The Effects of Learning American Sign Language on College Students’ Spatial Cognition

by

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Abstract

Previous research has shown that knowing a signed language enhances visuospatial cognition in numerous ways. The present study examined how much experience with and/or fluency in American Sign Language is needed to enhance hearing college students’ spatial cognitive skills. In Study 1, beginning students of ASL ($n = 20$) and of new spoken languages ($n = 6$) were tested on a battery of spatial cognition tasks before and after one semester of language instruction. Few significant differences were found between or within these groups from pretest to posttest, indicating that more ASL fluency is needed for spatial benefit to appear. In Study 2, there were no significant differences on task performance between control participants ($n = 8$), beginning ASL participants ($n = 20$), and intermediate ASL participants ($n = 16$). However, correlations between spatial task performance and both self-report measures and ASL instructor-rated measures were pervasive, suggesting underlying relationships between ASL confidence/improvement/fluency and performance on various visual-spatial tasks. The results suggest that, while neither one nor three semesters is sufficient for significant differences in spatial cognition to be observed on a group level, individual-level correlations between increased proficiency in sign language and heightened spatial cognition are already apparent. After such a short period of time, it seems that time learning ASL is, on a broad scale, too coarse a measure of assessment, but individual attainment is more illuminating in terms of spatial cognitive enhancement early in the learning process.
Introduction

How do signed or spoken languages’ diverse treatments of space affect the spatial understanding of their users? One way of examining this question is to consider the differences in spatial cognitive abilities between individuals with spoken language and those with signed language. Because sign languages have a strong focus on space as a primary mode of communication and grammar within their structure, these languages provide a lens through which to investigate the relationship between visual-spatial language and spatial cognition.

Previous studies have shown that knowledge of American Sign Language (ASL) and other sign languages has immense cognitive benefits for deaf and hearing, native and nonnative signers. Particularly when learned from early childhood, signers begin developing motor and language skills at the same time or even before their peers learning spoken languages (Meier & Newport, 1990; Petitto, Holowka, Sergio, Levy, & Ostry, 2004). Because motor skills develop before spoken language, hearing infants who are taught gestures or signs are able to generate vocabulary several months before children typically form their first words (Bonvillian, Orlansky, & Novack, 1983; Goodwyn & Acredolo, 1993; Goodwyn, Acredolo & Brown, 2000), thereby increasing their overall linguistic ability and vocabulary size. When sign language instruction continues, these advantages grow and turn into other kinds of cognitive benefits later in childhood and adulthood. Further, studies suggest that the linguistic and morphological complexity of ASL knowledge varies based on the age of acquisition, where deaf adults who were native signers (from birth) outperformed early signers (who began ASL immersion in residential schools at age 4-6) who in
turn outperformed late signers, suggesting the importance of early learning for more complete attainment of the language (Morford & Carlson, 2011; Newport, 1990).

Additionally, there is some evidence that for both deaf signers and English-ASL bilinguals, ASL activates both the left and right hemispheres (Emmorey et al., 2002; Peperkamp & Mehler, 1999), suggesting that the representation of speech in native ASL users is a bilateral process. This is particularly true in terms of the encoding of spatial information and/or relationships, suggesting the importance of space in the processing and production of such language. These findings supplement other research that shows that both native and nonnative signers demonstrate various improvements in their perceptual, visual, and spatial abilities (Emmorey, Kosslyn, & Bellugi, 1993; Keehner & Gathercole, 2007), and motivate the question, how much experience with a sign language is needed for these cognitive benefits to appear? Because the majority of existing research has focused on either native signers or fluent nonnative signers, this question of experience is cause to wonder about the process and trajectory of deriving spatial benefit from ASL in earlier stages of second language learning.

**American Sign Language: A Spatial Language**

American Sign Language, among other sign languages, is often termed a “spatial language” due to the fact that all aspects of it—vocabulary, grammar, verb directionality, expressiveness, imagery—are constructed visually and spatially, rather than orally and aurally as in spoken languages. That is, spatial, rhetorical, communicative, and comparative relationships between people and objects are represented by visual constructions in physical space. To further explain the ways in
which sign language is constructed, it is necessary to break it down in terms of the phonological and morphological parameters of signs, which come together in a unique grammar to form the spatial language that is American Sign Language (Pyers, 2012).

**Handshape.** In American Sign Language, each word begins with a particular shape of the hand. Similar signs are often modified with handshapes to mean different but related things. For example, the sign for “group” is two open hands touching thumbs, moving in a circle, and touching pinkies. The sign for “class” has the same movement, to indicate a kind of group, but the hands are in a C handshape; for “team,” a T handshape; for “family” an F handshape. Further, a handshape with an extended pointer finger indicates a personal pronoun (i.e. “her”) while a flat hand indicates a possessive one (i.e. “hers”; Pyers, 2012). The ways in which handshapes influence meaning is an important spatial aspect of ASL.

**Location.** ASL uses physical space to generate meaning. Signs can occur above the head, near the waist, or out to either side of a signer. The locations of signs in space serve multiple purposes, and can change the meaning of words similar to the way that handshapes can. For example, male signs (i.e. father, uncle, boy) are expressed in the top half of the face while female signs (i.e. mother, aunt, girl,) are expressed in the bottom half. That is, for a gender-neutral sign like “cousin,” the location of the C handshape and movement that indicates “cousin” can be positioned by the top or bottom half of the face to indicate the gender of the cousin to whom the signer refers. Perhaps most importantly, the location of signs sets up the positions of objects in space. For example, when talking about two people, a signer might place
one person to the right side of his or her signing space, and the other person to the left side, and then describe the different people and/or their interactions by referring to those reference points. This is a common and fundamental aspect of the spatial grammar of ASL.

**Movement.** Movement is another crucial aspect of the spatial nature of ASL that helps to construct its unique grammar, particularly in terms of verbs. In English, one might say “I helped you” or “he gave her a gift.” In ASL, these pronouns are often omitted as the directionality of the movement of a verb sign indicates who is on either end of an interaction. In terms of the above examples, the sign for “help” would move from the signer’s body toward the person they are talking to, or the sign “give” would move between two people set up in the signing space (as per the location aspect discussed earlier). Additionally, movement indicates single pronoun verbs as well, where movement can signify an action, such as a person running or escaping, as well as speed, such as how slowly a line of people is moving or how fast a car was driving before it crashed into a tree. The speed at which a sign is produced can also change the meaning in more subtle ways, where a slower version of “day” can mean “all day” or an extended version of “past” can mean “a very long time ago.”

**Orientation.** Orientation, specifically palm orientation, also helps construct meaning in ASL. A palm facing in (towards the signer) or out (towards the observer) can mean the difference between talking about days of the week or fingerspelling, counting to four or saying that something costs four dollars. Further, palm orientation indicates directionality similar to the way that motion does; the direction a palm faces can indicate the direction that a person is facing or walking, or demonstrate the
orientation of an object. The positioning of the body is also crucial, as rotating/shifting body positions can reflect a conversation between two people through perspective taking.

**Non-manual markers.** Non-manual markers are more visual than spatial aspects of ASL. They primarily involve the use and movement of the face, head, and shoulders to help generate meaning. Facial expressions are a crucial element of ASL grammar—without a facial expression, the sign for “surprised” just means “awake,” and without a furrowed brow, a question becomes a statement. The expressiveness of the face produces a huge amount of meaning, and without it much can be misinterpreted or taken out of context. Other important non-manual markers include things like head tilts, shoulder shrugs, or mouth shapes, which help indicate expressiveness beyond the face. Head shaking is also an essential manual marker because often an affirmative sign needs to be accompanied by a headshake to make it negative. For example, instead of signing “I don’t understand” as “I-NOT-UNDERSTAND,” a signer would accompany the sign “understand” with a shaking head and a confused facial expression, where these expressive aspects make up the rest of the sentence’s morphemes in context when combined with the sign itself.

**Classifiers.** Classifiers are perhaps the most complex aspect of the spatial grammar of American Sign Language, as well as the most central. Classifiers are handshapes that are used for the express purpose of representing the locations and movements of objects in space. For example, when describing a room, in English one might use spatial language like “to the right of” or “behind” to explain how furniture is positioned, whereas in ASL the objects’ locations and orientations need to be
physically represented in space (Emmorey & Kosslyn, 1996; Emmorey et al., 1993). Classifiers allow for this representation, as a B handshape can illustrate the shape of a table, a C handshape the shape of a couch, an S handshape for a mug sitting on the table. Further, classifiers are used to signify people, animals, or objects in motion. There are different classifiers for a single person or animal, a group of people or animals, cars, planes, or any number of similar things, which can be placed in relation to one another in space and paired with direction and speed to demonstrate verb action. This is certainly one of the most spatial aspects of ASL, and one of the most commonly researched ones (Emmorey & Kosslyn, 1996; Emmorey et al., 1993).

All of these aspects combine together to form the unique visual-spatial language that is ASL. The combination of location, movement, handshapes, classifiers, orientation, and expressiveness quite literally forms pictures in space that describe moments in daily life. These elements can form “iconic” signs—signs that represent the shape of an object with handshape, the function of an object with movement, etc.—or can be less overt while still illustrating meaning (Pyers, 2012). Although gesture is an important part of spoken language (Kendon, 1986; McNeill, 1992), it does not serve the same crucial grammatical function that is present in ASL (Taub, Galvan, Piñar, & Mather, 2008). Does learning a language with such inherent spatial construction force the learner to pay more attention to visuospatial information, thereby resulting in an enhancement of visuospatial cognition?

**The Visuospatial Benefits of American Sign Language**

A great deal of research on the spatial nature of sign languages has found that signers perform significantly better on tasks that test visual and spatial aspects of
cognition than their non-signing deaf or hearing peers. These benefits are present across deaf and hearing signers, and exist within multiple areas of visual and spatial cognition, from facial recognition, visual perception, and spatial memory to image generation and mental rotation. These benefits stem from a variety of different aspects of the spatial grammar of American Sign Language.

Deaf signers performed better on the Benton Facial Recognition Task than hearing controls (Bellugi et al., 1990; Bettger, Emmorey, McCullough, & Bellugi, 1997; Emmorey et al., 1993). That is, they were better able to discriminate and match faces in different light levels and spatial orientations. This visual ability comes from the attentiveness to facial expressions that are essential to ASL; facial expressions and body orientations are extremely important to signing with proper grammar, understanding context, and representing meaning during conversation. Therefore, it makes sense that signers might have improvements in this area. Parasnis and colleagues (1996) concluded that this improvement comes exclusively from exposure to sign language, rather than from deafness itself, because when deaf and hearing nonsigners were compared, deaf nonsigners did not outperform hearing nonsigners.

Signers also demonstrate visual-spatial cognitive enhancements in terms of the extent to which they can detect and interpret moving light displays. When Chinese pseudo-characters were drawn with light in the air and participants were asked to trace the form of the character, Chinese deaf children (whose language was Chinese Sign Language) and American deaf adults (whose language was ASL) outperformed Chinese hearing children and American hearing adults (Klima et al., 1996). These findings indicate that visual field attentiveness in deaf signers results in a specific
perceptual improvement in the detection of visual-spatial stimuli. A further benefit for signers is an enhancement in peripheral vision, presumably as a compensatory mechanism for a lack of auditory input. When compared to hearing controls, congenitally deaf, signing adults were better at detecting movement in their peripheral visual fields (Neville & Lawson, 1987a). In a follow-up study, Neville and Lawson (1987b) found that hearing children of deaf adults (CODAs) whose first language was ASL had similar enhancements and activation as deaf signers.

Beyond visual cognition, researchers have also examined the effects of sign language on working memory. Both deaf and hearing signers performed better than nonsigners on visual-spatial memory matching games, where children had to remember objects and faces (Arnold & Mills, 2001; Arnold & Murray, 1998). Wilson and Emmorey (1997) suggest that a visuospatial “phonological loop” exists in signers, similar to the one that exists for speech, where this rehearsal-loop is used for verbal working memory. This study emphasizes that knowledge of this visual-spatial language supplements working memory in this modality in a way similar to auditory/vocal working memory in spoken languages.

Additionally, many researchers have assessed signers’ visuospatial working memory both linguistically and non-linguistically. Wilson and colleagues (1997) tested hearing and deaf children between ages 8 and 11 on several working memory tasks presented in different modalities. On a digit span task (performed in the child’s native language, e.g. spoken for hearing children, signed for deaf), hearing and deaf children performed similarly on forward recall, while deaf native signers outperformed hearing children on the backward recall task, suggesting a difference in
how order information is stored in these different languages. Additionally, deaf native signers outperformed hearing children on the Corsi Block task, which tests spatial memory by having participants tap sequences of blocks that match what was demonstrated to them by an experimenter. This suggests that the use of a certain modality increases working memory within that modality (that is, verbal forward recall for hearing children, spatial recall for deaf signers). Wilson et al. (1997) suggest that this enhancement might be the result of linguistic spatial representations being recruited for nonlinguistic purposes. The use of the Corsi task is a prevalent measure of nonlinguistic reasoning and spatial memory.

Signers also perform significantly better than nonsigners on image generation tasks. Emmorey and Kosslyn (1996) found that deaf signers generated mental images faster and used different areas of the brain when compared with hearing nonsigners, as a result of the ways in which spatial relations are processed and encoded in the right hemisphere instead of the left in spoken language. Further, in an examination of image generation, maintenance, and rotation, deaf and hearing signers both performed better than hearing nonsigners on both an image generation task, where participants were asked if an uppercase version of a presented lowercase letter would intersect with a presented probe (requiring participants to mentally draw the uppercase letter in the grid), and mental rotation task, where participants had to rapidly determine whether a rotated image was the same or a mirror image (Emmorey et al., 1993). This pattern of results may be due to the spatial linguistic requirements of the language, particularly the use of spatial memory and mental rotation needed for the use of classifiers.
Taking a closer look at mental rotation enhancement, a crucial part of interpreting sign language is understanding the way in which a signer’s description of the placement of objects in space relates to and can be different from what the viewer is directly seeing. That is, if a signer explains that the chair was to the right of the desk and that the window was to the left of the desk, the viewer must mentally represent the opposite orientation from what they are actually seeing. This process inherently requires mental rotation, and is essential to efficient communication and understanding in ASL. It follows, then that signers would be better at mental rotation, if only as a result of their increased exposure to this rotational process as compared to a nonsigner. Indeed, typically hearing adults often struggle with mental rotation (Emmorey, Klima, & Hickok, 1998; Emmorey et al., 1993), and many researchers have found evidence to support that signers have better mental rotation abilities than nonsigners.

In a seminal study on mental rotation in users of American Sign Language, Emmorey and colleagues (1998) found that deaf signers performed significantly better than hearing nonsigners on mental rotation tasks. In the first experiment, deaf signers were more accurate at correctly describing a room when it was initially explained from a rotated perspective than from a non-rotated one. In Experiment Two, although they performed more poorly when placing objects in a 180-degree rotated manner than a non-rotated one, deaf signers performed significantly better on this task than hearing nonsigners. Further, when the positions of the stimuli were signed instead of physically viewed, the rotation effect disappeared and signers performed better in the 180-degree mental rotation condition. These effects could be a
result of the fact that ASL signers, as opposed to signers of other languages such as NSL (Pyers & Senghas, 2007), are used to viewing descriptions of events from the narrator’s perspective and rotating their own point of view.

Talbot & Haude (1993) used two-dimensional and three-dimensional objects that were either rotated or reflected then rotated to gauge the extent to which knowing American Sign Language might improve performance on this Mental Rotation Test. They found that the more experienced group of signers performed better on both aspects of this test, indicating that the spatial and perspective-taking aspects of ASL encourage mental rotation ability. In another series of studies, Pyers and colleagues (2010) examined the spatial cognition and mental rotation abilities of varying cohorts of Nicaraguan signers. Experimenters conducted two tasks using a rectangular room with a red landmark wall: a disoriented search task, where participants searched for a hidden object in the room after being disoriented, and a rotated box task, where a model of the room was rotated before the search instead of physically disorienting the participant. They found that second cohort signers, who had higher levels of language than first cohort signers, performed better on both tasks. This suggests that having more robust spatially descriptive language, not simply using a language in the visuospatial modality, is necessary to the understanding of spatial relationships and the cognitive benefits of sign language. Further research has shown that age of acquisition strongly predicts mental rotation ability in both child and adult Nicaraguan signers, and that benefits are stronger when rotational tasks occur on a more familiar horizontal rather than vertical plane (Martin, Senghas, & Pyers, 2012). These findings demonstrate the importance of practical language experience for
spatial improvement, as well as evince the existence of a sensitive period for deriving cognitive benefit from sign language.

**ASL as a Second Language**

While they have not been studied as extensively as native signers, hearing individuals who learn a sign language as a second language (L2) also appear to experience similar, though perhaps not as robust, enhancements in various aspects of their language and spatial cognition abilities. Research suggests that the more experience with the language that signers have, the better their performance on certain tasks.

In general, second language learners, particularly those who begin learning additional languages during early childhood, experience linguistic benefits, such as increased phonological awareness and word recognition (Campbell & Sais, 1995; Yelland, Pollard, & Mercuri, 1993), as a result. Many researchers believe that the sensitive period of language learning extends to the learning of additional languages, where children within this period will learn the new language more effectively than older individuals learning new foreign languages for the first time (DeKeyser, 2000; Pinker, 1994; Johnson & Newport, 1989). Such benefits are even present after only marginal exposure to the new language, as first graders who received one hour of Italian instruction each week showed a significantly higher level of word awareness in reading acquisition than their monolingual counterparts after only six months (Yelland, Pollard, & Mercuri, 1993). An alternative to this absolute sensitive period theory suggests that second language proficiency declines steadily as age of initial exposure increases (Hakuta, Bialystok, & Wiley, 2003), which suggests that learning
new languages might be more effective in the high school and college years than later in adult life.

Sign language offers a particularly interesting insight into second language acquisition, as it requires learning not only a new language’s rules, but also an entirely new and different modality of communication. This fluency in both a spoken language and a sign language is termed bilingual bimodalism. Deaf adults who learned ASL as a second language later in childhood outperformed those who learned it as a first language at the same late age on a number of language tasks (Mayberry, 1993). Further, deaf signers who learn ASL at an early age have greater success learning spoken languages later in life (Mayberry, 2006). These findings suggest a nuance to existing second language acquisition hypotheses in terms of how early L1 proficiency, whether in a visual-spatial or oral-aural modality, is clearly needed for effective L2 acquisition.

When compared to both native and nonnative deaf signers, hearing ASL signers who acquired the language later in life ($M = 21.83$ years) performed better than deaf signers who also acquired the language later in life on sign recognition tasks (Morford & Carlson, 2011), indicating that similar fluency in ASL can be achieved even when it is acquired in adulthood. This success in sign recognition could be the result of hearing learners’ reliance on handshape and iconicity when initially learning ASL (Mayberry, 2006), which can either turn into successful fluency with practice or, alternatively, can lead to a less-refined sign language known as pidgin when classifier constructions are not emphasized in curriculum. Although hearing learners of ASL
can identify signs well in this way, their sign recognition ability does not necessarily reflect their fluency with the spatial/grammatical aspects of the language.

Additionally, neuroscience studies have suggested that hearing ASL signers recruit the RH angular gyrus, as native signers do, only if they began learning the language prior to puberty, lending greater insight into the sensitive period hypothesis for L2 ASL learning (Newman, Bavelier, Corina, Jezzard, & Neville, 2001). If this is the case, spatial enhancement that occurs in late-learning L2 ASL signers may recruit different cognitive processes and therefore have different outcomes in their spatial cognition.

Daniels has done a great deal of research on the effects of American Sign Language for hearing children’s literacy. She argues that teaching children ASL as a second language at a young age significantly increases their vocabulary and reading levels after one year of exposure. On the Peabody Picture Vocabulary Test (PPVT), preschoolers who received immersive sign instruction as part of their daily classroom routine scored 15 points higher than students in non-signing classes (Daniels, 1994). Similar effects were found in kindergarteners, in addition to improvement in reading skills (Daniels, 1996, 2004).

Many researchers have used the Corsi task as a measure of nonlinguistic working memory and spatial cognitive ability, particularly for L2 sign language learners. Capirci and colleagues (1998) tested Italian-speaking first graders who were either learning Italian Sign Language, English, or no new language after one or two years of instruction. At both time points, signing children’s scores were significantly higher than their non-signing counterparts on both the Raven Progressive Matrices
test of visual perceptual discrimination, and the Corsi Block-Tapping task for spatial memory. Additionally, Keehner and Gathercole (2007) tested interpreters of British Sign Language, who had learned BSL as adults, on their spatial memory and mental rotation abilities with the Corsi Block-Tapping task, as well as rotated versions of this task. Signers performed better than nonsigners on the 180-degree rotation condition, presumably due to the mental rotation requirements of the language.

Additionally, researchers have found a number of significant relationships between L2 ASL learning and co-speech gesture. Taub and colleagues (2008) examined whether preexisting ASL-like gestures accompanying spoken language were predictive of certain aspects of rapid ASL grammar acquisition in adult L2 learners after eight months of study. They found that some early emerging characteristics of ASL spatial grammar, including classifier use in third person discourse and spatial location, were indeed produced correctly in the same people that gestured in similar ways (i.e. used classifier-like handshapes or object placements), while no correlations were found between gesture and ASL in measures of first person discourse. Casey, Emmorey & Larrabee (2012) found that beginning L2 ASL learners produced significantly more co-speech gestures than Romance language learners after one academic year of instruction. Thus, people’s predisposition toward spatial gesture supports acquisition of sign language, and sign language learning in turn supports spatial cognition. These findings about the dual directionality of relationships between ASL and spatial gesture, particularly after such short periods of learning and in adulthood, prompt further questions about how spatial concepts either predict ASL acquisition or change as a result of it.
The Effects of ASL on Spatial Cognition

Current Study

The majority of research into the benefits of ASL acquisition for late learners to date focuses on subjects who have either had a great deal (2 or more years) of exposure (Emmorey, Borinstein, & Thompson, 2005; Keehner & Gathercole, 2007; Morford & Carlson, 2011) or focuses primarily on the linguistic benefits of the language (Daniels, 1994, 1996, 2004). Less research has explored the potential spatial benefits in ASL signers early on in the learning process. The current study takes up this question.

Considering the development of heightened spatial cognition in late-learning beginning signers naturally leads to another question, how much exposure to the spatial grammar of ASL is necessary for visual-spatial benefits to emerge? In the present study, we sought to examine the spatial cognitive effects of a short length of exposure to American Sign Language in college students, based primarily on the work of Capirci et al. (1998) and Keehner and Gathercole (2007). In these studies, children and adults with some nonnative exposure to a sign language performed better than non-signing controls on spatial cognitive tasks testing spatial memory, mental rotation, and other aspects of visual-spatial perception, suggesting that the spatial nature of sign languages benefited their understanding of space in important ways. The present study used similar training paradigms and tasks to assess the effects of American Sign Language on spatial cognition. The following study investigates introductory level ASL students in adulthood instead of children as in Capirci et al. (1998), and unlike Keehner and Gathercole’s (2007) examination of fluent, well
practiced L2 signers, the present study’s participants have little to no prior ASL exposure.

College-aged ASL students were tested at the earliest points of their learning the language. In this way, we hoped to learn how early potential benefits of knowing a spatial language might emerge. Introductory American Sign Language students were tested at the beginning of the first semester of ASL coursework, and again approximately 10 weeks later, at the semester’s end. At this point in the year they had received at least 36 hours of immersive instruction, had practiced signing consistently, and had learned the basics about classifier use and the spatial relationships that ASL emphasizes. Further, intermediate ASL students with greater proficiency and more spatial practice were tested once after three full semesters of ASL exposure.

Pretest and posttest batteries were the same for each participant. Each consisted of four elements. The Block Design subtest on the Wechsler Adult Intelligence Scale (Wechsler, 1981) is considered a good predictor of general intelligence and intellectual ability (Ronnlund & Nilsson, 2006), but has also been found to be a good predictor of everyday spatial ability (Chamberlain & Mayberry, 2008; Groth-Marnat & Teal, 2000). The Corsi Block-Tapping task (Milner, 1971) has been used by numerous researchers examining the spatial effects of sign language (Capirci, Cattani, Rossini, & Volterra, 1998; Keeler & Gathercole, 2007; Wilson et al., 1997) in terms of spatial memory. Further, the 180-degree Rotated Corsi task tests mental rotation abilities in nonnative signers (Keeler & Gathercole, 2007). Finally, the Rotated Box search task used to test mental rotation abilities in Nicaraguan
signers (Pyers, Shusterman, Senghas, Spelke, & Emmorey, 2010) was the last task in the battery.

The current study asked several questions. Firstly, how much exposure to ASL is needed before spatial cognition can improve in significant ways? Is it a rapid, stepwise shift that comes naturally with an increase in awareness of space as required by the language, or is more time, practice, and/or fluency necessary to experience spatial benefits? Further, are reliance on iconicity and general vocabulary knowledge, which tend to be emphasized in early ASL learning (Mayberry, 2006), enough to offer visuospatial cognitive enhancement, or can this only occur with a deeper and more practiced understanding of the more complex elements of ASL’s spatial grammar, such as classifiers and referential shifts? Finally, if the relationship between ASL and spatial cognition is present early in the learning process, is this relationship directional? That is, does spatial cognitive ability predict ASL acquisition in a similar way as gesture does (Taub et al., 2008), or does learning ASL directly enhance spatial cognition as suggested by Capirci et al. (1998)?
Study 1

Method

Participants. Participants were 26 college students (21 female, 5 male) enrolled in introductory language classes at Wesleyan University. Participants were between 18 and 21 years of age at the first session ($M = 19.04$ years).

Of the 26 participants, 20 were students in the American Sign Language training condition (16 female, 4 male), and 6 were students from other introductory language courses (5 female, 1 male). Three additional participants (ASL $n = 2$, control $n = 1$) were excluded because they did not participate in the posttest. One participant from the ASL group was excluded due to experimenter error, and two participants from the control group were excluded because their posttest scores were extreme outliers compared to other participants in both groups. All participants were recruited from introductory language classes at Wesleyan University by the experimenter.

Participants in the ASL group received one semester of instruction in American Sign Language, totaling approximately 3 hours each week for 14 weeks. Students learned the basics of ASL, including vocabulary and basic syntax, and they were also introduced to the use of basic classifiers.

Control participants did not receive any American Sign Language instruction. They were recruited from other introductory language courses that expected little to no previous exposure to the language and met for comparable amounts of time. Subjects’ new languages of instruction included Italian ($n = 2$), German ($n = 3$), and Japanese ($n = 1$).
**Assessment procedure.** Participants in both groups were tested within the first three weeks of the semester for the pretest, and again approximately 10 weeks later for the posttest ($M = 10.42$, $SD = 1.27$). Each session consisted of an assessment battery designed to examine various aspects of spatial cognition, including visual-spatial abilities, spatial memory, and mental rotation.

**ASL experience.** Prior to assessment, all participants were asked how much previous experience with American Sign Language they had before beginning the class. Participants reported varying levels of experience, and responses were coded on a 4-point scale (where 0 was no prior knowledge and 4 was instruction within the last 5 years, see Appendix A for coding details).

**WAIS-IV Block Design task.** This task is a subtest of the WAIS-IV (Wechsler, 1981). In the Block Design task, participants were shown pictures in a book and use two, four, or nine white and red blocks to construct a matching object as quickly as they can. The task was scored based on the correctness and speed with which participants solved the Block Design. The WAIS Block Design task serves as a general measure of spatial cognition and perceptual reasoning skills, as it has been found to be a good predictor of everyday spatial measures (Chamberlain & Mayberry, 2008; Groth-Marnat & Teal, 2000; Ronnlund & Nilsson, 2006).

**Corsi Block-Tapping tasks.** The Corsi task, a measure of spatial working memory, has been used often in studies of signers’ spatial cognition skills (Capirci et al., 1998; Keehner & Gathercole, 2007; Parasnis et al., 1996; Wilson & Emmorey, 1997). This study followed the testing paradigm laid out in Keehner and Gathercole’s (2007) study. Two sets of identical Corsi blocks were constructed on boards that
measured 34cm by 25.5cm. Nine 1.5-inch square cubes were painted black and arranged in a quasi-random order on the board. Blocks were labeled with the numbers 1-9, which could be seen only by the experimenter. Two different trial orders were randomly generated in Microsoft Excel, and each participant received one order for each version of the task (regular and rotated). At posttest, orders were switched for each participant. Both tasks were scored on three measures: span (the final full sequence length passed, e.g. failure on a sequence of 7 blocks gives a span score of 6), raw score (one point assigned for each completely correct block), and modified (mod) score (raw score plus half a point for each order error).

In the traditional Corsi Block-Tapping task, sequences of blocks are tapped by the experimenter, which the participant then repeats on the same set of blocks. In the current version, participants watched the experimenter tap a sequence of blocks and then tapped the sequence on their own set, which requires a translation. The experimenter explained the rules and gave two practice taps of one and two blocks, respectively, before the trials began. Sequences consisted of four trials for each length, beginning with one block and continuing sequentially up to a possible sequence length of nine blocks. As soon as a participant failed two trials of a given sequence length, the task ended.

The second part of the Corsi task used here is a 180-degree rotated version of the Corsi task described above (Keehner & Gathercole, 2007). Prior to this task, the experimenter asked the participant to wait behind a partition while she set up for the next task. The experimenter rotated the participant’s blocks 180 degrees and switched the number labels. When the participant returned, the task began. The experimenter
explained the new rotated nature of the two sets and gave two practice taps, and the procedure resumed in the same way as in the first Block-Tapping task. This Rotated Corsi task occurred after the Rotated Box task (see below) to avoid interference between these two similar tasks with different rules. Emmorey and colleagues (1993) suggest that hearing signers struggle with the rotational requirements of ASL during initial learning, “they do not easily transform a signer’s articulations into the reversal that must be used to produce the signs” (p. 168). Because it is unclear how long this challenge might prevail, this tasks tested rotation and translation as basic cognitive skills with the hypothesis that practice might improve performance.

**Rotated Box task.** This task used the same apparatus and testing paradigm as Pyers et al. (2010). A tabletop rectangular box with three black walls and one red “landmark” wall was placed in front of the participant, with an eggcup in each corner (see Appendix B for pictures of all tasks). The participant was instructed to search for a coin hidden under a specific cup, indicated by the experimenter. The participant then either put on a blindfold or covered their eyes securely with their hands while the experimenter rotated the box 0°, 90°, 180°, or 270°. Then the participant removed the blindfold and searched for the coin. The experimenter timed the search for each trial, from when the blindfold was removed until the first reach. This task was scored based on the number of correct searches out of eight trials. Conditions were counterbalanced for two degrees of rotation orders and two search corner orders. Participants received a different condition at posttest.

For participants 1-12 at pretest, the participant watched the experimenter hide the coin, then searched until the coin was found. For the remaining participants, a
The Effects of ASL on Spatial Cognition

coin was already hidden underneath each cup before testing began, so that
participants would not receive feedback on the correctness of their searches. No
significant differences were found between these two procedures, indicating that the
early participants did not benefit from the feedback; therefore, results were collapsed
during analysis.

Results

The independent variables of interest in this study were Group and Time.
Participants were divided into two groups based on whether or not they were learning
American Sign Language, and are referred to as the ASL group and the control group.
The time measure is simply the division of pretest scores and posttest scores. The
dependent measures were scores on the various assessments in the battery: the WAIS
Block Design, Corsi task (measured by span, raw score, and modified score), 180-
dergree Rotated Corsi task (with the same measures), and Rotated Box task. Because
both score improvement from pretest to posttest and differences between the ASL and
control groups were examined, independent samples t-tests, repeated measures
ANOVAs, and paired samples t-tests were used to analyze the data.

Independent samples t-tests were conducted on the pretest data in order to
gauge similarity between groups before significant ASL instruction began. There
were no significant differences between the ASL and control groups at pretest.

Repeated measures ANOVAs were run on all task data with time (pretest and
posttest) as the within subjects factor and group (ASL and control) as the between
subjects factor. On the WAIS Block Design task, the ASL group had a mean score of
48.00 (SD = 11.11) on pretest and 54.70 on posttest (SD = 8.67), and the control
group had a mean score of 54.00 (SD = 9.63) on the pretest and 58.17 (SD = 8.26) on the posttest, and there was a main effect of time on the Block Design task, $F(1, 24) = 7.87, p = .01$. On the Rotated Box task, the ASL group had a mean score of 6.55 (SD = 1.54) on pretest and 7.10 on posttest (SD = 1.21), and the control group had a mean score of 6.00 (SD = 2.53) on the pretest and 7.67 (SD = .52) on the posttest, and there was a main effect of time on the Rotated Box task, $F(1, 24) = 11.34, p = .01$. There were no significant effects on any measure of either Corsi task.

To further examine the relationship between ASL learning and spatial cognition, paired samples t-tests were run on the data. These tests revealed a significant improvement in Block Design scores from pretest to posttest in the ASL group, $t(19) = -3.58, p = .002$, but not in the control group, $t(5) = -1.25, p = .27$. No other tasks showed significant change from pretest to posttest based on the results of paired samples t-tests. Additional independent samples t-tests comparing difference scores (posttest score – pretest score) were conducted on the data, no significant differences were found between the ASL group and the control group.

Although these tests show marked improvement from pretest to posttest on the Block Design task in the ASL group, none of them showed significant differences between the ASL and control groups, suggesting that more experience with the language might be needed to see benefits in these areas.

Surprisingly, independent samples t-tests on individual pre- and posttests revealed that the control group performed significantly better than the ASL group at posttest on the Corsi task, both on the raw score measure, $t(24) = 2.33, p = .03$, and the modified measure, $t(24) = 2.31, p = .03$. The Corsi span measure approached
significance, \( t(24) = 2.03, p = .05 \). This difference could be due to a selection bias within the control group, where they chose to participate because they had better initial spatial cognition.

To examine whether previous experience with ASL might influence performance on spatial cognitive tasks, a secondary independent variable was ASL Experience, an ordinal variable that ranked participants’ exposure to ASL prior to the first session of the study from 0 to 3. In the ASL group, 7 participants reported having no previous ASL experience (0), 9 reported knowing the manual alphabet or a few words (1), 3 reported knowing the manual alphabet and a few words (2), and 1 reported having had classroom instruction in ASL more than five years ago (3). In the control group, all participants reported having no previous exposure to ASL (0).

Because it was expected that performance might be a function of pre-training exposure to ASL, repeated measures ANOVAs were run on the data with time (pretest and posttest) as the within subjects factor and ASL experience (0, 1, 2, or 3) as the between subjects factor. An effect of time persisted on the Block Design task, \( F(1, 22) = 5.18, p = .03 \), further reinforcing that some relationship might be present between performance on this task and ASL acquisition.

**Discussion**

Both independent samples t-tests and ANOVAs revealed no significant differences between ASL learners and control participants, though several tests showed improvement in the ASL group on the Block Design and Rotated Box tasks from pretest to posttest. The null effects that appear across the board in Study 1 in terms of comparing ASL learners and other language learners raise a number of
interesting issues. Each assessment given was designed to incorporate a different aspect of spatial cognition that could be influenced by learning American Sign Language. The fact that the only scores that changed significantly from pretest to posttest were the Block Design scores for ASL students indicates that 10 weeks of ASL exposure is not nearly enough to see the kind of improvement that Capirci et al. (1998) and Keehner and Gathercole (2007) have found in L2 signers.

The WAIS Block Design task was meant to examine general visual perception and spatial cognition abilities. The ASL group’s greater increase in performance, both in accuracy and speed of interpretation, could be demonstrative of heightened spatial awareness resulting from ASL learning. Specifically, this group’s increased practice attending to space, handshape, and iconicity could influence their general visual perceptual abilities and awareness of spatial relations. Alternatively, because the control group’s scores were initially higher (though not significantly so), this increase could merely be a practice effect in the ASL group.

The Corsi block task is an assessment of spatial memory. Spatial memory is of great importance in ASL communication, as it is crucial to hold in mind another person’s signs, particularly in terms of classifier use, in order to properly respond. The control group scored significantly higher than the ASL group on the posttest (raw and modified scores), possibly due to a selection bias (people who chose to participate may have been more interested in learning about and/or developing their spatial cognition). However, there was no significant difference in the difference scores from pre to post between ASL and control groups, indicating that, while
selection bias may have produced higher scores, one group did not improve more than the other from pretest to posttest on this task.

The Rotated Corsi and Rotated Box tasks both focus on mental rotation abilities, as this is considered the central benefit that signers have in terms of spatial cognition (Emmorey et al., 1998). There were no significant changes from pretest to posttest on either of these tasks in either group. The fact that the ASL group did not have extensive conversational practice with the spatial grammar of ASL can potentially explain this null effect. Students had minimal exposure to the more intricate rotational elements of this grammar, including classifiers and perspective shifts, as well as very little experience practicing them following introduction.

From these interpretations, a few major issues emerge that could be the source of these pervasive null effects:

**Time.** 13 weeks and roughly 40 hours of experience with ASL seem not to be enough time to see significant changes in spatial cognition with 10 weeks between pre- and posttests. Most previous studies see spatial improvements in second language signers after at least one year of exposure in children (Capirci et al., 1998), or in fluent adult interpreters (Keehner & Gathercole, 2007). This suggests that later time points are needed for further analysis of when spatial benefits might start to appear.

**Spatial grammar exposure.** Performance on more complex tasks may not have changed because more complex elements of the language, which could potentially lead to spatial benefits, were not learned or practiced extensively within this introductory period. More emphasis was placed on the vocabulary, handshape,
and location basics of the language, but less spatial memory or 180-degree rotation was required without immersive practice using classifiers, referents, and other spatial aspects of the language’s grammar. Again this informs us that more fluency and practice with ASL’s spatial aspects may be required for spatial cognitive benefits to be seen.

**Control group size and selection bias.** Because control participants were recruited to the study with the knowledge that it was based on spatial cognition, it is possible that those who chose to participate were more interested in that subject and/or considered themselves to be good at it. This could explain the high scores of the control group, and the fact that the control group’s means were often higher, albeit not significantly, than those of the ASL group. Furthermore, because of the specific requirements of control participant recruitment (students enrolled in their first semester of a brand new language), the group was too small to draw significant comparisons.

**Alternative hypothesis: Spatial cognition predicts ASL acquisition.** Because spatial cognitive skills did not improve significantly early on in ASL learning, a possible explanation is that in fact the relationship may move in the opposite direction, similar to the gesture-ASL relationship suggested by Taub et al. (2008). That is, perhaps people with greater interest and/or skill in spatial cognition are more inclined to take ASL, enjoy ASL, and/or improve to a greater degree than those with poorer spatial cognitive skills.

In order to confront these issues, three solutions were developed:
Intermediate ASL group. In order to examine students further along in the ASL acquisition process, intermediate ASL students were tested on the same measures to see if their pretest scores were significantly higher than the beginning ASL or control groups at posttest. Adding this group allowed for deeper analyses of both the time and spatial grammar exposure explanations, since students with three semesters of ASL had achieved greater skill in the language over time and were more practiced at utilizing the more complex aspects of ASL’s spatial grammar.

Additional control participants. Adding more control participants recruited from an introductory psychology course eliminated the possibility of self-selection. This was reasonable because it was important to ascertain whether previous interest in spatial grammar motivated participation and/or high scores on spatial tasks in the initial control group, as well as to increase overall size of this comparison group.

Follow-up surveys. Surveys were developed to ask participants questions about languages, preexisting interest in spatial cognition, and ASL learning. These surveys examined selection bias in study participation for both groups. Additionally, the ASL participants’ instructor rated their fluency and improvement on multiple measures. Both the participant and instructor surveys reveal individual-level sensitivity to spatial cognition and ASL, and allow for the analysis of the directionality of the relationship between sign language and spatial cognition; if students with higher previous interest in spatial cognition achieved greater fluency in ASL, then the alternative hypothesis is supported.

With the addition of these new participants and measures, a clearer picture of the L2 acquisition process for ASL emerged.
Study 2

Methods

Participants. 67 total participants were included in Study 2.

New participants were 36 college students (28 female, 8 male), 16 of whom (13 female, 3 male) were enrolled in an intermediate level American Sign Language course and 20 of whom (15 female, 5 male) were randomly assigned to this study via the introductory psychology course’s participant pool. Intermediate ASL (ASL2) students had completed 3 full semesters of ASL at the time of testing, or roughly 120 hours of in-class instruction.

The data from 28 students from Study 1 were also analyzed in Study 2, which included two control participants from Study 1 that had been previously excluded as outliers. 20 (16 female, 4 male) were enrolled in beginning ASL (ASL1) courses and 8 (7 female, 1 male) were enrolled in other introductory language courses.

Assessment procedure. Intermediate ASL students were tested at a single time point on the same assessment battery used in Study 1, with the addition of the WAIS Matrix Reasoning subtest in order to control for general non-spatial reasoning. They were also given the follow-up survey approximately two weeks after participating. Additional control participants were tested on the same assessment battery used in Study 1. Participants from Study 1 were asked to complete the follow-up survey so that they could be included in analysis.

WAIS-IV Matrix Reasoning task. This task is a subtest of the WAIS-IV (Wechsler, 1981). In the Matrix Reasoning task, participants were asked to choose which picture completes a set of pictures in a matrix. Based on the Raven’s
Progressive Matrices Assessment, this matrix analogy task provides a reliable measure of general cognitive and intellectual abilities (Goldstein & Hersen, 2000) beyond perceptual reasoning alone. Intermediate ASL students completed this task during testing. Study 1 participants and additional controls will complete this subtest during their final posttest, following the submission of this paper.

**Follow-up surveys.** Additional data provided by surveys were analyzed in order to gain a deeper understanding of the relationship between ASL and spatial cognition, including questions of time, fluency, grammar requirements, directionality, and individual differences.

**Participant Survey.** A follow-up survey was given to all participants who had completed testing (initial control group, beginning ASL group, and intermediate ASL group). The survey asks all participants a number of questions about languages spoken, interest in spatial cognition, and performance on the assessment. Further, ASL students are asked about their confidence with ASL, hours of extra practice per week, perceived relationship between ASL and spatial cognitive skills. Most questions were answered on a 0 to 5 scale. For the full survey, please see Appendix A.

**Instructor Survey.** An additional measure of the follow-up survey is an instructor evaluation. ASL participants who gave consent on their survey were rated from 0 to 5 by their ASL instructor on measures of fluency and improvement over time. For fluency, the instructor was asked, “How fluent is the student in ASL? Please consider use of proper ASL grammar, speed, vocabulary size, etc. (0 - beginner, no fluency, 5 - completely fluent).” For improvement, the instructor was asked “How
much has the student improved in ASL since beginning ASL courses at Wesleyan? (0 - no improvement, 5 - very strong improvement).”

**Results**

**Group comparisons.** An independent samples t-test was conducted on the data to discern if there were any significant differences between the two control groups at pretest. No scores were significantly different, so pretest scores were collapsed across both groups.

A series of one-way ANOVAs revealed no significant differences between the control group, beginning ASL group, or intermediate ASL group on any task at pretest. This suggests that neither one semester nor three semesters of American Sign Language exposure was enough to demonstrate marked benefit on classic spatial cognition tasks. There were also no significant differences when the measure of previous ASL experience was used as the factor.

The data support the hypothesis that on the WAIS Block Design task, improvement in scores in the beginning ASL group was most likely due to practice effects rather than spatial benefit from learning ASL, as intermediate ASL signers ($M = 48.06, SD = 13.51$) who had an additional two semesters of ASL practice did not significantly outperform beginners ($M = 48.00, SD = 11.11$).

As shown in Table 1, a correlation matrix of the task battery reveals that these elements of spatial cognition hang together in a fascinating way. Across all participants at pretest in Study 2, it seems that these tasks are interrelated across multiple areas of visuospatial cognition, and participants develop these skills in conjunction with one another. The Block Design task is significantly correlated with
all other tasks \((p < .05)\), indicating that it is indeed a strong measure of general spatial cognitive ability. All measures of the Corsi task and the Rotated Box task are correlated with everything but the Rotated Corsi task, demonstrating similar cognitive processes between these tasks. The Rotated Corsi task shows fewer correlations, most likely due to generally poor performance on this task across groups as compared to other tasks.

Table 1

*Two-Tailed Intercorrelations Between Spatial Cognition Tasks*

<table>
<thead>
<tr>
<th></th>
<th>WAIS Block Design</th>
<th>Corsi (span)</th>
<th>Corsi (raw)</th>
<th>Corsi (mod.)</th>
<th>Rotated Corsi (span)</th>
<th>Rotated Corsi (raw)</th>
<th>Rotated Corsi (mod.)</th>
<th>Rotated Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAIS Block Design</td>
<td>—</td>
<td>.39**</td>
<td>.43**</td>
<td>.43**</td>
<td>.27*</td>
<td>.26*</td>
<td>.27*</td>
<td>.39**</td>
</tr>
<tr>
<td>Corsi (span)</td>
<td>—</td>
<td>—</td>
<td>.95**</td>
<td>.96**</td>
<td>.05</td>
<td>.03</td>
<td>.04</td>
<td>.27*</td>
</tr>
<tr>
<td>Corsi (raw)</td>
<td>—</td>
<td>—</td>
<td>.99**</td>
<td>.09</td>
<td>.08</td>
<td>.09</td>
<td>.32*</td>
<td></td>
</tr>
<tr>
<td>Corsi (mod.)</td>
<td>—</td>
<td>.08</td>
<td>.07</td>
<td>.08</td>
<td>.31*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotated Corsi (span)</td>
<td>—</td>
<td>—</td>
<td>.95**</td>
<td>.95**</td>
<td>—</td>
<td>.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotated Corsi (raw)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>.99**</td>
<td>.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotated Corsi (mod.)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>.14</td>
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<tr>
<td>Rotated Box</td>
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</tbody>
</table>
Follow-up surveys. Follow-up surveys were given to participants in the beginning ASL group, intermediate ASL group, and the initial control group. The new control group will complete the survey along with their posttest, which will occur following the submission of this paper. 43 participants completed the survey across beginning ASL ($n = 20$), intermediate ASL ($n = 16$), and control group ($n = 7$). One participant from the initial control group did not complete the follow-up survey, and the participant previously excluded due to experimenter error remained excluded in this set of analyses.

One-way ANOVAs were run on the data to reveal any differences in ratings across groups. There was no effect of group on any of the self-reported measures about spatial cognition that examined all three groups, or on measures about ASL that examined beginning and intermediate groups.

In order to assess the issue of potential selection bias in the initial control group, one-way ANOVAs were performed on the survey data. No significant differences were found between the initial control group, the beginning ASL group, or the intermediate ASL group on the measures of puzzle enjoyment, $F(2,40) = .70, p = .50$, previous interest in spatial cognition, $F(2,40) = .04, p = .97$, or increase in interest in spatial cognition, $F(2,40) = 1.2, p = .31$. The data indicate that the original control group was not significantly more spatially inclined than either ASL group.

Spearman correlations were run on the data from the follow-up surveys and revealed several notable correlations. As shown in Figure 1, correlation between previous interest in spatial cognition and memory span on the pretest Corsi Block-
Tapping task was significant, $r_s(41) = .43, p = .004$, suggesting that unprompted interest in spatial cognition may predict spatial memory skills in some capacity. Notably, a significant correlation coefficient exists between self-reported confidence in ASL ability and the rotated Corsi task, $r_s(34) = -.33, p = .05$, indicating that, despite the difficulty of this task, there may be an association between ASL confidence and/or ability and this task that strengthens throughout the learning process.

Figure 1. Correlation between participant-reported previous interest in spatial cognition and Corsi span across participants in all three groups, $r_s = .43, p = .004$.

Furthermore, a number of illuminating correlations between the instructor evaluation measures and various assessments help tease apart the relationship between early ASL learning and spatial cognition (see Table 2). 33 participants were
evaluated by the instructor on measures of fluency and improvement, both on a scale from 0 to 5. 19 participants were from the beginning ASL class and 14 were from the intermediate ASL class. Two participants who filled out the survey in the intermediate ASL group did not give consent to be evaluated (1 male, 1 female), and one student who dropped the beginning ASL course was also not evaluated by the instructor.
Table 2

One-Tailed Correlations Between Instructor-Rated ASL Measures and Spatial Cognition Tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>ASL fluency</th>
<th>ASL improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginning ASL students after 1 semester (n = 19)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAIS Block Design</td>
<td>-.34</td>
<td>.20</td>
</tr>
<tr>
<td>Corsi (span)</td>
<td>.33</td>
<td>.72***</td>
</tr>
<tr>
<td>Corsi (raw)</td>
<td>.37</td>
<td>.78***</td>
</tr>
<tr>
<td>Corsi (modified)</td>
<td>.39</td>
<td>.79***</td>
</tr>
<tr>
<td>Rotated Corsi (span)</td>
<td>.07</td>
<td>.18</td>
</tr>
<tr>
<td>Rotated Corsi (raw)</td>
<td>.08</td>
<td>.16</td>
</tr>
<tr>
<td>Rotated Corsi (modified)</td>
<td>.05</td>
<td>.16</td>
</tr>
<tr>
<td>Rotated Box</td>
<td>.26</td>
<td>.72***</td>
</tr>
<tr>
<td><strong>Intermediate ASL students after 3 semesters (n = 14)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAIS Block Design</td>
<td>.49*</td>
<td>.60*</td>
</tr>
<tr>
<td>Corsi (span)</td>
<td>.51*</td>
<td>.80***</td>
</tr>
<tr>
<td>Corsi (raw)</td>
<td>.47*</td>
<td>.77**</td>
</tr>
<tr>
<td>Corsi (modified)</td>
<td>.48*</td>
<td>.79***</td>
</tr>
<tr>
<td>Rotated Corsi (span)</td>
<td>.15</td>
<td>.31</td>
</tr>
<tr>
<td>Rotated Corsi (raw)</td>
<td>.22</td>
<td>.30</td>
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<tr>
<td>Rotated Corsi (modified)</td>
<td>.23</td>
<td>.30</td>
</tr>
<tr>
<td>Rotated Box</td>
<td>.48*</td>
<td>.32</td>
</tr>
</tbody>
</table>

*Note:* *p < .05, **p < .01, ***p < .001
Several significant correlations were present between instructor-rated improvement since beginning the course (either over one semester for beginning ASL students or three semesters for intermediate ASL students) and performance on spatial tasks. There were highly significant two-tailed correlations between instructor-rated ASL improvement and performance on the Corsi Block-Tapping task for both the beginning ASL group’s scores on the posttest, $r(17) = .79, p < .001$, and the intermediate ASL group’s scores on the pretest, $r(12) = .79, p = .001$ (see Figure 2). The beginning ASL group’s pretest Corsi score, however, was not significantly correlated, $r(17) = .29, p = .23$, suggesting that instructor ratings are a better indicator of ASL acquisition than length of study. These results, along with the fact that previous interest in spatial cognition did not predict ASL fluency, $r(31) = .12, p = .52$, or improvement, $r(31) = .22, p = .22$, furthers the hypothesis that ASL acquisition predicts heightened spatial cognition, not the other way around.
Figure 2. Correlations between instructor-rated ASL improvement and Corsi modified score for both beginning ASL students after one semester, $r(17) = .792$, $p < .001$, and intermediate ASL students after three semesters, $r(12) = .79$, $p = .001$.

Additionally, there is a significant correlation between instructor-rated ASL improvement and Rotated Box performance on the posttest in the beginning ASL group, $r(17) = .72$, $p = .001$ (see Figure 3), as well as WAIS Block Design performance on the pretest in the intermediate ASL group, $r(12) = .60$, $p = .02$ (see Figure 4). Again, the beginning ASL group’s performance on the Rotated Box task
did not correlate significantly with improvement at pretest, $r(17) = .21, p = .40$.

Strangely, Rotated Box performance is not significant in the intermediate ASL group, $r(12) = .32, p = .26$. However, significant one-tailed correlations between instructor-rated fluency and performance on WAIS Block Design, $r(12) = .49, p = .04$, Corsi span, $r(12) = .51, p = .03$, and Rotated Box, $r(12) = .48, p = .04$ in the intermediate group indicate that spatial cognition skills are indeed increasing across different abilities after a mere three semesters of ASL.

*Figure 3.* Correlation between instructor-rated ASL improvement and Rotated Box performance in the beginning ASL group at posttest, $r(17) = .72, p = .001$. 
When non-spatial cognitive ability, as measured by the Matrix Reasoning task, was controlled for in the intermediate ASL group, many correlations remained significant. Compared to ASL fluency, all three Corsi measures remained significantly correlated, $r(11) = .57, p = .02; r(11) = .51, p = .04; r(11) = .53, p = .03$, respectively. Additionally, ASL improvement was significantly correlated with Block Design, $r(11) = .62, p = .01$, Corsi span, $r(11) = .80, p < .001$, Corsi raw score, $r(11) = .77, p = .001$, and Corsi modified score, $r(11) = .79, p = .001$, supporting the hypothesis that heightened spatial cognition is a direct result of ASL learning, not simply general cognitive ability.

*Figure 4. Correlation between instructor-rated ASL improvement and WAIS Block Design performance in the intermediate ASL group, $r(12) = .60, p = .023$.***
Discussion

As observed in Study 1, null effects in terms of differences between groups’ assessment scores remain pervasive in Study 2. The follow-up surveys, however, provided some fascinating new insights into the data, as numerous correlations show significant relationships between learning ASL and improved spatial cognition.

Of the three primary issues raised in Study 1, selection bias in the initial control group can be ruled out as a source of similarity between the control participants and those in both ASL groups. This is possible not only because of a lack of significant differences between the pretest scores of the two control groups, but also because the follow-up surveys for initial control participants did not reveal any strong biases toward spatial cognition as a motivating factor in participation as compared to the ASL groups. However, results show that unprompted interest in spatial cognition may predict spatial memory or vice versa across participants, which motivates questions about how the randomly selected control group will fit into this finding once they complete the follow-up survey. The current conclusion that there was no selection bias leaves us to further explore the explanations of insufficient time and insufficient exposure to/practice with more complex spatial elements of American Sign Language, as well as the directionality of the spatial language-ASL relationship.

**Insufficient time and/or fluency.** The results of Study 2 indicate that even a year and a half of ASL exposure and practice in college is not enough to develop any kind of spatial cognitive benefits that are seen in other populations. Although a relationship appears to exist between ASL confidence and spatial memory/mental
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rotation as evidenced by the rotated Corsi task, one wonders why this measure of confidence did not manifest in other tasks. Previous studies that have found spatial improvements in either native signers (Emmorey et al., 2005) or L2 signers with extensive experience with the language (Keehner & Gathercole, 2007; Morford & Carlson, 2011) suggest that either a) more time with the language is required and/or b) complete fluency, such as what might be present in interpreters, is required in order to see changes in spatial cognition.

These findings are supported by the fact that there are no significant correlations with instructor-rated fluency in the beginning ASL group. This could be due to the measure of evaluation (that is, the instructor rated students on a scale from 0 – no ASL to 5 – completely fluent, rather than a scale with the upper limit as a typical high-achieving ASL 2 student) and/or its lack of variability (n = 2 received a rating of 3 with the remainder of participants being in the 1-2 range), and perhaps on a different scale more insight could be gained from these evaluations. Even so, these results combined with the prevalence of correlations between instructor-rated fluency and task performance in the intermediate ASL group reinforce the hypothesis that there is, in fact, a directional relationship between ASL acquisition and spatial cognition. The correlations that exist with instructor-rated improvement hint at this hypothesis as well, since participants who improved their ASL skills to a greater extent also performed at a higher level on the Corsi (both groups), Rotated Box (beginning ASL), and Block Design (intermediate ASL) tasks after ASL instruction. These correlations in the absence of significant difference scores from the control
group suggest that individual-level analyses are more effective than group-level ones for assessing spatial cognitive skill at this early stage in ASL learning.

**Insufficient spatial grammar exposure and/or practice.** Even intermediate ASL signers appear to lack enough practice with ASL’s unique spatial grammar to see benefits in spatial cognition. Although the correlation between self-reported ASL confidence and performance on the Rotated Corsi task suggests that there may be some link between sign language proficiency and spatial memory for 180-degree rotated objects, a benefit that could potentially stem from the spatial grammar of ASL, the source of this correlation is unclear. That this task is the only one not correlated with either ASL improvement or fluency is unsurprising considering its level of difficulty and that participants did not have extensive or fluent conversational practice with the rotational aspects of the language. This finding certainly motivates a deeper look into how greater exposure to and practice with the spatial grammar of ASL might change or fit into these results.

Many of the null effects from this study could be due to the more Pidgin Signed English constructions that many second language learners tend to fall into (Mayberry, 2006). Although the instructor emphasizes the unique grammar of the language during class, even students in ASL2 largely sign with more English grammatical structure, often mouthing words and constructing English sentences by neglecting classifier usage in favor of focusing on vocabulary. This non-ASL signing could be influencing a lack of considerable improvement in spatial cognition. Here again it seems that greater/more correct use of the spatial grammar of ASL is needed in order to derive spatial cognitive benefit.
**Directionality of the ASL-spatial cognition relationship.** With the inclusion of follow-up surveys, correlations between improvement in ASL and various assessments of spatial cognitive ability shed new light on the nature of this relationship. Because these correlations do not indicate a causal direction, the source of this relationship remains slightly unclear: is it learning ASL that changes spatial ability or is it confidence in spatial cognition that improves ASL acquisition? On the one hand, there were no significant improvements in group-based analyses of spatial cognition abilities in either Study 1 or Study 2. On the other hand, previous interest in spatial cognition did not predict either fluency or improvement in ASL. Notably, the relationships between ASL improvement and various elements of spatial cognition were only significant after at least one semester of ASL. Further, correlations between fluency and nearly all measures of spatial cognitive assessments in the intermediate ASL group illustrate the strength of this relationship overall. These findings indicate that, although the nature of this relationship is not yet causally illuminated, instructor assessments of individual language ability provide a much different and more enlightening view into the nature of the relationship between ASL acquisition and spatial cognition than broad group comparisons. The data strongly suggest the likelihood that it is ASL learning that predicts spatial ability, not vice-versa.
General Discussion

This study demonstrates that deriving cognitive benefits from American Sign Language is an extremely slow process in second language students learning to sign in adulthood. Throughout these studies there are a few small hints, such as Block Design score improvement and multiple instructor rating correlations, that something is happening cognitively with the adjustment to learning a visual-spatial language in the manual modality.

We asked the question, how much exposure to ASL is needed before spatial cognition can improve in significant ways? This question is still unanswered by the scope of this study. We predict that significantly more time and/or fluency are required for benefits to be seen, as shown in other studies with L2 signers.

We wondered whether this process is a rapid shift that comes naturally with an increase in awareness of space, or if more time, practice, and/or fluency are necessary to experience such benefits. Clearly the further development of spatial cognition as a result of visual-spatial language exposure is a much slower process in a less plastic adult brain. The findings suggest that a reliance on iconicity, handshape, and vocabulary is not a strong enough basis for improvement, and that the spatial cognitive enhancements that accompany ASL fluency are indeed rooted more deeply in the complexity of spatial grammar.

Finally, our results prompted questions about the directionality of learning ASL’s relationship to spatial cognition. Preexisting, self-reported spatial ability does not seem to readily influence ASL learning, and performance on various spatial tasks was strongly correlated with ASL improvement in both groups and ASL fluency in
the intermediate group. These findings seem demonstrative of this relationship moving in the initially hypothesized direction, where ASL learning predicts spatial cognition ability on an individual basis, even if three semesters of ASL learning is not enough for substantial quantitative change on a group level.

The explanations for the null effects, that both beginning and intermediate ASL students have insufficient time with/fluency in ASL and/or a lack of spatial grammar practice, strongly motivate a sensitive period hypothesis for second language learning, where it is significantly harder to learn language, particularly in a new modality, later in life (Mayberry, 2006; Newman et al., 2001). However, evidence from other studies still indicates the possibility that with more exposure and practice, achieving fluency is possible and can subsequently shape spatial cognition in profound ways (Keehner & Gathercole, 2007). Perhaps with daily lessons, extensive practice outside of class, and more time with the language overall, as well as a focus on immersive conversation rather than reliance on spoken English grammatical constructions, spatial benefits could be found in more advanced L2 populations.

Furthermore, this sensitive period hypothesis motivates further research on second language ASL acquisition in children of various ages. Because Caprici and colleagues (1998) found spatial cognitive improvement after only five months of Italian Sign Language instruction for two hours a week in first graders, similar work with ASL could reveal exciting new things about the process of visual-spatial cognitive development as a result of learning sign languages. Additionally, using similar testing paradigms at different points of initial age of ASL acquisition (e.g.
elementary school, middle school, high school) could help to focus the sensitive period hypotheses and determine which explanation is more accurate.

Many questions about the nature of the relationship between spatial cognition and sign languages persist, but this study certainly illuminates some aspects of the early stages of second language ASL acquisition. While it seems to take fluency in, or at least greater exposure to, ASL in order for large-scale spatial cognitive benefit to be seen, ASL skill and improvement over time appear to predict performance on spatial cognitive tasks. Further insight into the development of this relationship can be gleaned in future research from broader longitudinal studies, as well as similar ones with children. A greater understanding of the relationship between spatial language and spatial cognition can have deeper implications for both second language acquisition and ASL study more broadly.
References


Appendix A

ASL Experience Measure Coding Guidelines

How much, if any, experience with American Sign Language do you have?

0 – No previous experience

1 – Alphabet \textbf{or} a few words

2 – Alphabet \textbf{and} a few words

3 – Took ASL classes more than 5 years ago

4 – Took ASL classes within the last 5 years
Language and Spatial Cognition Follow-up Survey

Name:

1. What is your first language?

2. What other languages, if any, do you speak? (please include length of time spoken)

3. Why did you decide to participate in this study?

4. How much do you enjoy puzzles, word games, brain exercises, etc.?
   0 1 2 3 4 5

5. How interested/confident were you in visual/spatial reasoning before participating in this study?
   0 1 2 3 4 5

6. How much has your interest in spatial reasoning increased since first participating in this study?
   0 1 2 3 4 5

7. How would you rank your desire to perform well on this study?
   0 1 2 3 4 5

8. How would you rank your desire to improve your performance on this study?
   0 1 2 3 4 5
9. Why did you decide to take ASL?

10. To what extent did learning ASL increase your interest/confidence in visual/spatial reasoning?

12. How would you rate your interest in ASL before beginning the course? Your interest now?

   0  1  2  3  4  5  0  1  2  3  4  5

13. How confident do you feel with ASL after your experience learning it so far?

   0  1  2  3  4  5

14. How many hours per week do you practice ASL outside of class time?

   0  1  2  3  4  5+

15. Do you plan to continue studying ASL in the future?

☐ Please check here if you will allow your instructor to rate your fluency and improvement in ASL for the experimenter
Appendix B

WAIS Block Design task

Rotated Box task
Corsi Block-Tapping task (left participant view, right experimenter view)

Rotated Corsi Block-Tapping task (left participant view, right experimenter view)