Fisher Z-transformed Spearman correlation between that participant's semantic association pattern (i.e., pairwise semantic similarity/relatedness ratings) and those of all other participants. We then calculated the Pearson correlation between this index and each IRQ factor score across participants. RSM = representation similarity matrix; IRQ = Internal Representations Questionnaire. B. Forest plot of meta-analysis results across nine semantic rating experiments showing correlations between each of the three IRQ factor scores and semantic conformity. Dot color (light to dark) reflects sample size (small to large samples). Error bars represent the 95% confidence interval of the Fisher Z-transformed correlation coefficient. Red squares denote significant meta-analytic results. Experiment labels indicate participant counts, stimulus sets, and semantic assessment type (Sem = semantic similarity/relatedness; Emo = emotional similarity), corresponding to Table 1. CHE = correlated and hierarchical effects.

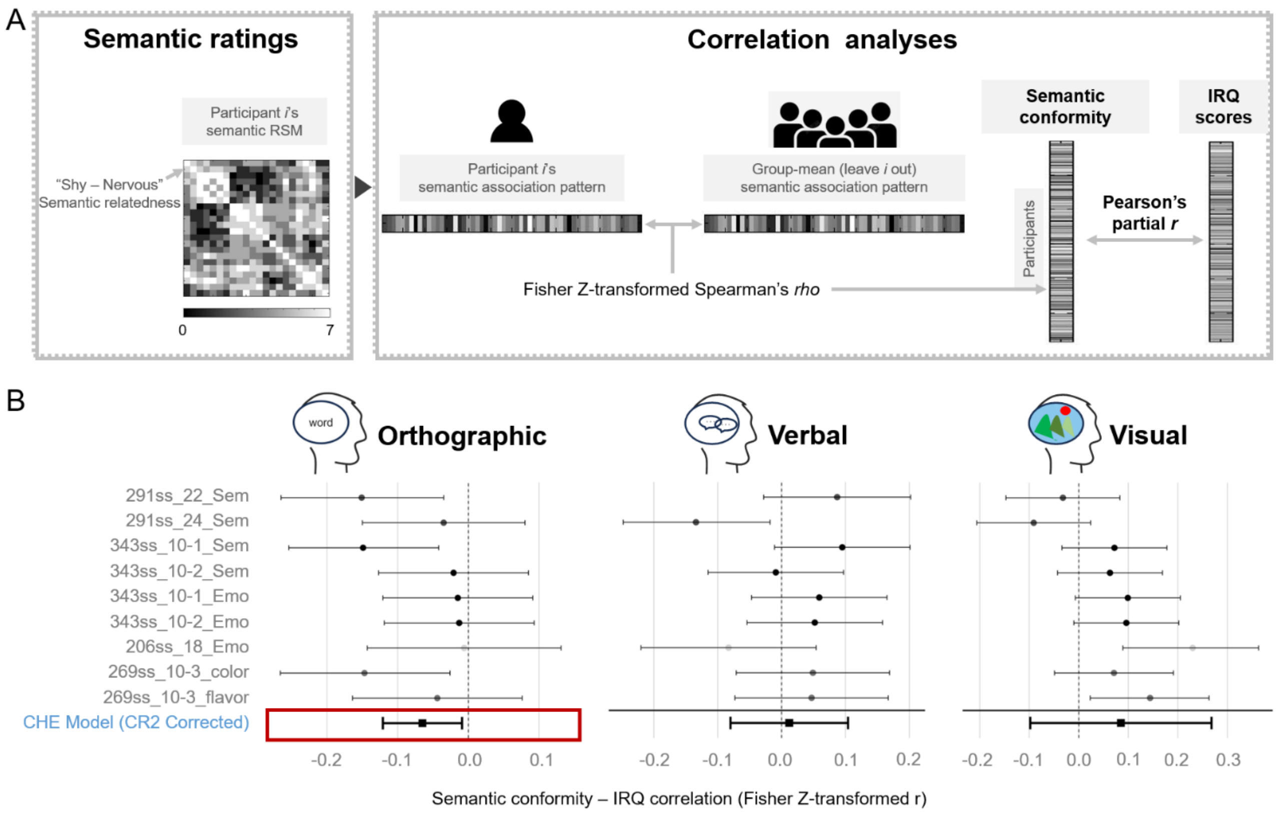
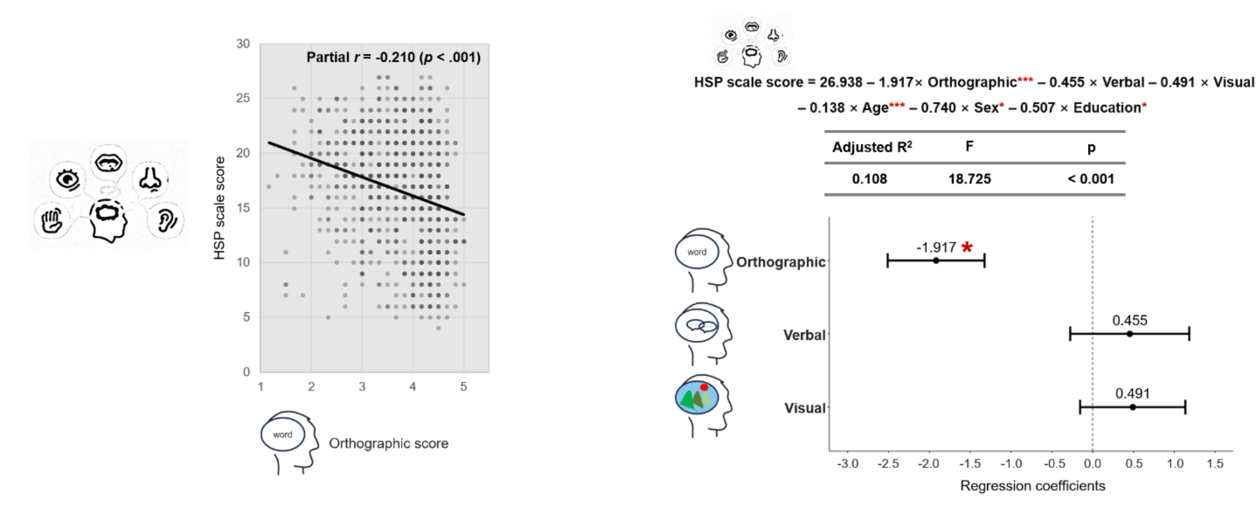


Figure 6

A. Results from Study 2: Correlations between IRQ scores and HSP scale scores. Left panel: Scatter plot showing the relationship between IRQ orthographic scores and HSP scale scores. Right panel: Multiple linear regression results predicting HSP scale scores from IRQ factor scores. B. Results from Study 3: Correlations between IRQ scores and media-specific app usage time. Left panel: Partial correlation coefficients showing associations between each app category and each IRQ factor, controlling for total usage time, demographic variables (age, sex, education), and the other two IRQ factors. Right panel: Results of the multiple linear regression predicting reading app usage time from IRQ factor scores. Total usage time reflects the cumulative time spent using various app categories (i.e., video, audio, reading, gaming, music, news). Regression coefficients were unstandardized. Error bars represent the 95% confidence interval (CI) for each unstandardized coefficient. HSP = Highly Sensitive Person; IRQ = Internal Representations Questionnaire. Red asterisks indicate statistically significant coefficients. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

A. Results from study 2: Correlations between IRQ scores and HSP scale scores



B. Results from study 3: Correlations between IRQ scores and media-specific app usage time

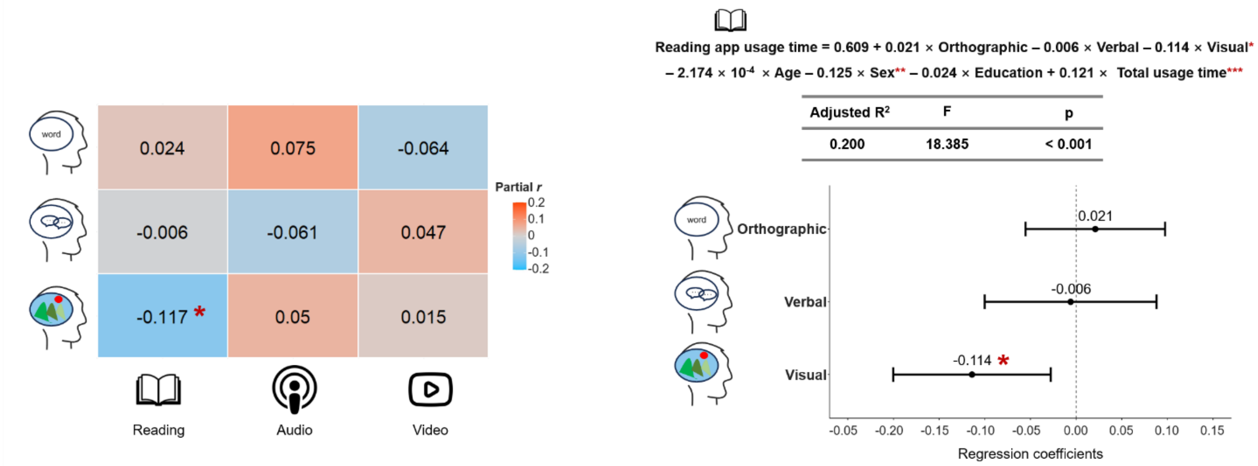


Figure 7.

Summary of key results. Diagram illustrating the main findings across Studies 1–3.

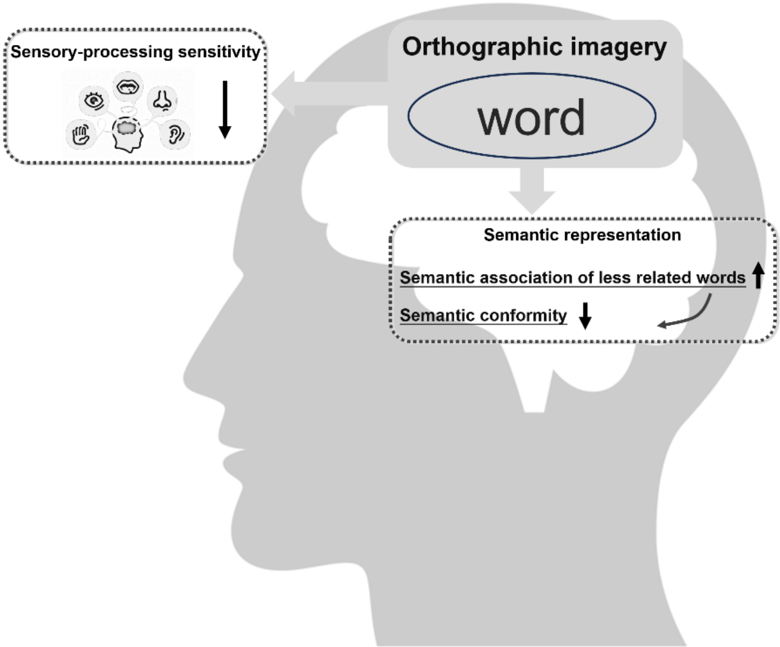


Table 1

Semantic association rating experiments

Group (*n*)	**Items label**	**Items**	**semantic rating type**
Group 1 (291)	22	shy nervous distressed troubled annoyed startled irritated comfortable relaxed satisfied excited joyful rainbow moon cloud fog aurora story dialogue speech knowledge eternity 害羞 紧张 难受 困扰 心烦 惊吓 恼火 舒适 放松 满足 兴奋 欣喜 彩虹 月亮 云 雾 极光 故事 对话 演讲 知识 永恒	semantic relatedness
Group 1 (291)	24	teacher student homeroom-teacher schoolbag chalk classroom lectern campus doctor patient nurse white-coat mask hospital emergency-room pharmacy referee audience athlete football baton track stands stadium 老师 学生 班主任 书包 粉笔 教室 讲桌 校园 大夫 病人 护士 白大褂 口罩 医院 急诊 药房 裁判 观众 运动员 足球 接力棒 跑道 看台 体育场	semantic relatedness
Group 2 (343)	10-1	child soldier death ward vaccine oxygen unit leader switch lab 孩子 士兵 死亡 病房 疫苗 氧气 队伍 领袖 开关 实验室	semantic relatedness & emotional similarity
Group 2 (343)	10-2	soldier election bridge lightning truth problem lab sin etiquette engineer 士兵 选举 桥梁 闪电 真理 问题 实验室 罪恶 礼仪 工程师	semantic relatedness & emotional similarity
Group 3 (206)	18	love triumph joy satisfaction interest relief awe desire amusement surprise confusion embarrassment anxiety sadness disgust fear anger suffering 爱 胜利 喜悦 满足 感兴趣 宽慰 敬畏 渴望 好笑 惊讶 困惑 尴尬 焦虑 难过 厌恶 恐惧 愤怒 痛苦	semantic similarity
Group 4 (269)	10-3	banana lemon cherry strawberry tomato carrot cucumber broccoli celery potato 香蕉 柠檬 樱桃 草莓 番茄 胡萝卜 黄瓜 西兰花 芹菜 土豆	color similarity & flavor similarity

Table 2

Correlations among IRQ factors and their associations with demographic variables

	Orthographic		**Verbal**		**Visual**	
	r	*p*	*r*	*p*	*r*	*p*
Orthographic	-	-	-	-	-	-
Verbal	0.677	*< 0.001****	-	-	-	-
Visual	0.406	*< 0.001****	0.296	*< 0.001****	-	-
Age	0.078	*0.004***	0.011	*0.679*	0.039	*0.145*
Sex	0.051	*0.056*	0.002	*0.950*	$2.934*10^{-4}$	*0.991*
Education level	0.081	*0.002***	0.090	*< 0.001****	0.067	*0.012**

*Note: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.*

Table 3

Partial correlations between semantic structure metrics and IRQ factors

Semantic structure metrics	Datasets	orthographic		verbal		visual	
		r	*p*	*r*	*p*	*r*	*p*
overall semantic association pattern	**291ss_22_Sem**	0.146	0.008**	-0.010	0.571	-0.063	0.847
	291ss_24_Sem	0.109	0.039*	0.131	0.016*	0.096	0.038*
	343ss_10-1_Sem	0.095	0.048*	0.006	0.452	-0.001	0.496
	343ss_10-2_Sem	0.175	0.001**	0.062	0.140	0.042	0.221
	343ss_10-1_Emo	0.091	0.059	0.009	0.440	0.068	0.146
	343ss_10-2_Emo	-0.066	0.967	0.022	0.321	0.122	0.004**
	206ss_18_Emo	0.130	0.032*	-0.066	0.822	0.229	0.001**
	269ss_10_Color	0.042	0.201	0.160	0.003**	0.209	<.001***
	269ss_10_Flavor	0.084	0.058	-0.050	0.783	0.261	<.001***
Between-cluster association strength	**291ss_22_Sem**	0.059	0.316	0.051	0.391	0.037	0.530
	291ss_24_Sem	0.077	0.191	0.065	0.270	0.018	0.764
	343ss_10-1_Sem	0.166	0.002**	-0.003	0.956	-0.011	0.836
	343ss_10-2_Sem	0.142	0.009**	0.071	0.192	-0.032	0.552
	343ss_10-1_Emo	0.120	0.028*	-0.003	0.959	0.054	0.325
	343ss_10-2_Emo	0.031	0.567	0.053	0.329	0.019	0.732
	206ss_18_Emo	0.121	0.088	0.037	0.604	-0.176	0.012*
	269ss_10_Color	0.127	0.039*	-0.038	0.536	-0.170	0.006**
	269ss_10_Flavor	0.054	0.380	0.024	0.699	-0.159	0.010*
Within-cluster association strength	**291ss_22_Sem**	0.002	0.975	0.124	0.035*	0.095	0.108
	291ss_24_Sem	-0.079	0.183	0.059	0.322	0.054	0.362
	343ss_10-1_Sem	0.032	0.554	0.103	0.057	0.023	0.670
	343ss_10-2_Sem	0.003	0.951	0.079	0.149	-0.011	0.833
	343ss_10-1_Emo	0.096	0.077	0.081	0.139	0.114	0.036*
	343ss_10-2_Emo	0.011	0.841	0.081	0.138	0.092	0.091
	206ss_18_Emo	0.160	0.023*	0.022	0.757	0.120	0.090
	269ss_10_Color	-0.044	0.478	0.129	0.036*	-0.062	0.317
	269ss_10_Flavor	0.083	0.178	-0.003	0.958	-0.003	0.967
Semantic conformity	**291ss_22_Sem**	-0.150	0.011*	0.087	0.144	-0.032	0.588
	291ss_24_Sem	-0.035	0.551	-0.133	0.025*	-0.091	0.125
	343ss_10-1_Sem	-0.148	0.007**	0.095	0.082	0.072	0.187
	343ss_10-2_Sem	-0.021	0.705	-0.009	0.872	0.063	0.251
	343ss_10-1_Emo	-0.015	0.780	0.059	0.279	0.099	0.070
	343ss_10-2_Emo	-0.013	0.814	0.052	0.344	0.096	0.079
	206ss_18_Emo	-0.006	0.938	-0.083	0.239	0.226	0.001**
	269ss_10_Color	-0.146	0.017*	0.049	0.432	0.071	0.253
	269ss_10_Flavor	-0.044	0.475	0.047	0.445	0.143	0.020*

*Note: *** p < 0.001; ** p < 0.01; * p < 0.05.*

Table 4

Meta-analytic results for correlations between semantic structure metrics and IRQ factor scores

Semantic structure metrics	IRQ factor	Z_r	SE	t	p	95% CI	I^2_{level2} (%)	I^2_{level3} (%)	Heterogeneity test		Publication bias test			
									Q	p	Egger's method (t, p)		Rank correlation test (Kendall's tau, p)	
Overall semantic association pattern	Orthographic	0.093	0.017	5.58	0.015*	[0.036 – 0.150]	58.37	0	55.631	< 0.0001	0.488	0.640	0	1
	Verbal	0.028	0.019	1.50	0.241	[-0.036 – 0.093]	60.31	0	50.147	< 0.0001	-0.473	0.651	-0.252	0.375
	Visual	0.128	0.057	2.24	0.113	[-0.056 – 0.313]	25.11	52.38	45.647	< 0.0001	2.041	0.081	0.504	0.076
Between-cluster association strength	Orthographic	0.098	0.013	7.9	0.006**	[0.057 – 0.140]	34.12	0	22.447	0.0042	-0.298	0.775	-0.189	0.506
	Verbal	0.029	0.013	2.19	0.122	[-0.015 – 0.074]	14.24	0	10.846	0.2106	-0.201	0.847	-0.192	0.504
	Visual	-0.072	0.054	-1.32	0.280	[-0.245 – 0.102]	2.82	69.02	17.946	0.0216	-2.931	0.022	-0.504	0.076
Within-cluster association strength	Orthographic	0.032	0.030	1.07	0.370	[-0.068 – 0.132]	45.62	0	29.717	0.0002	0.823	0.438	0.063	0.825
	Verbal	0.072	0.012	5.84	0.012*	[0.031 – 0.113]	26.38	0	16.224	0.0393	-1.219	0.262	-0.192	0.504
	Visual	0.049	0.027	1.83	0.172	[-0.041 – 0.139]	36.33	0	24.312	0.0020	0.045	0.965	-0.063	0.825
Semantic conformity	Orthographic	-0.065	0.017	-3.94	0.035*	[-0.121 – -0.009]	51.85	0	40.639	< 0.0001	-0.022	0.983	-0.063	0.825
	Verbal	0.012	0.027	0.45	0.687	[-0.080 – 0.104]	58.25	0	47.905	< 0.0001	-1.265	0.246	-0.378	0.183
	Visual	0.085	0.057	1.48	0.235	[-0.098 – 0.268]	2.38	72.41	18.944	0.0152	0.902	0.397	0.189	0.506

Table 5

Predictive effects of IRQ factor scores on HSP scale scores

	b	***SE***	***t***	***p***
Orthographic	-1.917	0.303	-6.330	< 0.001***
Verbal	0.455	0.372	1.226	0.221
Visual	0.491	0.329	1.493	0.136
Age	-0.138	0.024	-5.846	< 0.001***
Sex	-0.740	0.346	-2.139	0.033*
Education level	-0.507	0.250	-2.023	0.043*

*Note: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.*

Table 6

Predictive effects of IRQ factor scores on media-specific app usage time

Dependent variable	Predictors	*b*	*SE*	*t*	*p*
Reading app usage time	Orthographic	0.021	0.039	0.523	0.601
	Verbal	-0.006	0.048	-0.124	0.902
	Visual	-0.114	0.044	-2.585	0.010*
	Age	$-2.170*10^{-4}$	0.003	-0.066	0.948
	Sex	-0.125	0.047	-2.657	0.008**
	Education level	-0.024	0.035	-0.669	0.504
	Total app usage time	0.121	0.012	10.401	< 0.001***
Audio app usage time	Orthographic	0.047	0.029	1.647	0.100
	Verbal	-0.047	0.035	-1.345	0.179
	Visual	0.035	0.032	1.085	0.278
	Age	0.015	0.002	6.259	< 0.001***
	Sex	-0.007	0.034	-0.200	0.842
	Education level	-0.018	0.026	-0.702	0.483
	Total app usage time	0.125	0.008	14.745	< 0.001***
Video app usage time	Orthographic	-0.074	0.053	-1.405	0.161
	Verbal	0.066	0.065	1.021	0.308
	Visual	0.020	0.059	0.330	0.742
	Age	-0.013	0.004	-2.867	0.004**
	Sex	-0.034	0.064	-0.542	0.588
	Education level	-0.099	0.047	-2.096	0.037*
	Total app usage time	0.332	0.016	21.138	< 0.001***

*Note: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.*

Appendix A

Factor	Questions
Visual	I often enjoy the use of mental pictures to reminisce. 我经常喜欢用头脑中的画面来回忆往事。
	I can close my eyes and easily picture a scene that I have experienced. 闭上眼睛，我可以很容易地想出我经历过的场景的影像。
	My mental images are very vivid and photographic. 我头脑中的画面非常生动逼真，就像照片一样。
	The old saying "A picture is worth a thousand words" is certainly true for me "一张图胜过千言万语"这句俗语对我来说确实如此。
	When I think about someone I know well, I instantly see their face in my mind. 当我想起一个我很熟悉的人，就会在头脑中立刻浮现出他的脸。
	I often use mental imagers or pictures to help me remember things. 我经常使用头脑中的图像来帮助我记忆事物。
	My memories are mainly visual in nature. 我的记忆主要是以视觉的形式存在。
	When travelling to get to somewhere I tend to think more visually than verbally. 为了到达某个地方时，我会倾向于用视觉来思考而不是用语言来思考。
	If I talk to myself in my head it is usually accompanied by visual imagery. 如果我在头脑中自言自语，它通常伴随着视觉想象。
	If imagine my memories visually they are often moving than state. 如果我从视觉上回想我的记忆，它们通常是移动的，而不是静止的。
Verbal	I think about problems in my mind in the form of a conversation with myself. 我会以和自己对话的方式思考头脑中的问题。
	If I am walking somewhere by myself, I often have a silent conversation with myself. 如果我一个人走在某个地方，我通常和自己进行不出声的对话。
	If I am walking somewhere by myself, I frequently think of conversations that I've recently had. 如果我一个人走在某个地方，我会频繁想起自己最近的谈话。
	My inner speech helps my imagination. 我的头脑中的语言可以帮助我去想象。
	I tend to think things through verbally when I am relaxing. 当我放松的时候，我倾向于通过语言来想事情。
	When thinking about a social problem, I often talk it through thoughts in my mind. 当我思考一个社会问题时，我经常在头脑里把它说出来。
	I like to give myself some down time to talk through thoughts in my mind. 我喜欢给自己一些闲暇时间，在头脑里里讨论自己的想法。
	I hear words in my "mind's ear" when I think. 当我思考的时候，我头脑里中仿佛可以听到我思考所用的语言。
	I rarely vocalize thoughts in my mind. *

Factor	Questions
	我很少在头脑中说出我的想法。*
	I often talk to myself internally while watching TV. 我经常在看电视的时候在心里跟自己说话。
	My memories often involve conversations I've heard. 我的记忆经常涉及到我的谈话。
	When I read, I tend to hear a voice in my "mind's ear". 当我阅读的时候，我的头脑中仿佛能听到声音。
Orthographic	When I hear someone talking, I see words written down in my mind. 当我听到别人说话时，我头脑中会浮现出对应的文字。
	I see words in my "mind's eye" when I think. 当我思考的时候，我可以在我的头脑中看到文字。
	When I am introduced to someone for the first time, I imagine what their name would look like when written down. 当别人被第一次介绍给我的时候，我会想象他们的名字写下来是什么样子的。
	A strategy I use to help me remember written material is imaging what the writing looks like. 当需要背诵、记忆书面材料时，我会想象书面材料的文字看起来是怎样的来帮助我记忆。
	I hear a running summary of everything I am doing in my head. 能在头脑里听到关于我正在做的每件事情的一个快速总结。
	I rehearse in my mind how someone might respond to a text message before I send it. 在发送短信之前，我会在头脑中预演对方会如何回复。
Manipulation	I can easily imagine and mentally rotate three-dimensional geometric figures. 我可以很容易想象出一个三维几何图形，并在头脑中旋转它。
	I can easily choose to imagine this sentence in my mind pronounced unnaturally slowly. 我可以很容易想象出这句话在我的头脑中被非常缓慢地念出来的样子。
	In school, I had no problems with geometry. 在学校时，学习几何对我来说没有困难。
	It is easy for me to imagine the sensation of licking a brick. 我很容易想象出舔一块砖头的感觉。
	I find it difficult to imagine how a three-dimensional geometric figure would exactly look like when rotated.* 我很难想象一个三维的几何图形旋转后会是什么样子的。*
	I can easily imagine someone clearly talking, and then imagine the same voice with a heavy cold. 我可以很容易地想象出某一个人在清晰地讲话，然后再想象出同一个人患重感冒时讲话的声音。
	I think I have a large vocabulary in my native language compared to others.

Factor	Questions
	与别人相比，我认为我的母语词汇量很大。
	I can easily imagine the sound of a trumpet getting louder. 我可以很容易地想象出小号的声音变得越来越大。
Attention-check questions	The Chinese character "王" has two strokes. “王”字的笔画数是二。
	Elephants are larger in size than dogs. 大象的体型比狗大。
	Most people have five legs. 大多数人都有五条腿。

*Items that are reverse coded

Appendix B

No.	Questions
1	我难以忍受强烈的感觉刺激。 I am easily overwhelmed by strong sensory input.
2	我似乎很注意周围环境中的细节。 I seem to be aware of subtleties in your environment.
3	他人的情绪会影响我。 Other people's moods affect me.
4	我对疼痛非常敏感。 I tend to be more sensitivity to pain.
5	一旦太忙，我就想躲进被窝里、躲进黑暗的房间里，或是其他任何可以不受打扰、缓解刺激的地方。 I find myself needing to withdraw during busy days into bed or into a darkened room or any place where I can have some privacy and relief from stimulation.
6	我对咖啡因的作用特别敏感。 I am particularly sensitive to the effects of caffeine.
7	我难以忍受强光、浓郁的气味、粗糙的面料或近在咫尺的警笛声。 I am easily overwhelmed by things like bright lights, strong smells, coarse fabrics, or sirens close by.
8	我的精神世界丰富多元。 I have a rich, complex inner life.
9	刺耳的噪音让我很难受。 I am made uncomfortable by loud noises.
10	艺术或音乐作品能深深地打动我。 I am deeply moved by the arts or music.
11	我的神经系统有时容易疲惫不堪，我不得不抽身独处。 My nervous system sometimes feels so frazzled that I just have to get off by myself.
12	我非常认真负责。 I am conscientious.
13	我容易受惊。 I am startle easily.
14	如果短时间内要做很多事，我会坐立难安。 I get rattled when I have a lot to do in a short amount of time.
15	如果周围环境令人不适，我很清楚该如何调整得舒适些（譬如调整灯光或座位）。 When people are uncomfortable in a physical environment, I tend to know what needs to be done to make it more comfortable, like changing the lighting or the seating.
16	一次性给我安排太多任务，我会很恼火。 I am annoyed when people try to get me to do too many things at once.
17	我竭力避免犯错或忘事。

	I try hard to avoid making mistakes or forgetting things.
18	我不看有暴力内容的电影电视。 I make a point to avoid violent movies and TV shows.
19	如果身边发生太多事，我会心烦意乱。 I become unpleasantly aroused when a lot is going on around me.
20	饥饿会给我造成强烈影响，搅乱我的注意力和心情。 Being very hungry creates a strong reaction in me, disrupting my concentration or mood.
21	生活中的变动让我心神不宁。 Changes in my life shake me up.
22	我留意并享受细腻优雅的气息、味道、声音和艺术品。 I notice and enjoy delicate or fine scents, tastes, sounds, works of arts.
23	一时之间发生太多事会令我不快。 I find it unpleasant to have a lot going on at once.
24	有条不紊地安排好生活，避免混乱或负担过重是我的头等大事。 I make it a high priority to arrange my life to avoid upsetting or overwhelming situations.
25	强烈的刺激令我深为困扰，譬如噪音或混乱场面。 I am bothered by intense stimuli, like loud noises or chaotic scenes.
26	必须与人竞争或有人盯着我做事时，我会情绪紧张、战战兢兢，表现得相当失常。 When I must compete or be observed while performing a task, I become so nervous or shaky that I do much worse than I would otherwise.
27	小时候，父母和老师似乎都认为我很敏感、很害羞。 When I was a child, my parents or teachers seemed to see me as sensitive or shy.