Both Symbolic and Embodied Representations Contribute to Spatial Language Processing; Evidence from Younger and Older Adults

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Abstract

Building on earlier neuropsychological work, we adopted a novel individual differences approach to examine the relationship between *spatial language* and a wide range of both verbal and nonverbal abilities. Three new measures were developed for the assessment of spatial language processing: spatial naming, spatial verbal memory, and verbal comprehension in spatial perspective taking. Results from a sample of young adults revealed significant correlations between performance on the spatial language tasks and performance on both the analogous (non-spatial) verbal measures as well as on the (non-verbal) visual-spatial measures. Visual-spatial abilities, however, were more predictive of spatial language processing than verbal abilities. Furthermore, results from a sample of older adults revealed impairments in visual-spatial tasks and on spatial verbal memory. The results support dual process accounts of meaning, and provide further evidence of the close connection between the language of space and non-linguistic visual-spatial cognition.

Keywords: Spatial Language; Embodied Cognition; Visual-Spatial Abilities; Ageing

Introduction

Our ability to use words to refer to physical entities and relationships (e.g., spatial relations) is vital for managing everyday activities and constitutes a core part of human linguistic communication. The nature of the relationship between language and the physical world has been a major subject in cognitive science, leading to two approaches; distributional models suggest that the meaning of a word is based on how it is used within a language (Griffiths, Steyvers, & Tenenbaum, 2007) whereas embodied approaches propose that semantic representation is acquired through experiencing and acting in the physical world (Barsalou, 1999; Zwaan, 2004).

It has been suggested that experiential data are linked to concrete terms from the physical world (e.g., *tree*), whereas distributional models better describe rather abstract representations (e.g., *freedom*; Andrews, Vigliocco, & Vinson, 2009). Spatial language, however, forms a natural linkage between linguistic and perceptual representations. Previous research has revealed a strong connection between linguistic and non-linguistic representations of space, across behavioural (e.g., Coventry, Griffiths, & Hamilton, 2014; Hayward & Tarr, 1995), cross-linguistic (e.g., Munnich, Landau, & Dosher, 2001), and neuroimaging (e.g., Noordzij, Neggers, Ramsey, & Postma, 2008) investigations. On the other hand, evidence from studies with atypical populations suggests that these two types of representation are more distantly related. For example, there have been reports of relatively preserved aspects of spatial language production in descriptions of motion events in children with William's syndrome, a neurodevelopmental condition characterized by deficits in spatial cognition (Landau & Zukowski, 2011). Furthermore, lesion studies have reported a double dissociation between spatial language and spatial abilities (Tranel & Kemmerer, 2004), suggesting that the meanings of spatial words are language-specific semantic structures which are to some extent independent from the nonlinguistic perceptual representation (Kemmerer & Tranel, 2000).

Data exists to support both symbolic and grounded theories of meaning, however, seldom have these competing approaches been considered simultaneously within the same paradigm. Some researchers are currently adopting an integrative view according to which language processing involves both symbolic and embodied representations (Andrews et al., 2009). Connell and Lynott (2010) propose an embodied conceptual combination model in which a representation of knowledge integrates both linguistic distributional information and situated simulation. Evidence from neuroscience also supports these hybrid accounts. Accumulated findings yield shared neuronal circuits between language and sensorimotor brain systems during semantic learning of action- or perception-related words, but common neuronal grounds have also been identified during the processing of abstract words (Pulvermüller, 2012).

In this study we adopt a novel approach to investigate whether *spatial language* (i.e., the use of words describing spatial relations) is related to verbal vs nonverbal visuospatial abilities or to both of them. This approach may help us identify the relative extent to which each account (symbolic vs grounded) contributes to spatial language production, comprehension, and memory. Additionally, taking into account the well-described age-related changes in visuospatial cognition (Klencklen, Després, & Dufour, 2012), we further examine whether spatial language abilities change in ageing. A simultaneous change in both spatial language and non-verbal visuospatial abilities in older adults would be suggestive of a close relation between these two types of cognition.

Methods

Participants

Thirty-four healthy young adults (18-28 years old; 18 female) were recruited from the University of East Anglia community, and 34 healthy older adults (61-81 years old; 18 female) were recruited from the local community. Participants gave informed consent and received course credits or monetary compensation for participation. Participants who were non-English speakers and had a neurological and/or psychiatric diagnosis or a learning disability were excluded from the study. Testing took place on an individual basis in one session lasting approximately 2 hours (including breaks when needed).

Measures

All participants were tested on an extended battery of well-established neuropsychological tests assessing different aspects of cognition. For the assessment of verbal abilities the following tests were administered: the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 2001) was used as a measure of confrontation naming; the Logical Memory subscale (immediate and delayed recall) from the Wechsler Memory Scale (Fourth Edition UK; Wechsler, 2010) was used to assess verbal memory; verbal intelligence was assessed with the Mill Hill Vocabulary Test (Raven, 1981). For the assessment of visual-spatial abilities the following tests were used: the Hooper Visual Organization Test (Hooper, 1983); the Mental Rotation Task (Shepard & Metzler, 1971); the Rey-Osterrieth Complex Figure Test (immediate and delayed recall; Osterrieth, 1944) was used to assess visuospatial memory; nonlinguistic visuospatial intelligence was assessed with the Matrix Reasoning subscale from the Wechsler Adult Intelligence Scale (Fourth Edition UK; Wechsler, 2010). For a detailed description of the measures see Lezak, Howieson, Bigler, & Tranel (2012). In order to assess spatial language processing, we developed three new tasks described below.

Spatial Naming Test. We developed the Spatial Naming Test in order to assess confrontational naming abilities specifically for static and dynamic spatial relations, as an analog of the Boston Naming Test (Kaplan et al., 2001). The stimuli consisted of thirty line drawn pictures of simple geometrical shapes (Figure 1), and in particular a red ball as the located object and an open cube as the reference object (or more cubes when necessary, as in cases of *between*, *in the middle*, *among*). Black balls were also depicted in order to create a set of different spatial relationships in an attempt to elicit the most suitable response for the target spatial relation in a way that is distinguishable from the non-target relations. Geometrical shapes were deliberately chosen instead of everyday concrete objects in order to avoid biased responses based on typical descriptions of commonly encountered spatial relationships (e.g., 'The cat is on the mat' or 'The apple is in the bowl'). Each picture was intended to correspond to a single English spatial preposition, although in some cases more than one preposition was appropriate (e.g., *under*, *underneath*, *below*). Spatial prepositions were divided into two main categories – locative/relational (15 items; see Figure 1, samples A and B) and directional (15 items; see Figure 1, samples C and D). Locative/relational prepositions are used for static spatial relationships that describe the location of one object in relation to another, whereas directional prepositions are used in dynamic spatial relationships to describe a change of position (Coventry & Garrod, 2004).

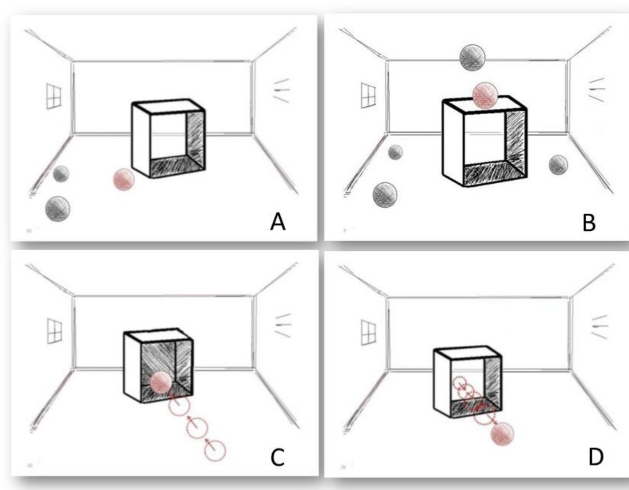

Figure 1: Stimuli samples of the Spatial Naming Test (A: *near*; B: *on*; C; *into*; D: *through*).

Participants were given one locative/relational example and one directional, based on a viewer-centred frame of reference. Next, they were asked to similarly name as accurately as possible the location of the red ball in relation to the cube in a way that it was differentiated from the black balls' location. Optimal responses were scored one point, whereas a less accurate but not incorrect response was scored as a half point.

Spatial Verbal Memory. Two novel stories were developed, containing spatial information in an egocentric (e.g., *When he saw the Blue Lake in front of him, he turned left)* or an allocentric (e.g., *The Gardens are nearby, located to the left of the City Hall*) frame of reference, respectively. Each story contained 25 semantic units, similarly to the Logical Memory subscale of the Wechsler Memory Scale (Wechsler, 2010), 10 of which provided spatial information. Participants were asked to repeat each story immediately and after a 30 min delay.

Verbal Comprehension in Spatial Perspective Taking. The VCSPT task was developed to assess verbal comprehension under the absolute (environment-centred) frame of reference (also see Levinson, 2003). The apparatus consisted of a central circular board, on which the reference object (a glass) was placed, surrounded by a rotating board on which the located object (a ball) was placed (Figure 2). An arrow pointing to the north was placed ~ 5 m away at an angle of 45 degrees to the right of the participant's position (Figure 2). Participants were asked to judge as true or false 16 different statements of spatial relations between the located and the reference object (e.g., *The red ball is SW of the glass*).

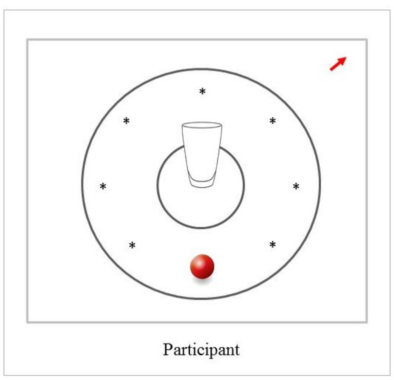

Figure 2: Schematic representation of the absolute condition in the Verbal Comprehension in Spatial Perspective Taking task

Results

Correlations among all measures (data from younger adults, aged 18-28) are presented in Table 1. All spatial language measures were strongly correlated with nonverbal intelligence ($p < .05$) but not with verbal intelligence ($p > .05$). Moreover, spatial verbal memory positively correlated with visual-spatial memory ($p < .05$; and with mental rotation in the egocentric condition at $p < .05$), while spatial verbal naming was positively correlated with all visual-spatial measures ($p < .05$). However, positive correlations were also revealed between each spatial language measure and their analogous verbal measure. Spatial naming was significantly correlated with Boston naming ($p < .05$), and both egocentric and allocentric verbal memory with verbal memory ($p < .01$ and $p < .05$, respectively). Finally, verbal comprehension in the absolute frame of reference was related only to non-verbal intelligence and the other spatial language measures ($p < .05$), but not to any verbal abilities ($p > .05$).

Further analyses took place in order to investigate whether performance in verbal vs visuospatial measures could predict performance in spatial language measures. All verbal and non-verbal measures were submitted to an exploratory factor analysis with principal axis factoring as the extraction method with initial eigenvalues greater than 1 and oblimin rotation with Kaiser Normalization. Pattern matrix loadings for the two-factor solution are presented in Table 2. As expected, all language measures loaded strongly onto Factor 1, whereas all non-verbal measures loaded onto Factor 2. Consequently, the first factor was interpreted as 'verbal abilities' and the second one as 'visual-spatial abilities', and both factors were extracted as two separate variables.

Next, we applied multiple linear regression analysis using Factor 1 (verbal abilities) and Factor 2 (visual-spatial abilities) as predictors for our dependent variables (i.e., performance on each spatial language task). According to the results, the visuospatial abilities factor predicted performance of all novel spatial language measures ($p < .05$), however, the verbal abilities factor alone did not ($p > .05$). Table 3 presents the unstandardized and standardized beta coefficient values along with their standard error values. However, the combined model, including both predictor variables, was significant for spatial language measures, and more particularly for spatial naming [$F(2, 31) = 9.586$, $p < .001$, $R^2 = .382$], egocentric [$F(2, 31) = 8.385$, $p < .001$, $R^2 = .351$] and allocentric spatial verbal memory [$F(2, 31) = 3.524$, $p < .05$, $R^2 = .185$], as well as for language comprehension in the absolute frame of reference [$F(2, 31) = 3.304$, $p < .05$, $R^2 = .176$]. Hence, the verbal measures did not stand on their own but according to the combined two-factor model they are still contributing to spatial language processing.

Furthermore, we applied one-way analysis of variance, with age as the between-subjects factor, in order to examine possible differences between young and older adults in spatial language processing, as well as verbal and visual-spatial abilities. Older adults performed significantly worse in all visual-spatial measures compared to younger adults. More specifically, their performance was poorer in visual-spatial reasoning [$F(1, 66) = 8.322$, $p < .005$] and memory [delayed recall; $F(1, 66) = p < .05$], mental rotation [F(1,

66) = 8.085, $p < .01$], and visual organization [$F(1, 66) = 4.151$, $p < .05$]. On the other hand, older adults outperformed their younger counterparts in verbal intelligence [$F(1, 66) = 26.753$, $p < .001$], as well as in confrontation naming [$F(1, 66) = 4.934$, $p < .05$], while no significant differences were found between the groups in verbal memory ($p > .05$). Across spatial language measures, significant differences between the two groups were revealed in the delayed recall condition of both egocentric [$F(1, 66) = 6.473$, $p < .05$] and allocentric [$F(1, 66) = 4.301$, $p < .05$] spatial verbal memory tasks, with older adults performing worse in both conditions. Older adults recalled significantly less spatial information in both egocentric [$F(1, 66) = 7.782$, $p < .01$] and allocentric [$F(1, 66) = 12.277$, $p < .001$] subscales. Performance of both groups in all spatial language measures is presented in Figure 3.

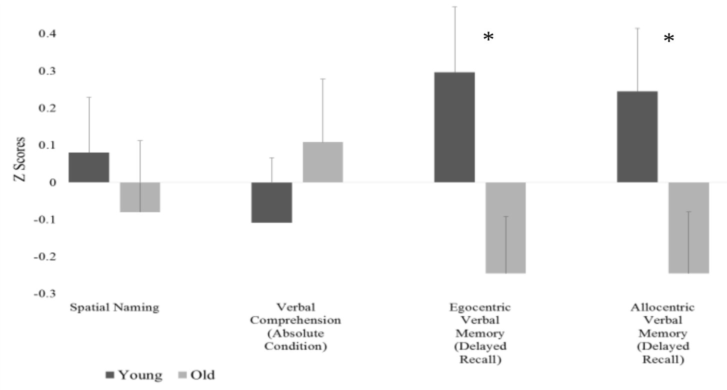

Figure 3: Mean values (±SEM) of performance of young and older adult groups on spatial language measures. Older adults performed worse in both egocentric and allocentric spatial verbal memory (* $p < .01$).

Table 1: Correlation matrix for all variables.[1]

	Egocentric Verbal Memory	Allocentric Verbal Memory	VS Memory	Spatial Naming	Boston Naming	Absolute Perspective	Visual Organization	Mental Rotation	VS IQ	Verbal IQ
Verbal Memory	**.41***	**.36***	.3	.2	**.46****	.02	.23	.08	.26	**.4***
Egocentric Verbal Memory		**.43***	**.42***	.24	.22	.2	.31	**.38***	**.47****	.12
Allocentric Verbal Memory			**.45****	.12	.3	.17	.11	.05	**.4***	.12
VS Memory				**.36***	.28	**.36***	.23	.29	**.55****	.10
Spatial Naming					**.38***	**.44****	**.56****	**.39***	**.39***	.04
Boston Naming						-.13	.04	.17	-.01	**.53****
Absolute Perspective							.22	.21	**.44****	-.24
Visual Organization								**.49****	**.35***	-.15
Mental Rotation									**.56****	-.06
VS IQ										.013

Table 3: Multiple linear regression analysis predicting performance in all spatial language measures[3]

	Spatial Naming			Egocentric Verbal Memory			Allocentric Verbal Memory			Comprehension in Absolute condition		
Predictors	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Visual-spatial abilities	1.15	.287	**.57****	4.99	1.47	**.49****	3.55	1.47	**.39***	1.66	.68	**.4***
Verbal abilities	.343	.276	.17	2.64	1.42	.27	1.22	1.53	.13	-.19	.66	-.19

[1] Significant correlations are in bold; * $p < .05$, ** $p < .01$ (young adults sample).
[3] Significant predictions are in bold; *$p < .05$, **$p < .01$ (young adults sample, $N = 34$).

Table 2: Factor loading from exploratory analysis after oblimin rotation.[2]

Measure	Factor 1	Factor 2
Visual-Spatial IQ	.006	**.662**
Visual-Spatial Memory	.321	**.657**
Mental Rotation	-.002	**.605**
Visual Organization	-.108	**.678**
Verbal IQ	**.746**	-.264
Logical Memory	**.521**	.115
Confrontation Naming	**.744**	-.016

Discussion

In the present study, we applied a novel approach using an extended battery of both verbal and visual-spatial measures within the same group of participants in order to investigate their relation with spatial language production and comprehension. More specifically, we developed three new measures assessing 1) picture naming of static and dynamic spatial relations, 2) verbal memory of spatial information presented in an egocentric or an allocentric perspective, and 3) verbal comprehension in spatial perspective taking (absolute frame of reference).

Our results revealed strong correlations between the novel spatial language measures and both verbal and non-verbal visual-spatial abilities. However, visual-spatial abilities were found to be consistently more predictive of spatial language processing than verbal measures. The 'quasi-neuropsychological' method adopted reveals simultaneously the relative loadings of visuospatial and verbal components on different aspects of spatial language processing for the first time. Similarly, previous investigations of dual task paradigms reported that both verbal and visuospatial components of working memory are involved in the memory of descriptions that contain spatial information (Brunyé & Taylor, 2007; De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005).

Furthermore, a comparison between a group of younger and a group of older adults yielded significant differences in verbal memory of spatial information presented either in an egocentric or an allocentric frame of reference; in both cases older adults retained less spatial information after a delayed recall. This novel finding is suggestive of significant alterations in aspects of verbal processing of spatial information across adulthood. Group comparisons revealed that young adults performed better than older adults in visual-spatial measures, while on the contrary, older adults outperformed younger adults in linguistic measures. These findings are consistent with previous reports of a decline in spatial cognition in ageing (for a review, see Klencklen, Després, & Dufour, 2012) while linguistic processing (particularly semantic and word knowledge) remains relatively intact (Burke & Shafto, 2008). Taking into account the age differences in visual-spatial cognition when considering the present finding of age-related differences in spatial verbal memory suggests that (non-verbal) grounded representations are indeed critical in spatial language processing. However, both groups of older and younger adults performed equally on tasks of spatial naming and verbal comprehension in perspective taking. This finding further supports the idea that linguistic (symbolic) and non-linguistic (embodied / grounded) representations of space map onto each other, at least to some extent, and that both types of representation contribute to spatial language processing.

Recent neuroimaging investigations have demonstrated that spatial language (and spatial prepositions in particular) is mainly supported by frontal and parietotemporal areas of the left hemisphere whereas the right hemisphere has a key role in nonverbal schematic representation of space (Amorapanth et al., 2012; Göksun, Lehet, Malykhina, & Chatterjee, 2013). Despite differences in the neural and mental organization of linguistic and nonlinguistic representations of space, however, these two domains seem to interact (Chatterjee, 2001), and our results provide further evidence for this close relationship. Processing of locative prepositions has been associated with increased activation in left inferior parietal areas, independent of the context (visual vs verbal) in which the prepositions are presented, suggesting a flexible representation of space in both linguistic and nonlinguistic visuo-spatial modalities (Noordzij, Neggers, Ramsey, & Postma, 2008).

Despite the fact that symbolic and embodied approaches of meaning have been studied independently of each other, with evidence typically being separately presented for each theoretical line, more recent views propose an integration of the two approaches (Andrews et al., 2009; Lynott & Connell, 2010). Our study provides experimental evidence to further support the idea that effective processing of lexical constructions, and more specifically of words referring to spatial relations, require both symbolic and grounded representations. However, our findings suggest a greater loading of spatial language processing onto visual-spatial cognition. Additional investigations that adopt this novel approach and methodology are required in order to draw stronger conclusions. Furthermore, cross-sectional studies, sampling across adult lifespan, may shed light on the rate of age-related changes in spatial language abilities and provide more information regarding the role that verbal and non-linguistic visual-spatial abilities might have on this process.

[2] Significant loading factors are in bold.

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