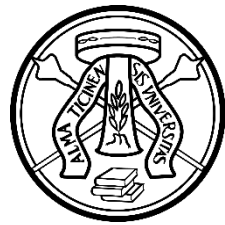


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**Department of Brain and Behavioral Sciences (DBBS)
MSc in Psychology, Neuroscience and Human Sciences**



**UNIVERSITÀ
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IUSS

Abstract Concepts and the Role of Expertise: An fMRI Investigation on Social, Political and Spatial Domains

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Academic year 2025/2026

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Abstract

Neuroscientific research on conceptual representation has traditionally focused on concrete categories, such as living things and tools, whereas abstract knowledge has only recently received systematic attention. Emerging evidence suggests that abstract concepts do not constitute a homogeneous category but instead encompass distinct domains, including social and affective concepts. According to embodied cognition accounts, the representation of both concrete and abstract concepts is grounded in the neural systems engaged by the experiences through which their meanings are acquired. Building on this framework, the present study investigates the cognitive organization and neural representation of concepts from three abstract domains, namely social, political and spatial, and examines whether greater domain-specific experience modulates their behavioral and neural processing. Twenty-four healthy subjects, characterized for the level of social and political abilities and experience, underwent an fMRI familiarity judgement task involving social, political, and spatial words. Results showed domain-specific patterns of activation. Social concepts preferentially recruited left temporal and medial frontal regions, consistent with the involvement of neural systems supporting social cognition and the integration of socially relevant conceptual information. Political concepts preferentially activated regions belonging to the default mode and executive control networks, potentially reflecting the integration and manipulation of complex and context-dependent knowledge. Spatial concepts preferentially engaged the left posterior inferior temporal gyrus, possibly reflecting the perceptual and visual components inherent to the meaning of some spatial concepts. Behaviorally, participants with higher levels of domain-specific social or political abilities and experience showed greater selectivity in dimensional ratings, assigning higher ratings to concepts along the relevant dimension and lower ratings along non-relevant dimensions. Crucially, higher levels of social and political abilities and experience were associated with reduced BOLD activity in domain-relevant networks, a pattern consistent with the neural efficiency hypothesis and suggesting more efficient processing of abstract conceptual knowledge.

1. Introduction

1.1. Semantic memory

1.1.1. Long term memory: episodic and semantic memory

Memory is divided into two principal systems: the long-term memory and the short-term memory. The latter one is characterized by short retention time, usually seconds, and is divided into the visuo-spatial and the auditory short-term memory components. Long term memory is traditionally divided into nondeclarative memory and declarative memory, which can be further divided into episodic memory and semantic memory (Slotnick, 2024).

Episodic memory allows for the encoding and retrieval of personal events and facts. It includes, for example, the knowledge of our favorite food, the last vacation we went on, the name of our first pet, the concert we attended one year ago and so on, but still heavily depends on retrieval of conceptual knowledge. The episodic memory system is supported by specific processes of encoding, consolidation and retrieval, each of them happening at a different neurobiological level, with several neural networks and structures involved (Binder, 2021). Encoding is supported by the hippocampus, the medial temporal lobe (MTL) and the perirhinal cortex, which bind information from sensory cortices, identify novelties, and allow the formation of a mnestic trace, while the prefrontal cortex manages attention, organization and semantic encoding. The consolidation of mnestic traces happens both as cellular consolidation, through synaptic changes and long-term potentiation (LTP), as well as system consolidation through the transfer of information from hippocampus to the neocortex (Daumas et al., 2005). At this point, retrieval of an encoded memory is no longer dependent on the hippocampus and MTL, but it features the re-activation of cortical traces that were originally involved during the process of encoding, with more recent memories still depending on the hippocampus (Barry, 2018).

Tulving (1972) states that the presence or absence of contextual information differentiates episodic memory from semantic memory. Episodic memory might be

more properly seen as a particular kind of knowledge manipulation, susceptible to errors and biases, that creates spatial-temporal configurations of object/event concepts (Binder et al., 2011), allowing the retrieval of specific events. On the other hand, semantic memory is more likely to be the result of different information accumulated across different contexts and then generalized, resulting in a dynamic store of knowledge and facts about the world.

Semantic memory is defined as a system responsible for encoding, storing, and retrieving general knowledge, including facts, ideas, word meanings, and the conceptual information acquired through experience but dissociated from the specific spatial and temporal context of the initial learning episode (Fernandino & Binder, 2024). In this system, *semantic cognition* refers to our ability to flexibly use semantic information to correctly perform a task, accordingly to the cognitive demand and, more broadly, being able to retrieve the correct information necessary to understand and produce appropriate thoughts and behaviors (Binder, 2021).

1.1.2. Organization of semantic knowledge: abstract and concrete concepts

Different theories have been proposed to account for the organization of semantic knowledge.

One of the most discussed properties of semantic knowledge is whether the conceptual representations are amodal or modality-specific, each supported by different theoretical frameworks. On one hand, *Amodal theories* claim that conceptual representations are in an amodal symbolic format, distinct from the representation in sensory and motor system (Mahon & Caramazza, 2009). On the other hand, theories of *Embodied cognition* argue that concepts are represented in a distributed manner across the same sensory-motor systems used to perceive and interact with the world, rather than in abstract, symbolic formats (Kiefer & Barsalou, 2013). According to this theory, we represent this knowledge through simulation: understanding the meaning of coffee, for example, involves reinstantiating the neural states involved in touching, smelling, seeing, and drinking coffee (Davis, 2021).

More recently, the *Grounded cognition framework* suggests that conceptual processing relies on a hierarchical architecture including modal, bimodal, and multimodal regions, converging in amodal semantic hub areas, while also incorporating representations in language-related regions (Kiefer & Harpaintner, 2020). These multiple representations are assumed to be flexibly recruited depending on contextual demand. No agreement is yet present regarding the nature and localization of the putative hubs brain areas. For example, the *Hub-and-Spoke theory* suggests that the "Spokes" are modality-specific regions (sensory, motor, auditory, linguistic) distributed throughout the brain that store specific attributes and features, while the "Hub" is located in the anterior temporal lobe (ATL). The ATL acts as a central hub that links disparate spokes together to form a unified, coherent concept (e.g., binding "yellow," "sweet," and "curved" into "banana"). The activity within the network for semantic representation must often be controlled to ensure that the system generates representations and inferences suited to the immediate task or context (Lambon Ralph et al., 2017).

Traditionally, concrete concepts have been divided into taxonomic categories based on shared semantic properties, with the principal distinction between living things and artifacts. Within these broad domains, concrete concepts can be further classified into different categories such as animals, fruits and vegetables, tools, vehicles, musical instruments and furniture, each characterized by different perceptual, functional, and action-related features (Warrington & Shallice, 1984). Abstract concepts (e.g., *friendship, justice*) have long been more challenging to study than concrete concepts, leading to their relative neglect in the literature. Furthermore, when investigated, they have typically been conceptualized as a single, homogeneous category to be compared to concrete ones. In this scenario, two key examples are the Dual-coding Theory by Paivio (1971) and the Context Availability Theory by Schwanenflugel and Shoben (1983).

Dual-Coding Theory (Paivio, 1971) posits that semantic information is processed through two distinct representational systems: a verbal system dealing with linguistic symbols and a non-verbal imagery system dealing with mental images. According to Paivio's theory, while concrete concepts are represented in both visual and verbal systems, abstract concepts are only represented in linguistic format.

The *Context Availability Theory* (Schwanenflugel & Shoben, 1983) instead suggests that concrete concepts are more easily and richly linked to contextual information compared to abstract concepts, for which retrieving contextual cues is often challenging. Consequently, both theories suggest that elaborating abstract concepts requires more cognitive effort, thus resulting in the so-called *concreteness effect*, namely an overall better performance for concrete over abstract stimuli.

1.1.3 Multidimensionality of abstract concepts

The specificities and characteristics of abstract concepts have become the focus of interest only in the last decades. While Barsalou's seminal work (Barsalou, 1999) laid the foundation for understanding concepts as grounded in perceptual, experiential, and contextual dimensions, more fine-grained distinctions within the domain of abstract concepts have only recently been investigated systematically (Conca et al., 2021a, 2021b, 2024, 2025; Catricalà et al., 2014, 2020, 2021). As a result, several theoretical frameworks have emerged, each highlighting different dimensions that contribute to the representation and characterization of abstract concepts.

The *Affective Embodiment Account* highlights the role of internal affective experiences and emotional valence in grounding words that lack physical forms, suggesting that abstract meaning is heavily rooted in our emotional systems (Vigliocco et al., 2014).

The *Words As Social Tools* (WAT) Framework emphasizes that abstract concepts rely heavily on language, verbal acquisition, and social interaction (Borghi et al., 2019). According to the WAT model, words serve as physical tools to coordinate social behaviors, drawing simultaneously upon internal experiences, interoception, and metacognitive monitoring processes when external physical features are absent (Borghi et al., 2019).

Furthermore, different types of abstract concepts can be identified, and evidence shows that they are at least partially segregated in brain regions involved in processing the specific experiential dimensions that underpin their meaning (Conca et al., 2021a), such as introspection, affective, social, mental state, and magnitude-related aspects (Conca et al., 2021a; Binder, 2016; Borsa et al., 2025).

For example, neuroimaging and neurostimulation studies show that social concepts (e.g., *honor*, *generosity*) rely on an extended network centered on the superior part of the ATL (Catricalà et al., 2020; Zahn et al., 2007), overall implied in social cognition functions. Also, patients with semantic variant of primary progressive aphasia (svPPA) and behavioral variant of frontotemporal dementia (bvFTD) exhibited marked impairments in the processing of social concepts. In svPPA, these deficits likely reflect degeneration of the ATL, a region critically involved in representing knowledge about individual identity and social behavior (Adolfi et al., 2017; Olson et al., 2013; Zahn et al., 2017). In bvFTD impairments are related to degeneration of widespread frontotemporal networks, which support empathy, impulse control and the recognition of complex emotions (Ibáñez & Manes, 2012; Carr & Mendez, 2018; Mariano et al., 2020; Kipps et al., 2009).

Similarly, converging evidence from neuroimaging, neurostimulation, and neuropsychological studies indicate that concepts belonging to different dimensions of magnitude (e.g., *perimeter*, *extension*) preferentially recruit left fronto-parietal regions, particularly the intraparietal sulcus (IPS), implicated in the representation of generalized magnitude across domains such as number, space, and time (Walsh, 2003; Conca et al., 2021). Indeed, patients with parietal lesions, especially involving the IPS, as well as patients with corticobasal syndrome (CBS), show impairments in processing magnitude-related concepts, including numerical, spatial, temporal, size, quantity, weight, and length concepts, supporting the existence of a shared fronto-parietal representational system tuned to the elaboration of magnitude-related concepts (Cappelletti et al., 2014; Catricalà et al., 2020; Conca et al., 2021; Walsh, 2003).

Emotion-related concepts (e.g., *fear*, *happiness*) rely on a distributed limbic and paralimbic network, including the amygdala, insula, anterior cingulate cortex, and ventromedial prefrontal cortex, together with temporal semantic regions, reflecting the integration of affective experience with conceptual knowledge (Lindquist et al., 2012; Vigliocco et al., 2014; Catricalà et al., 2020). Patients with frontotemporal degeneration, particularly bvFTD, and focal lesions in these regions exhibit impairments in processing this specific conceptual category, often with deficits in emotion recognition and emotional awareness (Kumfor et al., 2013; Binney et al., 2016; Mariano et al., 2020). Neurodevelopmental evidence from autism spectrum

disorder (ASD) show that Individuals with ASD frequently struggle in understanding and interpreting emotion-related information, including emotional expressions and affective states, reflecting an atypical recruitment of the neural systems typically involved in emotion processing and social cognition, such as the amygdala, medial prefrontal cortex, and anterior cingulate cortex (Uljarevic & Hamilton, 2013). *Interoceptive approaches* propose that internal bodily states are an additional source of experiential information that contribute to the organization of abstract concepts. Specifically, physiological signals as heart rate and visceral changes are thought to contribute to the experiential grounding of concepts related to emotional states, linking conceptual knowledge to internal states (Connell et al., 2018; Vergallito et al., 2019).

1.2. The role of expertise

1.2.1 Introduction to expertise

Expertise can be defined as the ability to consistently exhibit high-level, efficient performance within a specific domain, achieved through experience and domain-specific training (Bilalić, 2017). Scientific research supports the idea that this ability of reducing the complexity of a situation by focusing on salient aspects, with pattern recognition and selective attention playing a crucial role, is linked to neuroplasticity, where recurring experiences structurally and functionally reshape the brain (Tashman et al., 2013). Recent evidence (Calvo-Merino et al., 2005; Harel et al., 2015; Martens et al., 2018) supports the *domain-oriented theory* of expertise, according to which the neural correlates of expertise depend on the specific domain of action and the task demands. Within this framework, expertise is commonly distinguished into three main domains, namely perceptual, motor, and cognitive expertise.

Perceptual expertise mainly relies on the efficient processing of sensory information, as in visual object recognition. For example, Harel and colleagues (2015) showed that car experts performing a visual repetition-detection task (cars vs. airplanes) exhibited greater activation in object-selective parietal and frontal regions, but only when processing domain-congruent stimuli. Similar domain-specific neural responses were reported by Martens and colleagues (2018), who compared ornithologists and

mineralogists and found enhanced activation for stimuli belonging to each group's domain of expertise.

Motor expertise relies on the ability to anticipate events and accurately execute highly skilled movements and has been associated with the activity of the mirror neuron system (Rizzolatti, 2004). Abernethy and Russell (1987) demonstrated that expert tennis players are more accurate than novices in predicting the landing position of the ball from visual cues. Consistent with the domain-oriented theory, Calvo-Merino and colleagues (2005) found that expert ballet and capoeira dancers showed greater activation of motor-related regions when observing movements belonging to their own motor routine than unfamiliar dance movements.

Cognitive expertise encompasses domains such as memory (Ericsson et al., 1989), calculation (Pesenti, 2005), board games (Duan et al., 2012), and spatial navigation (Maguire et al., 2000) and can be defined as the superior ability to process, organize, and manipulate domain-specific knowledge during complex problem-solving and decision-making situations (Bilalić, 2017). For example, Maguire and colleagues (2000) reported structural changes in the posterior hippocampi of London taxi drivers, showing that the prolonged use of navigational knowledge was associated with experience-dependent redistribution of gray matter supporting spatial navigation and thus spatial-expertise.

1.2.2 Conceptual knowledge and expertise

Most evidence supporting the role of experience in conceptual representation comes from studies investigating concrete concepts such as objects, animals and tools. Within this framework, expertise has served to investigate how experience shapes conceptual knowledge, demonstrating that prolonged training and domain-specific experience modify the neural processing of semantic knowledge, increasing the involvement of modality-specific and domain-relevant brain systems during semantic processing (Binder & Desai, 2011; Lambon Ralph et al., 2017). For example, Hoenig and colleagues (2011) showed that professional musicians, compared to non-musicians, recruited the auditory association cortex when identifying pictures of

musical instruments, suggesting that sensory knowledge acquired through experience is integrated into the conceptual representation of musical objects. Comparable domain-specific effects have been observed in visual object expertise, where experts show enhanced activation of object and attention-related regions when processing stimuli belonging to their field of expertise (Harel et al., 2015; Martens et al., 2018). Beilock and colleagues (2008) demonstrated that hockey players processing action-related language recruited the left dorsolateral premotor cortex more strongly than non-athletes, suggesting that motor experience influences the neural representation of action concepts. Together, these findings suggest that repeated interaction with a specific domain reshapes semantic representations by incorporating perceptual, motor, and experiential knowledge. However, whether similar mechanisms extend to abstract concepts, which lack direct sensory referents, remains a more recent and less explored question. Recently, Ulrich and colleagues (2023) found that senior psychology students, compared to first-year students, showed stronger grounding of abstract psychological concepts (e.g. *habituation*) in brain systems involved in social cognition and mentalizing, in line with domain-specific knowledge representation. Consistent with this view, Bechtold and colleagues (2019) reported that mathematical expertise modulates the electrophysiological processing of mathematical words, providing further evidence for the experience-dependent semantic processing of abstract concepts. Furthermore, this semantic reorganization also extends to other abstract domains, as Villani and colleagues (2022) found that legal experts perceived institutional concepts (e.g., *justice*, *norm*) as less abstract and more strongly grounded in sensorimotor experience than non-experts. Taken together, these studies show that the experience-dependent reorganization allows abstract and concrete concepts to be processed more efficiently by strengthening the interaction between domain-specific knowledge stored in semantic memory and the perceptual, motor, social or cognitive systems involved in their acquisition and retrieval.

1.3. Aims of the current work

The overall and broader project was designed to include three groups of participants:

1. Control subjects

2. Experts, namely Social media influencers and Politicians with high levels of social skills in social-media environments and real-life interactions
3. Parents of autistic children, with possible sub-clinical autistic traits involving social abilities

Despite the aim of the current work is to investigate the organization and neural correlates of different types of abstract concepts, namely social, political and spatial, as well as the role of expertise in their modulation among participants showing different levels of social and political expertise, due to the limited sample size currently available in the groups of professional experts and parents of autistic children, the present thesis focuses exclusively on the control group. Specifically, within the control group, participants were characterized according to individual differences in social and political abilities, interest and experience, assessed through ad-hoc questionnaires and characterized with tests targeting their personality, social and emotional functioning. Participants underwent a functional magnetic resonance imaging (fMRI) paradigm and behavioral tasks involving social, political, and spatial concepts.

2. Materials and methods

2.1 Participants

A total sample of 24 healthy controls ($f = 12$; age: mean = 28,79, $sd = 5,16$; education: mean = 16,21, $sd = 4,1$) were recruited through a combination of snowball recruitment (word-of-mouth) within the University of Pavia (PV), Università Vita e Salute San Raffaele (MI) and professional networks. Purposive sampling was used specifically for the experts' and ASD parents' groups, not included in this thesis. All participants met the inclusion criteria for this study.

All participants were screened for neurological disorders, psychiatric conditions, existing pathologies or MRI contraindications (e.g., metallic implants). They were all right-handed according to the Edinburgh Handedness Inventory (EHI; Oldfield, 1971).

Of note, for the current thesis only preliminary results on the control sample are reported.

	<i>N (f)</i>	<i>Average</i>	<i>std.</i>	<i>Min.</i>	<i>Median</i>	<i>Max.</i>
Age	24 (12)	28,79	5,16	22	28	41
Education		16,21	4,1	11	15	25

Table 1. Control group demographics

2.2 Procedure

The *experimental protocol* (Fig. 2) consisted in the administration of self-report paper-and-pencil questionnaires for the evaluation of personality traits, social and emotional abilities, and the ad-hoc questionnaires on social/political interest and online interactions. Participants underwent fMRI acquisition while performing the familiarity judgement task and, after that, dimensional ratings were collected. The entire procedure lasted approximately two hours on the same day. The study was conducted in compliance with the Declaration of Helsinki and was approved by the Ethics Committee of San Raffaele Hospital (Milan).

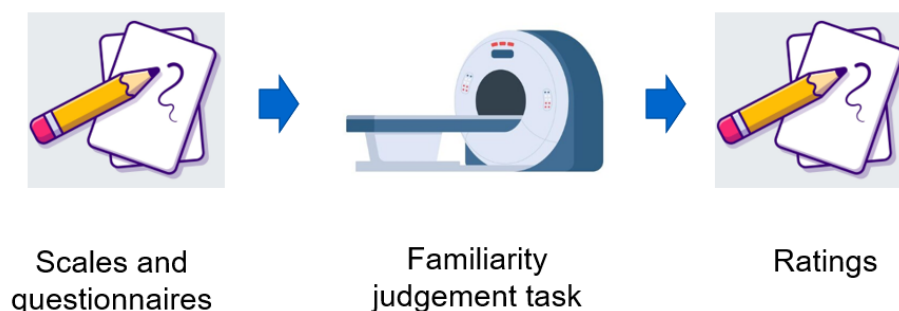


Figure 2. Experimental protocol

2.2.1 Familiarity Judgement Task

Stimuli selection. A set of 197 words was initially selected, including nouns referring to three semantic categories: social (62), political (76), and spatial (59). Following an adaptation from previous studies (Della Rosa et al., 2010; Conca et al., 2024; 2025; Borsa et al., 2025), words were rated on multiple dimensions including imageability, concreteness, Age of Acquisition (AoA), familiarity, valence, arousal, semantic

diversity, and semantic dimensions referring to social, political, spatial, introspection, mental state, moral, economic, theoretical, and quantitative contents. These ratings were collected online, using SoSci Survey software (Leiner, 2019; <https://www.soscisurvey.de/>) from 109 participants (71 females; mean age = 27 years, SD = 3.8; mean years of education = 18, SD = 2.5). None of them participated in other parts of the study. Participants were given a detailed explanation of the rating procedure, including a definition of the dimension to be rated and two example words not included in the final dataset, and were then asked to rate the word list. Each word was evaluated by at least 10 participants. Of this initial set of words, 150 nouns were selected for the fMRI task: 50 belonging to the political category (e.g., *decree*), 50 to the social category (e.g., *generosity*), and 50 to the spatial category (e.g., *length*). The three categories were matched for written form frequency, length, mean frequency of bigrams, imageability and exclusivity, which measures the extent to which each word is experienced along a unique dimension (Lynott and Connell, 2009).

	POLITICAL mean (min-max)	SOCIAL mean (min-max)	SPACE mean (min-max)	p-value (*difference between categories)	
N. Letters	9.24 (4-13)	9.22 (4-14)	9.56 (3-18)	.745	
Freq. (form, colfis)	84.32 (0-467)	93.62 (0-422)	57.24 (0-321)	.164	
Mean Freq. Bigrams	66353.49 (22201.42- 171727.5)	69632.17 (12311- 144403.07)	56317.54 (11928.08- 120217.37)	.085	
IMG	3.62 (1.88-6.5)	3.61 (2-6.32)	4.04 (2.33-6.3)	.069	
Social	4.82 (3.11-6.47)	6.19 (5.33-6.9)	2.38 (1-4.4)	.001**	
Political	6.50 (5.07-7)	2.82 (1.10-5.7)	2.34 (1.1-4.6)	.001**	
Space	1.78 (1.07-4.33)	2.01 (1.05-4)	6.06 (5-7)	.001**	
Exclusivity	16.16 (10.58-21.61)	15.87 (9.99-22.87)	17.21 (7.18-23.66)	.099	
CNC	3.48 (1.91-6.21)	3.17 (1.81-6)	3.87 (1.11-6.59)	.006*	
FAM	4.13 (1.80-6.07)	5.38 (2.60-7)	4.61 (2.7-6.55)	< .001**	
AoA	5.66 (4.00-6.44)	4.30 (2.24-5.71)	4.68 (2.57-9)	< .001**	
VAL	5.40 (3.00-7.55)	4.27 (1.32-8.80)	4.73 (1.75-6.95)	.003*	
ARO	4.68 (2.10-6.90)	5.36 (1.36-7.81)	5.68 (2.36-7.05)	.003*	
SEM_DIV	3.08 (1.45-5.29)	4.22 (2.056.23)	4.83 (2.4-6.71)	< .001***	
INTRO	2.45 (1.20-4.20)	4.11 (1.37-6.79)	2.39 (1-4.14)	< .001**	
MENTAL	2.26 (1.11-4.25)	4.06 (1.25-6)	2.33 (1.05-4.23)	< .001**	
MORAL	4.35 (2.29-6.20)	4.17 (1.37-6.32)	1.73 (1-3.13)	< .001**	
ECONOM	3.24 (1.55-5)	2.41 (1.00-5.25)	2.29 (1-5.1)	< .001**	
THEORET	4.40 (2.82-6.32)	2.58 (1.61-3.85)	3.40 (1.3-5.7)	< .001***	
QUANTITY	1.86 (1.10-3.60)	2.16 (1.00-5.05)	4.61 (1.25-6.78)	< .001**	

* = political-space
 * = political-social
 * = social-space

Figure 3. Variables of selected stimuli

Task. The task used was a familiarity judgement task, where “Familiarity” is defined as the frequency with which a word is used, heard, or seen. The task was developed based on the work by Fernandino et al. (2022). During fMRI, participants had to

indicate the familiarity of each word on a four-point scale (1 = not familiar at all, 4 = very familiar), using their left hand on an MRI-compatible response pad. The stimuli were projected on a screen in front of the scanner, visible through a mirror placed on the head coil above participants' eyes. If a word was familiar in one modality (e.g., spoken) but less familiar in another (e.g., written), participants were asked to use the highest familiarity rating across modalities.

In the scanner, each trial started with a fixcross (150 ms), followed by the word displayed in upper case in white font on a black background (500 ms), and by a black screen for 2500 ms (Fig. 4).

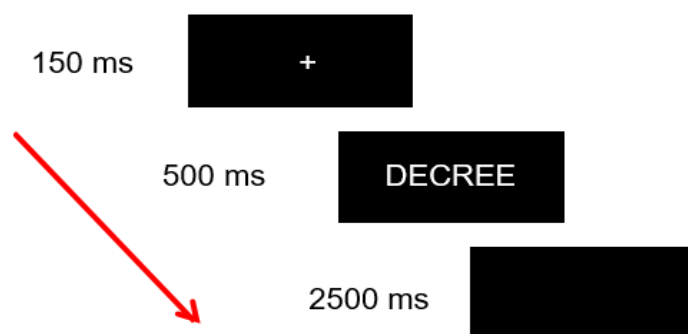


Figure 4. Example of an experimental trial

The 150 stimuli were organized into five different randomizations (runs) where each participant was administered three runs, each lasting approximately 13 minutes, with run order randomized across participants. Thus, each stimulus was presented three times.

2.2.2 Scales and questionnaires

Participants' personality was assessed using the *Ten Item Personality Inventory* (I-TIPI; Chiorri et al., 2015), a shortened version based on the Big Five model, investigating Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness to Experience. Participants were asked to rate several pairs of personality traits on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree) based on how accurately the items reflected their self-perception.

The *Interpersonal Reactivity Index* (IRI; Albiero et al., 2006) was used to measure Empathic responsiveness, as it measures empathic concern, personal distress,

perspective taking, and fantasy. Participants were presented with a series of self-descriptive statements (eg., “Resto veramente coinvolto dagli stati d’animo dei protagonisti di un racconto”; “In situazioni di emergenza, mi sento apprensivo e a disagio”) and asked to evaluate them based on personal frequency. Responses were recorded on a 5-point Likert scale, ranging from 1 (Never) to 5 (Always).

Social anxiety was measured using the *Social Interaction Anxiety Scale* (SIAS) and the *Social Phobia Scale* (SPS; Sica et al., 2007). The SPS measures fear of being observed or judged during everyday activities (eg., “Mi innervosisco se le persone mi fissano mentre cammino per la strada”), whereas the SIAS assesses anxiety experienced during social interactions (eg., “Nelle situazioni sociali di solito mi sento a disagio”). Both scales consist of items rated on a 5-point Likert scale.

Relational and social aspects were examined using the *Autism-Spectrum Quotient* (AQ; Baron-Cohen et al., 2001), which is a measure of adults' autistic traits across five domains: social skills, attention switching, attention to detail, communication, and imagination. The AQ yields a total score ranging from 0 to 50, with scores below 26 used as a cutoff to identify significant autistic traits.

To investigate participants' online social interactions and social media use, we developed the “*Online social interaction questionnaire*” (Fig.5), an ad-hoc test based on previous studies (Mantzouranis et al., 2019; Lamash et al., 2024). This questionnaire consists of 10 items (eg., “Mi piace interagire con più persone, ad esempio utilizzando chat di gruppo, e ampliare il mio gruppo di amici, ad esempio inviando richieste di amicizia”) assessing skills and motivation towards online-interaction, expression and recognition of emotions, and display assertiveness in both synchronous (e.g., video calls, live streams) and asynchronous or written contexts (e.g., likes, comments, and chats). Participants were asked to report their level of agreement (from “strongly disagree” to “strongly agree”) and the frequency of social media use, number of followers, and level and type of engagement, distinguished between active (e.g., content creation) and passive use (e.g., viewing videos).

Similarly, using the ad-hoc “*Political Questionnaire*” (Fig.6), we asked participants to report how interested they are in politics (not at all, a little, moderately, very, extremely), how frequently they follow political news and information (never, once a month or less, once a week, 2-6 times a week, daily), how frequently they talk about

politics (never - daily), and how frequently they participate in political events (e.g., protests, rallies) (never - daily).

Questionario social media

Le seguenti domande hanno l'obiettivo di valutare il tuo utilizzo dei social media. Indica la risposta che è vera per te, e ricorda che non ci sono risposte giuste o sbagliate.

1) Alcune persone utilizzano molto spesso i social media (es. X, Instagram, Facebook ecc), mentre altre solo di rado. Nello spazio sottostante elenca i social media che utilizzi e con che frequenza (ore al giorno) utilizzi ciascuno di essi:

2) Indica il maggior numero di *followers* che hai in uno dei social media indicato sopra:

< 500	500-1.000	1.000-5.000	5.000-10.000	>10.000
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3) I social media possono essere usati per *diversi scopi*. Nell'elenco seguente ne abbiamo indicati alcuni, tra cui indicare quello/i per cui utilizzi i social media normalmente:

- creazione di contenuti, quali ad esempio video
- promuovere prodotti
- informarsi su diversi argomenti di attualità
- mantenere e espandere la propria rete professionale
- interagire con amici/conoscanti
- fare nuove conoscenze
- giochi online
- guardare post, video di interesse ecc
- altro: (specificare) _____

4) Alcune persone sono più attive sui social, altre lo sono meno. Ad esempio, alcune persone pubblicano contenuti, scrivono post e commenti molto frequentemente, mentre altre no. Ti ritieni particolarmente attivo/a sui social media?

Per niente	Poco	Abbastanza	Molto	Estremamente
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Questionario politica

Le seguenti domande hanno l'obiettivo di valutare il tuo interesse, partecipazione e ricerca di informazioni relative alla politica. Indica la risposta che è vera per te, e ricorda che non ci sono risposte giuste o sbagliate.

1) Alcune persone sono molto interessate a ciò che accade nel governo e negli affari pubblici, e altri raramente, che ci sia una elezione in corso o meno. Quanto sei *interessato/a* alla politica, ad esempio a ciò che accade nel governo e nei partiti politici nazionali e/o internazionali?

Per niente	Poco	Abbastanza	Molto	Estremamente
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2) Alcune persone sembrano seguire ciò che accade nel governo e negli affari pubblici la maggior parte del tempo, e altri raramente, che ci sia una elezione in corso o meno. Con che frequenza *seguì notizie e informazioni* di politica in tv, radio, e tramite i social media?

Mai	Una volta al mese o meno	Una volta a settimana	Da 2 a 6 volte a settimana	Quotidianamente
-----	--------------------------	-----------------------	----------------------------	-----------------

3) Alcune persone parlano frequentemente di ciò che accade nel governo e negli affari pubblici, e altri raramente, che ci sia una elezione in corso o meno. Con che frequenza *parli* di politica con familiari, amici, o colleghi?

Mai	Una volta al mese o meno	Una volta a settimana	Da 2 a 6 volte a settimana	Quotidianamente
-----	--------------------------	-----------------------	----------------------------	-----------------

4) Alcune persone partecipano di frequente ad eventi politici, quali manifestazioni o comizi, mentre altri raramente, che ci sia una elezione in corso o meno. Con che frequenza *partecipi* ad eventi di natura politica?

Mai	Una volta al mese o meno	Una volta a settimana	Da 2 a 6 volte a settimana	Quotidianamente
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Figure 5. and 6. Social and Political questionnaires

2.2.3 Dimensional ratings

After the MR acquisition, using the same 150 words employed in the familiarity judgment task, participants performed the dimensional ratings of the stimuli. Ratings were collected for the social, political, and spatial dimensions, as well as for valence and arousal.

Political dimension: to what extent the word refers to the constitution, organization, and administration of the state and public life.

Social dimension: to what extent the word refers to social situations and to interactions between people in general, whether they involve social engagement or social exclusion.

Spatial dimension: to what extent the word refers to the spatial domain as position, location, and/or direction in space.

The scale used for the response ranged from 1 (not related to politics/social/space) to 7 (highly related to politics/social/space). Participants were instructed to use the full

range of the scale, and to rate accurately based on their judgment, regardless of whether they knew their exact meanings.

Valence-Arousal ratings. Words can evoke emotional responses that participants had to quantify using the *Self-Assessment Manikin* (Bradley & Lang, 1994), respectively indicating the valence (e.g., pleasant-unpleasant) and arousal (e.g., excited-calm) dimensions. For each word, participants had to provide one rating on both scales, each one with 9 response options, ranging from extreme happiness/arousal to extreme unhappiness/calm.

2.3 Imaging Technique

MRI scans were acquired with a 3 Tesla Philips Ingenia whole-body MR scanner (Philips Medical Systems) using an eight-channel sense head coil. Whole-brain functional images were obtained with a T2*-weighted gradient-echo, EPI pulse sequence, using BOLD contrast (TR 1.2 seconds). Each functional image comprised 50 contiguous axial slices (2.5 mm thick), acquired in interleaved mode (field-of-view: 210 x 210, matrix size: 96 x 96). Each participant underwent three consecutive functional scanning sessions, each comprising 690 volumes and lasted about 13 minutes. A high resolution T1-weighted anatomical scan (243 slices, slice thickness 0.7 mm) was acquired for each participant.

2.4 Data Analysis

2.4.1 Behavioral data

Analysis of behavioral data were performed on Jamovi software (The Jamovi project, 2024).

Participants responses in the ad-hoc questionnaires on social and political interest/engagement were converted in standardized scores, with a minimum value of 0 and a maximum value of 1. This standardization allowed the identification of two main indices later used for the statistical analysis: index A for Social expertise and index B Political expertise. The distribution of the indices followed a normal distribution

(*Saphiro-wilk normality test*, all $p > 0.05$), therefore this allowed us to consider participants as ranging along a continuum of expertise. To further explore whether different trends in participants' expertise could mask whole-group effects, an additional exploratory analysis was performed for each index, dividing the control sample into high (Group 1, $n=12$) and low expertise (Group 0, $n=12$) groups using a median split. Using the Kendall rank correlation coefficient (Kendall's tau) we investigated the correlations between indices (A and B) and the results from the dimensional ratings (spatial, social, political, and valence/arousal), the questionnaires and scales administered, and the behavioral performance in the fMRI task.

2.4.2 Imaging data

Imaging data were analyzed using SPM-12 and CAT-12 on the MATLAB software.

Preprocessing included slice-timing correction, realignment for motion correction, co-registration of functional and anatomical images, segmentation, and normalization to the MNI template. Normalized images were spatially smoothed with an isotropic Gaussian kernel (8 mm FWHM). The resulting images were visually inspected to ensure preprocessing quality and absence of excessive motion artifacts.

After the pre-processing, we first identified the cerebral activations for the main effects of social, political and spatial stimuli presented during the familiarity task and subsequently assessed the modulation of the expertise, using the two indexes of expertise (A and B) as covariates for the analysis. Furthermore, we examined contrasts between the three categories to identify domain-specific neural responses. Specifically, we analyzed: Political > (Social + Spatial), Social > (Political + Spatial), and Spatial > (Political + Social).

3.0 Results

3.1 Behavioral results

We first explored the distribution of the scores obtained from the scales assessing social and political expertise among the participants. As showing in Figure 7, scores on both scales showed sufficiently variability, they were distributed along a continuum

and did not significantly deviate from a normal distribution (Shapiro-Wilk tests, p -values $> .001$).

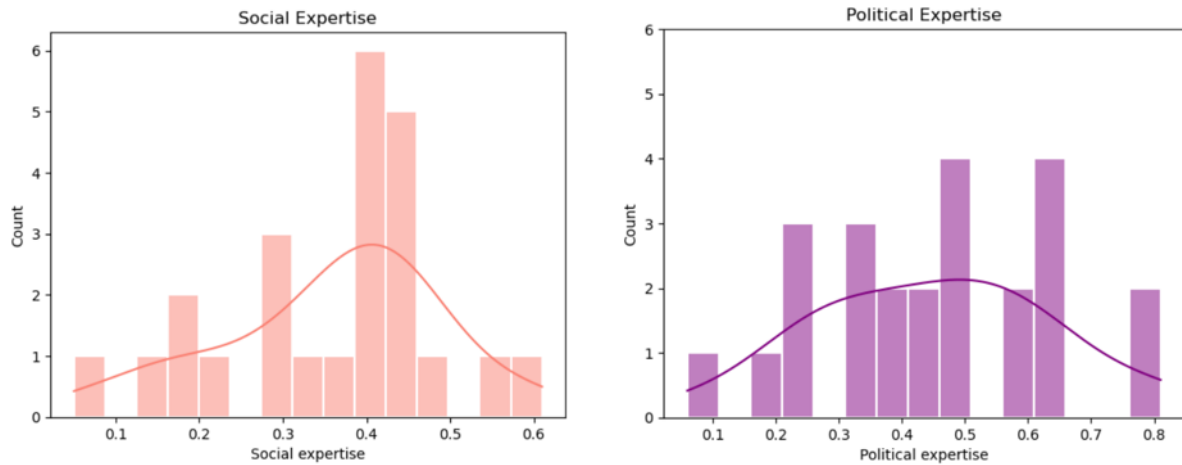


Figure 7. Distribution of Social and Political indexes

Since correlation analyses performed on the whole-group did not reveal any significant associations (all $p > .05$), we conducted the median-split analysis resulting in the high and low expertise groups. We explored for each groups the significant correlations between the level of expertise and the behavioral task, rating measures, and indexes of social, emotional and personality traits.

Significant results were reported only in relation to dimension ratings.

Specifically, high-social-expertise individuals rated social words higher on the social dimension ($\tau = 0.492$, $p = 0.027$) and assigned lower ratings to social words in the spatial dimension ($\tau = -0.478$, $p = 0.044$). Similarly, high-political-expertise participants rated political words higher on the congruent dimension ($\tau = 0.462$, $p = 0.039$) and lower on social ($\tau = -0.462$, $p = 0.039$) and spatial ($\tau = -0.462$, $p = 0.039$) dimensions. All the other correlations were not significant (all $p > 0.05$), meaning that expertise in our sample did not affect overall personality, socio-emotional traits nor the performance in the familiarity judgement task, both as response times (RTs) and judgments of familiarity.

3.2 Imaging results

Neural correlates of social, political, and spatial concepts. We first reported the main effects of social, political, and spatial concepts. For social concepts, we observed an activation of the left Inferior Frontal Gyrus (IFG) pars triangularis, left Precentral and right Postcentral gyrus, left inferior Parietal cortex, right Calcarine and bilateral Occipital areas, fusiform gyrus, anterior middle Temporal gyrus, left Cerebellum and bilateral Putamen.

The main activations for political concepts showed a similar network including left Supplementary Motor Area (SMA), precentral gyrus, left superior frontal gyrus, right postcentral and left inferior parietal cortex, calcarine and occipital, fusiform gyrus, bilateral cerebellum and left putamen.

Spatial concepts activated bilateral precentral gyrus, left inferior parietal and left inferior temporal gyri, calcarine and occipital cortices, fusiform gyrus, right cerebellum and left putamen. See Figure 8 below for the results (FWE corrected).

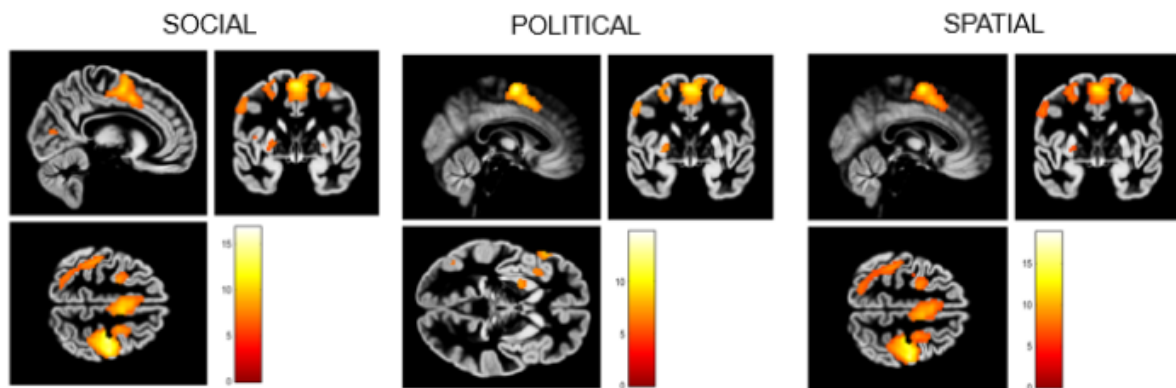


Figure 8. Main effects activations

Contrast analysis revealed the activation of specific areas related to each one category of concepts compared to the other two. Specifically, Political (vs. Social and Spatial) concepts elicited activity in left posterior cingulate cortex, left anterior inferior Temporal gyrus, left angular gyrus, left Frontal superior gyrus, and left thalamus. Social (vs. Political and Spatial) concepts elicited activity in left middle Temporal gyrus, posterior/ angular gyrus, and left frontal superior medial gyrus. Spatial (vs Social and Political)

concepts elicited activity in left posterior inferior temporal gyrus. See Figure 9 below for the contrast activations (FWE corrected).

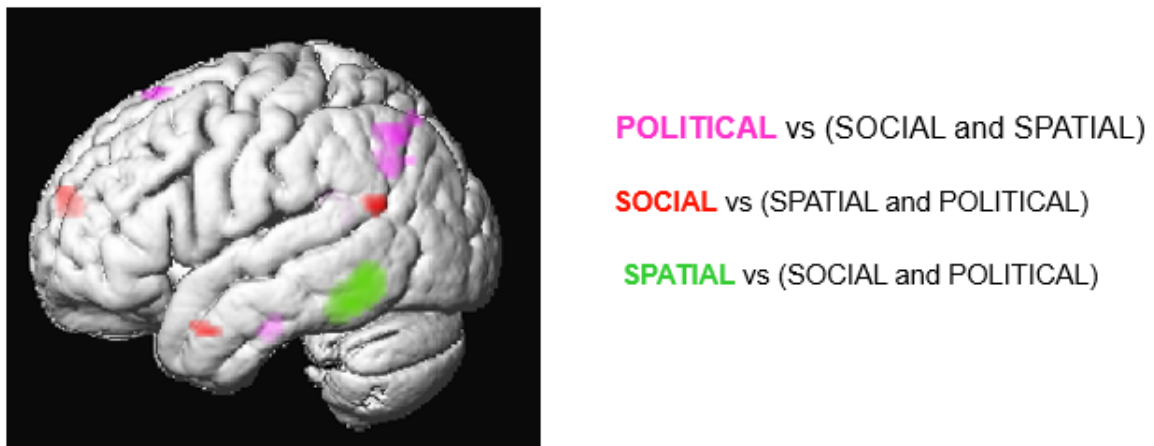


Fig.9 contrast activations

Effect of expertise. Concerning the effect of expertise, preliminary exploratory results were significant at an uncorrected p-value of 0.001 (see Figure 10). Social expertise negatively modulated the activity elicited by social concepts in the right caudate, superior frontal gyrus, and left precentral and lingual gyrus. Political expertise negatively modulated the activity elicited by political concepts in the right thalamus, insula, IFG, superior medial frontal and orbitofrontal cortices, superior temporal gyrus, precuneus, and occipital cortex.

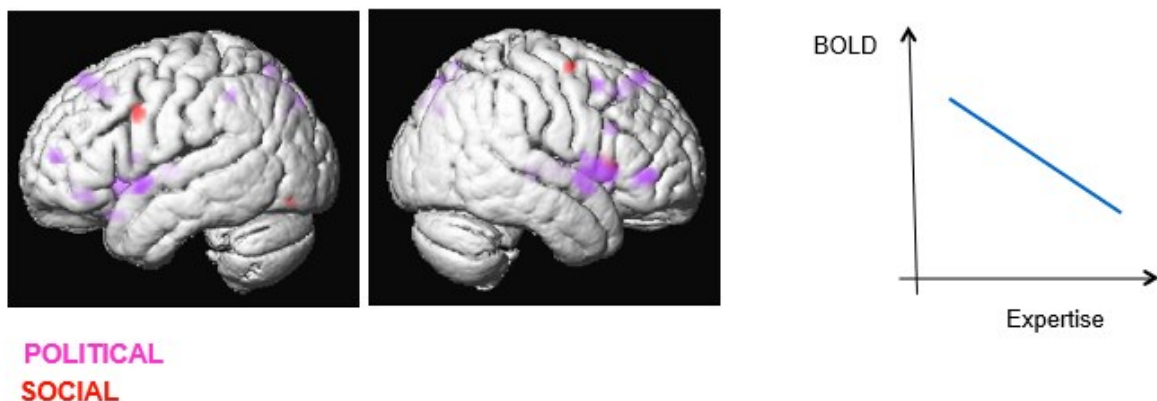


Fig.10 Expertise effect

4.0 Discussion

The aims of the broader project were to investigate whether domain-specific experience and abilities modulate the organization and neural correlates of abstract concepts. However, because the groups of professional experts did not reach an adequate sample size for the analyses, the present thesis focuses exclusively on the 24 healthy control participants. Within this sample, individual differences in social and political abilities, interest and experience were quantified through ad-hoc questionnaires, allowing us to investigate whether variability in these domain-specific characteristics was associated with differences in behavioral and neural measures. To this purpose, we reported preliminary analysis from 24 healthy control participants that underwent the fMRI paradigm and behavioral tasks, together with measures of expertise, personality, and socio-emotional functioning.

Social, political and spatial concepts.

Our results showed that social, political and spatial concepts are characterized by unique patterns of brain activations, as well as commonalities, particularly between social and political words.

Social words in our study involved words referring to social situations and to interactions between people. Imaging results revealed that these concepts showed preferential activations of left temporal and medial frontal regions, including the anterior middle temporal gyrus, posterior middle temporal gyrus/angular gyrus, and medial superior frontal gyrus. Overall, the areas belonging to this network have been previously reported in relation to social concepts and associated to social cognition processes. The involvement of anterior regions of MTL is in line with previous studies on abstract social concepts both in patients with neurodegenerative diseases as svPPA (Catricalà et al., 2021), as well as healthy subjects (Zahn et al., 2007; Catricalà et al., 2020; Conca et al., 2021b). Beyond their contribution to semantic representations, anterior MTL structures have also been implicated in social cognition tasks requiring the retrieval and integration of person-related knowledge and socially relevant information (Simmons et al., 2010; Spreng & Mar, 2012). Their involvement may reflect the need to access distributed conceptual information to construct coherent representations of abstract social concepts. Frontal regions, as the medial superior frontal gyrus, have been associated with the broad architecture of social

cognition and "Mentalizing network" (Carlson, 2013; Amodio & Frith, 2006), which subserves all the cognitive processes that are socially relevant (e.g. Theory of mind). Social concepts involve agents, relationships, and mental states, making this region particularly relevant in supporting the role of mentalizing network during social concept processing. The posterior middle temporal gyrus and angular gyrus are key components of the social cognition network. The posterior middle temporal gyrus and adjacent temporoparietal regions are consistently recruited during tasks requiring mental state attribution, perspective taking, and Theory of Mind (Saxe & Kanwisher, 2003; Frith & Frith, 2006; Schurz et al., 2014). Therefore, activation of these regions during social concept processing may reflect the construction of enriched and context-dependent representations that integrate semantic knowledge with socially relevant information (Davey et al., 2016).

Political concepts in our study involved words referring to the constitution, organization, and administration of the state and public life. fMRI results revealed that these concepts showed preferential activations of Left Posterior Cingulate Cortex, Left Anterior Inferior Temporal Gyrus, Left Angular Gyrus, Left Superior Frontal Gyrus and Left Thalamus. The involvement of the left posterior cingulate cortex is particularly noteworthy as this region is considered one of the principal hubs of the default mode network (Buckner et al., 2008; Raichle, 2015) and has consistently been associated with internally directed cognition, autobiographical memory, conceptual retrieval, and the construction of situation models (Leech & Sharp, 2014). Beyond episodic memory, the posterior cingulate cortex is recognized as contributing to semantic cognition by integrating information retrieved from distributed cortical systems into coherent conceptual representations (Binder & Desai, 2011). Political concepts often require access to broad conceptual knowledge as ideological beliefs, historical knowledge, cultural representations, and the complex relationships among social institutions, historical events, legal systems and people themselves, rather than the isolated semantic features. However, political concepts in the present study also carried a relevant social component (see Figure 3), as they involved words referring to social agents, collective values, and group relationships (e.g. *Alleanza*, *Comune*). Accordingly, their processing may partially recruit neural systems involved in social cognition, explaining the overlap between the networks supporting political and social concepts.

The engagement of the angular gyrus and the anterior temporal regions may reflect the integration of different social-related conceptual knowledge into coherent representations, allowing individuals to access socially relevant meanings that are highly dependent on contextual and relational information. Activation of frontal regions as the left superior frontal gyrus likely reflects the increased executive and reflective demands associated with political concepts. Dorsomedial and superior frontal regions have been implicated in cognitive control, abstract reasoning, metacognition, and the manipulation of internally represented information (Koechlin et al., 2003). The recruitment of superior frontal regions may therefore indicate greater reliance on executive processes that modulate semantic retrieval and support the flexible manipulation of complex abstract knowledge. However, since the behavioral task did not reveal significant differences between participants, the active areas may reflect a greater and more accurate lexical retrieval and control. Finally, the activation of the left thalamus suggests that subcortical structures also contribute to the processing of complex abstract concepts. Although traditionally viewed as a sensory relay, the thalamus is now recognized as an important component of distributed cognitive networks involved in memory, attention, executive control, and semantic processing through its extensive reciprocal connections with frontal and temporal cortices (Aggleton et al., 2010; Wolff & Vann, 2019). Considering this evidence, we could argue that the processing of political concepts may place greater cognitive demands, and the observed thalamic activation may reflect its contribution in the coordination of large-scale cortical networks supporting complex conceptual processing.

Spatial concepts were defined as words referring to the spatial domain as position, location, and/or direction in space. They revealed preferential activation of the left posterior inferior temporal gyrus. The posterior inferior temporal gyrus is part of the ventral visual processing stream (Martin, 2007; Peelen & Caramazza, 2012) and has been involved in the retrieval of visual information, such as shape, spatial configuration, or object-related properties (Chao et al., 1999; Martin, 2007). In this study, some concepts as *perimetro* and *estensione* are intrinsically linked to perceptual and visuospatial domains. Although the experimental stimuli were balanced across several variables, including concreteness and imaginability (see Figure 3), the specific involvement of the left pITG may be driven by the inherent visuospatial component linked to these concepts.

Summarizing, while social and political concepts preferentially recruited regions associated with social cognition and the integration of complex conceptual information, spatial concepts showed preferential activation of the left posterior inferior temporal gyrus, a region involved in visual and perceptual processing that may contribute to the representation of concepts with spatial and perceptual features. These findings suggest that the three categories may rely on partially distinct experiential and conceptual dimensions, in line with theories of grounded cognition (Barsalou, 2008).

How expertise modulates conceptual knowledge

With the purpose of accomplishing our second aim, we analyzed the behavioral performance, and the neural substrate associated with social and political expertise. Behavioral results indicated that expertise modulated only the dimensional ratings. Specifically, individuals with higher social experience/abilities assigned higher ratings to social concepts on the social dimension and lower ratings on non-relevant dimensions. Similarly, individuals with higher political experience/abilities assigned higher ratings to political concepts on the political dimension and lower ratings on non-relevant dimensions. These findings suggest that participants with greater expertise tended to assign higher ratings to words belonging to their domain of expertise on the relevant dimension, while assigning lower ratings on dimensions that were not relevant. No differences emerged concerning the other measures, indicating that expertise in our sample did not affect overall personality, socio-emotional traits, or the performance in the familiarity judgement task, but it's strictly related to the specific area of interest.

While behavioral findings provide important context for interpreting participants' expertise, the neuroimaging results offer a description of the underlying neural mechanisms as well as their expertise-mediated modulation.

The observed effects indicate that expertise is associated with reduced neural activity in several cortical and subcortical regions involved in the processing of such knowledge. Specifically, greater social expertise was associated with reduced activation in the right caudate, superior frontal gyrus, and the left precentral and lingual gyri during the processing of social concepts, while greater political expertise was associated with reduced activation in a widespread network including the right thalamus, insula, inferior frontal gyrus, superior medial frontal cortex, orbitofrontal

cortex, superior temporal gyrus, precuneus, and occipital cortex. Given the previously discussed contrast activations, these findings are consistent with the notion of neural efficiency (Neubauer & Fink, 2009), which posits that expertise modulates the efficiency with which abstract conceptual knowledge is processed, such that experts require fewer neural resources to access and elaborate conceptual representations. In particular, the negative relationship between social expertise and activity in the superior frontal gyrus is consistent with the results discussed so far, as well as reduced activation in the right caudate may similarly reflect increased processing efficiency: neuroimaging studies have shown that the caudate participates in the selection among competing cognitive representations to adapt behavior according to contextual demands (O'Doherty, 2004), therefore we might assume that as expertise increases there is a reduced need for such selection mechanisms. Similarly, decreased activity in the lingual gyrus with increasing expertise may reflect reduced reliance on visual imagery or orthographic processing during conceptual processing. The lingual gyrus has been associated with visual imagery, visual memory, and semantic processing of visually evocative information (Mechelli et al., 2004). A similar pattern emerged for political expertise, although involving a substantially broader neural network. Reduced activation of the inferior frontal gyrus, superior medial frontal cortex and orbitofrontal cortex is consistent with the results discussed so far, further supporting this interpretation. The anterior insula is a key component of the salience network and has been implicated in detecting cognitively relevant information and coordinating interactions between executive and default mode systems (Menon & Uddin, 2010) and its activation in less-expert individuals may reflect increased attentional resources and cognitive effort required to process political concepts whose meanings are less familiar or less readily available.

Within contemporary frameworks of abstract concepts, these results further suggest that experience and expertise strengthen the distributed semantic representations underlying domain-specific knowledge, and the neural representation of abstract concepts are not only multidimensional but also dynamic, shaped by individual experience and stored knowledge, in line with the most robust and recent accounts of conceptual representation (Borghi et al., 2019; Villani et al., 2022).

5.0 Conclusions, limitations and future directions

The relatively small sample size represents the principal limitation of the present work. Although significant effects were observed, both behavioral and neural, future studies should include larger samples to better clarify the generalizability of the present findings.

Another limitation concerns participants. They were mainly recruited through word-of-mouth between and within university networks (Professors, students, PhDs, researchers), resulting in a relatively homogeneous sample in terms of age, education and cultural background, which may have also limited the generalizability of obtained results.

Furthermore, recruitment of professional experts is still ongoing (July 2026), and it has proven to be considerably more challenging than recruiting control participants. This led the present thesis on focusing exclusively on control participants, without professional expert groups (politicians and social media influencers) originally recruited for the broader project and without parents of ASD children, which would theoretically represent, respectively, the top-end and the bottom-end of the social expertise continuum. This limited the investigation of expertise to the control group, that was computed through individual differences obtained from the ad-hoc questionnaires (see 2.2.1).

Future research should undertake a more fine-grained investigation into specific stimulus dimensions. For social concepts, future studies could control for and isolate additional affective attributes, such as emotional valence and arousal. Because social concepts inherently encompass multiple dimensions, it remains to be clarified whether individual features or specific feature combinations drive the BOLD signal and modulate neural activation patterns within the cortical regions involved in their elaboration.

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