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The relation between working memory and language comprehension in signers and speakers

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ABSTRACT

This study investigated the relation between linguistic and spatial working memory (WM) resources and language comprehension for signed compared to spoken language. Sign languages are both linguistic and visual-spatial, and therefore provide a unique window on modality-specific versus modality-independent contributions of WM resources to language processing. Deaf users of American Sign Language (ASL), hearing monolingual English speakers, and hearing ASL-English bilinguals completed several spatial and linguistic serial recall tasks. Additionally, their comprehension of spatial and non-spatial information in ASL and spoken English narratives was assessed. Results from the linguistic serial recall tasks revealed that the often reported advantage for speakers on linguistic short-term memory tasks does not extend to complex WM tasks with a serial recall component. For English, linguistic WM predicted retention of non-spatial information, and both linguistic and spatial WM predicted retention of spatial information. For ASL, spatial WM predicted retention of spatial (but not non-spatial) information, and linguistic WM did not predict retention of either spatial or non-spatial information. Overall, our findings argue against strong assumptions of independent domain-specific subsystems for the storage and processing of linguistic and spatial information and furthermore suggest a less important role for serial encoding in signed than spoken language comprehension.

1. Introduction

Language comprehension involves actively accessing, maintaining, and processing linguistic information. The impact of linguistic working memory (WM) capacity on spoken language comprehension has been well documented. For instance, WM measures that assess both processing and storage resources (e.g., reading and listening span tasks) have been found to be good predictors of narrative and sentence comprehension abilities (Caplan & Waters, 1999; Daneman & Carpenter, 1980; Daneman & Hannon, 2007; Daneman & Merikle, 1996; King & Just, 1991; Waters & Caplan, 1996). The ability to temporarily store information for further processing is limited in capacity (e.g. Cowan, 2001), and an important theoretical question concerns the domain-specificity of these limited resources (e.g., Baddeley, 2012; Cowan, 2005; Logie, 2011). In particular, there has been a long-standing debate about whether WM capacity is served by separate subsystems for linguistic and visuospatial processing (each with its own limited resource capacity) or by a single, central capacity-limited system (e.g., Barrouillet, Bernardin, & Camos, 2004; Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002; Fougnie, Zughni, Godwin, & Marois, 2015; Ricker, Cowan, & Morey, 2010; Saults & Cowan, 2007; Vergauwe, Barrouillet, & Camos, 2010). A consensus is now emerging that there are likely both domain-general capacity limits and domain-specific resource limitations on WM capacity (for discussion, see Cowan, Saults, & Blume, 2014; Morey, Morey, Van der Reijden, & Holweg, 2013).

An important part of the evidence in favor of the multiple-component approach to WM comes from studies that investigated dissociations of WM resources used to process linguistic and spatial information (e.g., Friedman & Miyake, 2000; Handley, Capon, Copp, & Harper, 2002; Shah & Miyake, 1996). For example, Shah and Miyake (1996), using a spatial span task that taxed both processing and storage components of spatial WM, found that spatial span and reading span did not correlate significantly and that reading span, but not spatial span, was correlated with language comprehension measures. They concluded that there are two separate pools of domain-specific

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resources that support the processing and maintenance of spatial and linguistic information. This dissociation between the processing of linguistic and spatial information is also emphasized in the dominant model of working memory initially proposed by Baddeley and Hitch (1974). This model includes two separate subsystems for the storage and processing of linguistic and spatial information, the phonological loop and visuospatial sketchpad (Baddeley & Logie, 1999; Baddeley, 1986, 2007; Logie, 1995; but see Barrouillet, Vergauwe, Bernardin, Portrat, and Camos (2007), Cowan (2005), and Oberauer (2009) for alternative models without an explicit separation between modality-specific memory representations).

Although general language processing (spoken or written) does not seem to rely on spatial WM resources, there is some evidence for an association between spatial WM mechanisms and the comprehension of spatial language, specifically. For example, Pazzaglia and colleagues investigated how reading comprehension of spatial and non-spatial texts were affected by concurrent articulatory or spatial tasks (De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Pazzaglia & Cornoldi, 1999; Pazzaglia, De Beni, & Meneghetti, 2007). They found that verbal suppression negatively impacted both spatial and non-spatial text comprehension, whereas spatial suppression selectively impacted spatial text comprehension. Furthermore, Meneghetti, Gyselinck, Pazzaglia, and De Beni (2009) showed that participants with high mental rotation scores were better able to preserve good spatial text comprehension during a spatial concurrent task compared to participants with low mental rotation scores (also see Meneghetti, De Beni, Pazzaglia, & Gyselinck, 2011).

The study of the relationship between WM systems for linguistic and spatial information predominantly comes from spoken language research. Given that sign languages are both linguistic and visual-spatial, they provide a unique avenue for investigation of modality-specific vs. modality-independent characterizations of working memory resources. Currently, there is evidence for strong similarities in the architecture of the WM system for sign and spoken languages, including a phonological loop for the storage and rehearsal of signs (Wilson & Emmorey, 1997, 1998, 2003). Furthermore, neuroimaging studies have shown largely overlapping neural systems for WM processes for sign and speech (Bavelier, Newman, et al., 2008; Buchsbaum et al., 2005; Pa, Wilson, Pickell, Bellugi, & Hickok, 2008; Rönnberg, Rudner, & Ingvar, 2004; Rudner, Fransson, Ingvar, Nyberg, & Rönnberg, 2007; for discussion, see Rudner, Andin, & Rönnberg, 2009).

On the other hand, there is also evidence for modality-specificity with respect to serial order processing mechanisms and differential reliance on serial order information in WM tasks for spoken vs. signed (for discussion, see Bavelier, Newman, et al., 2008; Hirshorn, Fernandez, & Bavelier, 2012; Rudner, Karlsson, Gunnarsson, & Rönnberg, 2013). Many studies have reported larger spans in the spoken than the signed modality for forward serial recall tasks, including digit, letter, and word span tasks (e.g. Bavelier, Newport, Hall, Supalla, & Boutla, 2006, 2008; Boutla, Supalla, Newport, & Bavelier, 2004; Geraci, Gozzi, Papagno, & Cecchetto, 2008; Hall & Bavelier, 2011; Wilson, Bettger, Niculae, & Klima, 1997; but see also Andin et al., 2013; Wilson & Emmorey, 2006a, 2006b). Importantly, modality differences are typically not found in backwards serial recall tasks or in tasks with reduced temporal organization demands, such as free recall (e.g., Bavelier, Newport et al., 2008; Boutla et al., 2004; Rudner, Davidsson, & Rönnberg, 2010; Rudner & Rönnberg, 2008a). Moreover, some studies have found that signers outperformed speakers on spatial serial recall tasks, such as the Corsi block test (e.g., Geraci et al., 2008; Lauro, Crespi, Papagno, & Cecchetto, 2014; Wilson et al., 1997; but see Logan, Mayberry, & Fletcher, 1996; Marschark et al., 2015).

The purpose of the current study was to investigate the relation between linguistic and spatial working memory resources and language comprehension for signed compared to spoken language. To this end, we administered several types of spatial and linguistic serial recall tasks commonly used in spoken language research to a group of deaf users of American Sign Language (ASL), a group of hearing monolingual English speakers, and a third group of hearing ASL-English bilinguals who participated in both the ASL and spoken English tasks. The tasks included both ‘short-term memory’ tasks (tapping the passive storage of information) and ‘complex working memory’ tasks (requiring the manipulation or transformation of information stored in memory). Specifically, linguistic and spatial short-term memory was assessed with a letter span task (Boutla et al., 2004; Wilson & Emmorey, 1997) and the Corsi block test (Corsi, 1972; Milner, 1971), respectively. Linguistic and spatial working memory were assessed with a listening/sign span task (Daneman & Carpenter, 1980; Turner & Engle, 1989; Wang & Napier, 2013) and a spatial span task (Shah & Miyake, 1996), respectively.

The letter span and language span tasks share a forward serial recall component, and therefore we predicted (in line with previous studies) that we would observe an advantage for spoken English on both span tasks compared to ASL. In contrast, based on previous research on visuospatial advantages in signers, we predicted an advantage for ASL signers (both hearing and deaf) compared to monolingual English speakers on the Corsi block test (Geraci et al., 2008; Lauro et al., 2014; Wilson et al., 1997) and also possibly the spatial span task, because this task involves mental rotation (see Emmorey, Klima, & Hickok, 1998; Emmorey, Kosslyn, & Bellugi, 1993; McKee, 1987).

We also assessed signed and spoken language comprehension using ASL and English narrative comprehension tasks that paralleled the reading comprehension task used by Daneman and Carpenter (1980). However, in contrast to Daneman and Carpenter (1980), the narratives were all descriptions of spatial layouts of environments (e.g., a college campus, a park, a furniture store, etc.). For ASL, such descriptions involve the use of signing space to indicate landmark locations, while for English these spatial scene descriptions involve the use of spatial prepositions. Following each narrative, participants were presented with comprehension questions that related either to spatial or non-spatial information in the narratives.

Given similarities in the basic architecture of WM and parallels in language processing for spoken language and sign language (for review, see Carreiras, 2010; Emmorey, 2007), we predicted that linguistic working memory would correlate with language comprehension ability for both ASL and English. However, because sign comprehension requires encoding visuospatial material into linguistic representations, we also hypothesized that sign language processing draws on resources that support spatial WM, particularly for spatial language comprehension. We note that Holmer, Heimann, and Rudner (2016) found no correlation between scores on a sign language comprehension test and spatial memory in deaf signing children, but their sign comprehension test did not specifically assess spatial language. It is also possible that spatial WM might be correlated with the comprehension of spatial language in both the signed and spoken modality (see Meneghetti et al., 2009). Either of these outcomes would challenge the idea that linguistic processing and visuospatial processing are two fundamentally distinct domains of human cognition. On the other hand, if spatial WM capacity is *not* correlated with sign language comprehension ability (nor with spoken language comprehension ability), this result would be consistent with models that propose domain-specific resources within linguistic working memory (e.g., Baddeley, 1986, 2007; Cocchini et al., 2002; Logie, 1995).

2. Method

2.1. Participants

Thirty-five deaf ASL signers (32 female, *M* age = 33.1 years, *SD* = 10.7) and 35 monolingual English speakers (17 female, *M* age = 22.5 years, *SD* = 3.8) participated in the study. In addition, a group of 19 hearing ASL-English bilinguals (12 female, *M* age = 32.0 years, *SD* = 9.2) also participated in the study. The monolingual