Correlating performance on the Listening in Spatialized Noise – Sentences Test (LiSN-S) with the Listening in Spatialized Noise – Universal Test (LiSN-U)

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Acronyms:

CAPD: central auditory processing disorder

CVCV: consonant-vowel-consonant-vowel

DV0: different voices 0°

DV90: different voices ±90°

LiSN-S: Listening in Spatialized Noise – Sentences test

LiSN-U: Listening in Spatialized Noise – Universal test

NMF: number memory forward

NMR: number memory reversed

SRT: speech reception threshold

SV0: same voice 0° condition

SV90: same voice ±90°

SPD: spatial processing disorder

TAPS-3: Test of Auditory Processing Skills – Third Edition

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Objective: The aim of this study was to correlate 6-7-year-old children’s results on each condition of the Listening in Spatialized Noise – Sentences test (LiSN-S) with the new language-independent version, the Listening in Spatialized Noise – Universal test (LiSN-U), to examine the strength of the relationship between them and with memory in a small sample of typically developing children.

Design: Correlational analysis.

Study Sample: Sixteen typically-developing 6-7-year-old children completed the LiSN-S and LiSN-U as well as the Test of Auditory Processing Skills – Third Edition (TAPS-3) number memory forward and reversed subtests which assess short-term memory and working memory, respectively.

Results: Moderate positive correlations were found between LiSN-S and LiSN-U spatially-separated conditions (though this did not reach significance), and co-located conditions. Correlations between the LiSN-S and LiSN-U conditions and number memory forward and reversed subtests were not significant.

Conclusions: This study shows a moderate relationship between the LiSN-S and LiSN-U when the distractors and target speech are co-located. A study with a larger sample of participants is needed to further understand the relationship between the two tests, especially for the spatially-separated condition.

Introduction

It has long been established that when the azimuths of sound sources of speech and noise are close together, the speech intelligibility is reduced, but when the sources are far apart, intelligibility improves (Hirsh, 1950). Spatial release from masking has been demonstrated in the free field by adults (e.g. Freyman, Balakrishnan, & Helfer, 2001; Noble & Perrett, 2002) and also by children (Johnstone & Litovsky, 2006; Litovsky, 2005).

The Listening in Spatialized Noise – Sentences test (LiSN-S) (Cameron & Dillon, 2009) measures a listener's ability to utilise inter-aural time and level cues to differentiate a target talker from distracting talkers. Target sentences are presented over headphones while at the same time two distractor tracks telling stories are played. The listener is asked to ignore the distractor tracks and repeat back the target sentences. The location of the distractor tracks (0° and ±90° azimuth) and the types of voices (same as or different to the target speaker) are changed in different conditions.

The LiSN-S software calculates the speech reception thresholds (SRTs) and z scores for each baseline condition, and also calculates comparative scores which represent the benefit in dB gained when either pitch, spatial, or both pitch and spatial cues are incorporated in the competing speech. For example, the spatial advantage measure is calculated as the difference in dB between the same voice 0° (SV0) condition and the same voice ±90° (SV90) condition. The use of relative measures of performance reduces the influence of higher-order communication skills on performance. Thus, the differences that inevitably exist between individuals can be controlled for, allowing for clearer evaluation of their abilities to use spatial cues to aid speech understanding.

The LiSN-S is a validated tool for assessing whether a listener has a spatial processing disorder (SPD) (Cameron & Dillon, 2007a, 2008, 2011; Cameron, Dillon, & Newall, 2005, 2006; Cameron, Glyde, & Dillon, 2012; Cameron, Glyde, Dillon, King, & Gillies, 2015; Glyde, Cameron, Dillon, Hickson, & Seeto, 2013; Glyde, Hickson, Cameron, & Dillon, 2011). SPD is a specific form of central auditory processing disorder (CAPD) whereby a listener has reduced ability to utilise inter-aural time and level spatial cues to differentiate a target talker from distracting talkers (Cameron & Dillon, 2011). The LiSN-S stimuli uses English sentences so the listener must be proficient in English to be able to complete the test.

Recently a language-independent version of the LiSN-S was created – the Listening in Spatialized Noise – Universal test (LiSN-U) (Cameron, Mealings, Chong-White, Young, & Dillon, 2019). Instead of using English sentences as the stimuli, both the target stimuli and the distractors use consonant-vowel-consonant-vowel (CVCV) pseudo-words (e.g. ti-gu). The consonants and vowels used are those that are common to many languages, with the aim of the test being suitable for people with language backgrounds other than English. Similar to the LiSN-S, the LiSN-U simulates a three-dimensional auditory environment presented over headphones and the listener is asked to repeat back target CVCV pseudo-words while the distractor speech streams, comprising strings of CVCV pseudo-words, are either spatially-separated from the target, or co-located with the target. The LiSN-U has been developed as an iPad application. The version of the LiSN-S test used in this study was also developed to run on the iOS platform on an iPad.

The aim of this study was to correlate the LiSN-S results for each listening condition with the LiSN-U results in typically-developing, English-speaking 6-7-year-old children in order to examine the strength of the relationship between the two tests. A secondary aim was to correlate the children's LiSN-S and LiSN-U results with their auditory memory results. It was hypothesised that the LiSN-S and LiSN-U spatially-separated conditions would be moderately correlated, as would the co-located conditions. It was further hypothesised that whereas the LiSN-S and LiSN-U spatial advantage measures would be correlated, the strength of the correlation would not be as strong due to the increase in measurement error occurring from comparing two sets of difference scores. It was also hypothesised that the LiSN-S and LiSN-U conditions would be correlated to the child's working memory as both require some working memory to perform the tasks accurately. However, both the LiSN-S and LiSN-U spatial advantage measure, which minimizes the impact of cognition on test performance, would not be correlated with working memory performance.

Method

Approval for the study was granted from the Australian Hearing Human Research Ethics Committee and the New South Wales Department of Education.

Participants

A total of 18 Year 1 children were recruited from a Sydney primary school to take part in the study. Two of the children did not pass the hearing screen leaving 16 children who completed the full test battery. There were seven females and nine males. Age range was six years two months to seven years three months, with an average age of six years 11 months. Written consent was obtained from the children's parents, and verbal consent was obtained from the child before testing. All children were reported by their parents to have English as their first and main language, and to not have any diagnosed or suspected attention, language, learning, or hearing difficulties, or a history of middle ear problems. The number of children was limited to 16 because of practical logistical and funding issues, but a power analysis using a one-tail bivariate normal correlation in G*Power version 3.1.9.4 indicated that a power of 0.80 with an alpha of 0.05 would be achieved if the true correlation coefficient was 0.6.

Test Environment

All testing was completed in a quiet room in the child's school. There were minimal noise sources entering the room, however, if there was noise e.g. a class walking past, testing was paused until the noise stopped. Children first completed a hearing screen, then the LiSN-S, LiSN-U, and auditory memory test with the order of the three tests counterbalanced across participants. Testing was completed up until lunchtime at the school to avoid the possible effect of fatigue if testing was completed in the afternoon.

Hearing Screen

Each child's hearing was screened using pure tone audiometry on the day of testing. Only those who passed the screening test progressed on to the test battery. The 16 children included in the study had normal hearing defined as equal to, or better than, 20 dB HL at all octave frequencies from 500 Hz to 8000 using an Interacoustics Audio Traveller A222 portable audiometer (Middelfart, Denmark) with Telephonics TDH 39P audiometric headphones (Huntington, NY) in H7A Peltor cups (3M, St. Paul, MN).

Listening in Spatialized Noise – Sentences Test (LiSN-S)

The LiSN-S (Cameron & Dillon, 2009) measures a listener's ability to utilise inter-aural time and level cues to differentiate a target talker from distracting talkers. For the current study, a version of the LiSN-S developed for the Apple iOS mobile operating system was used (Cameron, Dillon, & Chong-White, 2018). Four different test conditions were all presented over headphones: the Different Voices ±90° (DV90, also known as the high-cue condition), Same Voice ±90° (SV90), Different Voices 0° (DV0), and Same Voice 0° condition (SV0, also known as the low-cue condition). The child was asked to repeat back the sentence spoken by the target speaker who sounded like she was speaking from in front of them. At the same time there were distracting voices which, depending on the condition, sounded like they were coming from either side of the person (±90°) or from the front (0°), and either had the same voice or different voice to the target talker. The test began with a short practice phase of the DV90 condition, and then the child completed the four LiSN-S conditions. The distracter track level was set at a constant level of 55 dB SPL. The initial target presentation level was at +7 dB SNR (62 dB SPL). The app was pre-calibrated so that the above level is achieved when the volume on the iPad is set to maximum. At this pre-set level the combined distracters at 0° have a long-term root mean square (RMS) level of 55 dB sound pressure level (SPL) as measured in a Bruel and Kjaer Head and Torso Simulator type 4128-C-001 (Naerum, Denmark) using an Apple Air 2 iPad running iOS 10.2.1. The volume of the iPad sound card was automatically set by the LiSN-S software.

The target presentation level was adjusted adaptively in accordance with the number of words correctly identified. If less than 50% of the words were correct the target increased by 2 dB. If exactly 50% of the words were correct, there was no change in the target level. If more than 50% the words were correct, the target decreased by 4 dB before the first upward reversal and decreased by 2 dB after the first upward reversal The software calculated the child’s 50% speech reception threshold (SRT) and z scores (i.e. number of population standard deviations by which an individual score differs from the mean score for children of the same age) for each of the four conditions and advantage measures (Cameron & Dillon, 2007a, 2008). The LiSN-S was administered using Sennheiser HD200 Pro circumaural headphones (Hanover, Germany) connected to an iPad Air 2 (Apple Inc., California).

Listening in Spatialized Noise – Universal Test (LiSN-U)

The LiSN-U (Cameron, Dillon, Chong-White, & Mealings, 2018; Cameron et al., in press) is a new language-independent version of the LiSN-S. The test stimuli and administration are described in detail in (Cameron et al., in press). In summary, the target and distracter stimuli comprise consonant-vowel-consonant-vowel (CVCV) pseudo-words (e.g. ti-gu). The ten consonants and three vowels that are utilized to construct the CVCV pseudo-words are /p, b, t, d, k, g, m, n, s, h, i, a, u/ and were chosen because they are common to most languages. Each of the consonants were paired with each of the vowels to create CV pairs which were recorded in an anechoic chamber by a female speaker in a general Australian accent. The CVs were then convolved with head-related transfer functions. The target CVCV pseudo words always sounded like they were coming from 0° azimuth. The distractor tracks consisted of multi-syllable CV pseudo-words that were played at +90° and -90° azimuth for the spatially-separated condition, and at 0° azimuth for the co-located condition.

First the listener completed a familiarisation phase. This involved the listener repeating back a sample of the target pseudo-words containing each of the 10 consonants and three vowels, in quiet. The listener had to correctly identify each of the phonemes before moving on to the test phase. Then the listener completed the spatially-separated condition and the co-located condition which included a short, separate practice phase at the beginning of each. A short warning tone is presented before each CVCV pseudo-word. One point was scored for each C correct in any order, and one point was scored for each V correct in any order, with a maximum of four points per trial. The distracter track level was set at a constant level of 65 dB SPL. The initial target presentation level was at +11 dB SNR (76 dB SPL). The app was pre-calibrated so that the above output level is achieved when the volume on the iPad is set to maximum. At this pre-set level the combined distracters at 0° have a long-term root mean square (RMS) level of 65 dB sound pressure level (SPL) as measured in a Bruel and Kjaer Head and Torso Simulator type 4128-C-001 (Naerum, Denmark) using an Apple Air 2 iPad running iOS 10.2.1. The volume of the iPad sound card was automatically set by the LiSN-U software.

The target presentation level was adjusted adaptively in accordance with how many phonemes the child got correct. If no phonemes were correct the target increased by 3 dB. If one phoneme was correct the target increased by 2 dB. If two phonemes were correct the target increased by 1 dB. If three phonemes were correct there was no change in the target level. In the spatially-separated condition, all four phonemes were correct the target decreased by 4 dB before the first upward reversal and decreased by 2 dB thereafter. In the co-located condition, if four phonemes were correct, the target always decreased by 2 dB. The 75% speech reception threshold was calculated for each participant as the average of the SNRs presented after the first reversal.

The LiSN-U only uses the same voice conditions which we will refer to as SV90 (spatially-separated) and SV0 (co-located) for consistency with the LiSN-S. The software calculated z scores, based on the normative data reported in (Cameron et al., in press), for each condition as well as the spatial advantage measure, being the difference in dB between the SV90 and SV0 scores. The LiSN-U was also administered using Sennheiser HD200 Pro circumaural headphones (Hanover, Germany) connected to an iPad Air 2 (Apple Inc., California).

Auditory Memory Test

The Test of Auditory Processing Skills – Third Edition (TAPS-3) number memory forward (NMF) and number memory reversed (NMR) (Martin & Brownell, 2005) subtests were used to assess the children's short-term memory and working memory respectively. The children heard strings of numbers that were pre-recorded by a female Australian-English speaker and played to the children at a comfortable level over the inbuilt speaker of an iPad Air 2 (Apple Inc., California). The children were asked to recall them in the same order that they were presented for the number memory forward condition, and in the reverse order that they were presented for the number memory reversed condition. Age-appropriate percentile scores were calculated for each condition individually.

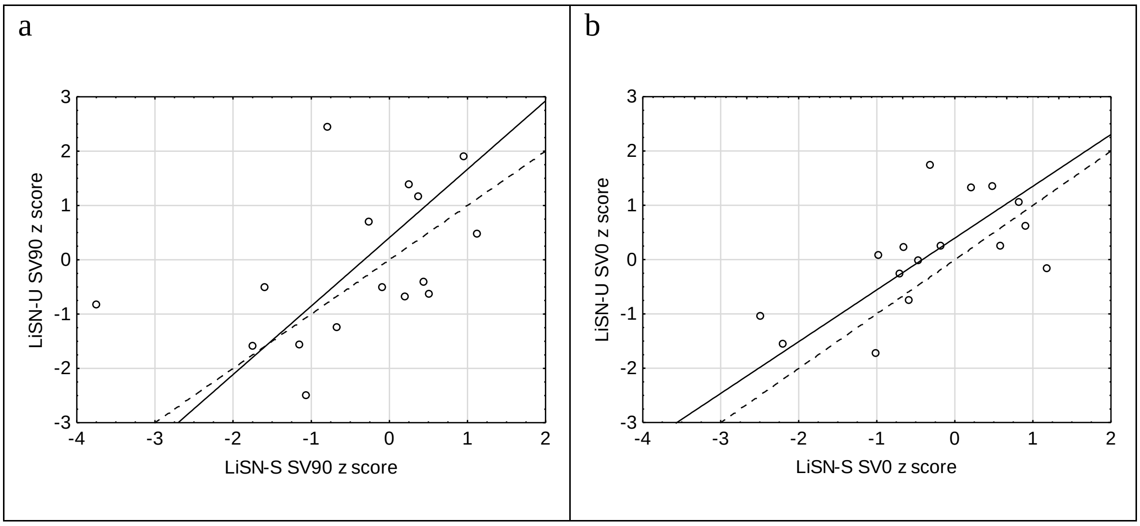
Results

Statistical analysis was performed using Statistica version 13 and R version 3.5.2. No children demonstrated a spatial processing disorder as defined by a z score less than -2 on the spatial advantage measure of the LiSN-S.

LiSN-S versus LiSN-U Correlations

Figure 1 (a, b, and c) shows the relationship between the LiSN-S z scores (which are based on the children's 50% SRT) and LiSN-U z scores (which are based on the children's 75% SRT) for each of the SV90, SV0, and spatial advantage measures. The corresponding correlation coefficients are 0.45 (p = 0.08), 0.65 (p = 0.006), and 0.22 (p = 0.42), respectively. As there were three comparisons, a Bonferroni correction was applied to the significance test, resulting in a per-comparison type-I error rate criterion of 0.0167, in order to hold the family-wise type-I error rate of 0.05. The correlation is significant for SV0, but not for the other two pairs of scores. The correlations for the two baseline conditions (i.e. SV0 and SV90) average 0.55. As r-values of this size have a 95% confidence interval around them of ±0.4, we do not attach any significance to the difference between these observed correlations.

As both the LiSN-S and LiSN-U contain measurement error, and as we do not wish to predict either of these measures from the other, the regression lines in Figure 1 are based on orthogonal regression. This regression method produces the same correlation coefficient as standard regression, but minimises the total deviation of the data points from the regression line, summed across both the x and y variables. For the two baseline measures, but not the difference measure, the slopes of these regression lines are close to unity and the intercepts are close to zero.



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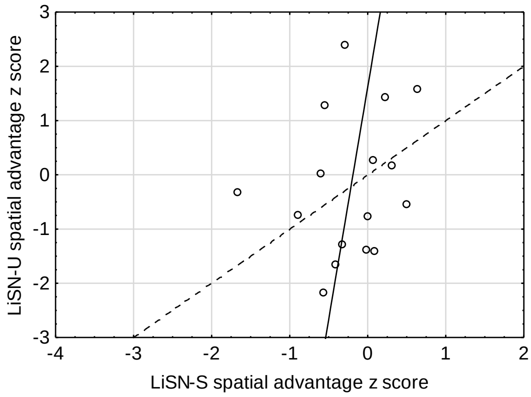

Figure 1: LiSN-S vs. LiSN-U correlations for a) SV90 condition, b) SV0 condition, and c) spatial advantage measure. The solid line represents the orthogonal regression line and the dotted line is the line of equality.

LiSN-S and LiSN-U versus Number Memory Correlations

Table 1 shows the LiSN-S and LiSN-U versus number memory correlations for each test condition. Moderate positive correlations were found for the LiSN-S DV90 and LiSN-U SV90 conditions and the LiSN-S and LiSN-U SV0 conditions with the number memory reversed percentiles. Because there are 16 comparisons with no clear hypotheses, except that the spatial advantage measures should not be correlated with memory, it is appropriate to apply a Bonferroni correction to the significance test, resulting in a per-comparison type-I error rate criterion of 0.0031, in order to hold the family-wise type-I error rate of 0.05. As the largest correlation was 0.55 (p = 0.026), none of the correlations were significant once the correction for multiple correlations were made. We note, however, that four out of the six correlations between number memory reversed and each of three LiSN-S and LiSN-U baseline scores have correlations > 0.5, which individually have uncorrected p values of 0.042 or less. With 16 comparisons, on average there would be only one that had $p < 0.05$ by chance alone, so with four of these reaching significance when uncorrected, it is very likely that the baseline LiSN scores are correlated with number memory reversed ability. However, as none individually are significantly correlated after correction, we cannot be dogmatic about which of these are correlated with number reversed memory. We note that both of the spatial advantage measures had smaller correlations, as expected.

Table 1: LiSN-S and LiSN-U versus TAPS-3 number memory correlations. No correlations were significant after Bonferroni correction ($p = 0.0031$).

	Number memory forward percentile	Number memory reversed percentile
LiSN-S DV90 z score	$r = 0.10$; $p = 0.71$	$r = 0.55$; $p = 0.03$
LiSN-S SV90 z score	$r = 0.31$; $p = 0.25$	$r = 0.45$; $p = 0.08$
LiSN-S DV0 z score	$r = 0.24$; $p = 0.38$	$r = -0.06$; $p = 0.84$
LiSN-S SV0 z score	$r = 0.43$; $p = 0.10$	$r = 0.51$; $p = 0.05$
LiSN-U SV90 z score	$r = -0.11$; $p = 0.70$	$r = 0.54$; $p = 0.03$
LiSN-U SV0 z score	$r = 0.13$; $p = 0.63$	$r = 0.54$; $p = 0.03$
LiSN-S Spatial Adv	$r = 0.04$; $p = 0.88$	$r = 0.22$; $p = 0.41$
LiSN-U Spatial Adv	$r = -0.16$; $p = 0.55$	$r = 0.37$; $p = 0.16$

Discussion

The aim of this study was to correlate typically-developing, English-speaking children’s scores on the LiSN-S with the newly developed language independent version of the test, the LiSN-U. As hypothesised, the LiSN-U baseline z scores (based on the children’s 75% SRT) were moderately correlated with their corresponding LiSN-

S z scores (which are based on their 50% SRT) ($r = 0.65$ for the co-located condition and 0.45 for the spatially-separated condition). Although the first of these was significantly different from zero ($p < 0.01$) and second was not ($p = 0.08$), we do not attach any importance to this difference given the small sample size, and resulting uncertainty range of the correlation coefficients. Based on the known test-retest reliability of LiSN-S (Cameron & Dillon, 2007b) and LiSN-U, the less than perfect correlations found for the two baseline measures do not indicate any lack of agreement between the two measures, rather, the inevitable consequence of random measure error. The much smaller correlation found for the spatial advantage measure is also likely to be the result of the much larger random measurement error present in any difference measure. The spatial advantage measure in dB is the difference in dB between the SV0 and SV90 speech reception thresholds. Consequently, both the LiSN-S and LiSN-U spatial advantage measures contain a greater degree of measurement error than the scores from which they were calculated. This increased measurement error is compounded in this experiment by the correlation being based on a small sample size, and the sample being drawn from a typically developing population with a consequential restricted range of scores. Although the two tests target different points on their psychometric functions, as both points are well within the sloping portions of their psychometric functions, we do not think it likely that this difference contributes to the less than perfect correlation. Validation that the LiSN-U quantifies spatial advantage in the same way as the LiSN-S will need to wait for a larger study, and/or one that includes people with a larger range of spatial processing abilities (i.e. those with spatial processing disorder).

The location of the regression lines for the two baseline measures in Figure 1 very close to the lines of unity (dashed lines) strongly support the hypothesis that the

LiSN-S and LiSN-U are measuring the same, or closely related abilities. The location of the regression lines are, of course, much less affected by random measurement error than the individual data points. Decibel scores on each test were scaled according to pre-existing and independent normative data for each test. The regression lines for the two baseline conditions were very close to the line of equality. This indicates that, on average, the ability of each typically developing child to understand speech relative to same-aged peers is rated very similarly by the two tests. This applied whether the target and speech were co-located or spatially-separated. Note that the LiSN-S also has different voices conditions for the co-located and spatially-separated conditions, however we only included the same voice conditions in the analysis as the LiSN-U only included same voice conditions.

The relationship between the children's auditory memory and their LiSN-S and LiSN-U scores was also examined. No significant correlations were found between the child's short-term memory and their LiSN-S or LiSN-U results. However, moderate (non-significant) positive correlations were found for the LiSN-S DV90 condition and LiSN-U SV90 condition and the LiSN-S and LiSN-U and SV0 conditions with the number memory reversed percentiles. This potential impact of working memory (or some other cognitive ability correlated with it) on speech identification is why the LiSN-S and LiSN-U software use difference scores to estimate spatial advantage (i.e. SV0-SV90). By using difference scores, cognitive effects such as an individual's working memory are controlled for. For example, if a child has better than average working memory and hence scores well on both the SV90 and SV0 conditions, when the difference between the two is taken, the impact of working memory on the difference score is greatly reduced. To this end, and as hypothesized, there was no significant correlation between the LiSN-S and LiSN-U spatial advantage scores and the number memory forward or reversed conditions of the TAPS-3. The greater measurement error expected to be in the spatial advantage scores may also have contributed to the lack of significant correlation.

A limitation of this study, in addition to the small sample size, is that the testing was completed at the child's school, whereas it is recommended that the testing is completed in a sound-attenuated booth. The room chosen was in a quiet location and there were minimal noise sources entering the room, however, there was occasional noise such as a class walking past. In these cases, testing was paused until the noise stopped. It is possible, however, that some of the noise may have resulted in underestimating the child's SRT.

Conclusions

This study shows a moderate relationship between the LiSN-S and LiSN-U when the distractors and target speech are co-located. A study with a larger sample of participants is needed to further understand the relationship between the two tests, especially for the spatially-separated condition.. The advantage of the LiSN-U is that it is language-independent, so the listener does not need to be proficient in English to be able to complete the test. It is also shorter as it does not include the different voice conditions, so it has potential to be an efficient tool to measure a listener's spatial processing abilities.

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Table

Table 1: LiSN-S and LiSN-U versus TAPS-3 number memory correlations. Asterisks show significant correlations (* < 0.05).

	Number memory forward percentile	Number memory reversed percentile
LiSN-S DV90 z score	0.10	0.55*
LiSN-S SV90 z score	0.31	0.45
LiSN-S DV0 z score	0.24	-0.06
LiSN-S SV0 z score	0.43	0.51*
LiSN-U SV90 z score	-0.11	0.54*
LiSN-U SV0 z score	0.13	0.54*
LiSN-S Spatial Adv	0.04	0.22
LiSN-U Spatial Adv	-0.16	0.37

Figure Caption

Figure 1: LiSN-S vs. LiSN-U correlations for a) SV90 condition, b) SV0 condition, and c) spatial advantage measure. The solid line represents the orthogonal regression line and the dotted line is the line of equality.