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Cultural Variation in Verbal Versus Spatial Neuropsychological Function Across the Life Span

Trey Hedden, Denise C. Park, Richard Nisbett, and Li-Jun Ji
University of Michigan

Qicheng Jing and Shulan Jiao
Chinese Academy of Sciences

Established culture-invariant measures are needed for cross-cultural assessment of verbal and visuospatial speed of processing and working memory across the life span. In this study, 32 younger and 32 older adults from China and from the United States were administered numerically based and spatially based measures of speed of processing and working memory. Chinese superiority on the numerically based tasks was found for younger adults. Age and increasing task demands diminished this cultural effect, as predicted by the framework proposed by D. C. Park, R. Nisbett, and T. Hedden (1999). However, the visuospatial measures of both working memory and speed of processing did not differ cross-culturally for either age group. The authors concluded that these visuospatial measures provide culture-invariant estimates of cognitive processes in East Asian and Western cultures, but that numerically based tasks show evidence of cultural and linguistic biases in performance levels.

It is by now common knowledge that certain cognitive skills decline as people age (Lindenberger & Baltes, 1997; Schaie, 1998). Older adults are especially disadvantaged on many basic cognitive measures in which prior knowledge plays little or no role in the requirements of the task (Schaie, 1998). The two most commonly studied indicators of cognitive aging are measures of speed of processing (Salthouse, 1996) and of working memory (Baddeley, 1986). Speed of processing is a measure of how quickly simple perceptual or mental operations can be performed, whereas working memory is the ability to simultaneously store and manipulate information in a temporary memory buffer. Measures of speed and working memory mediate a large proportion of the age-related variance in memory (Park & Hedden, in press; Park et al. 1996), reasoning (Salthouse, 1992, 1993a), and many other cognitive abilities (Lindenberger & Baltes, 1994).

In addition to their importance in the cognitive aging literature, speed of processing and working memory functions are important neurobiological and neuropsychological constructs as well. Lezak (1995) suggested that perceptual speed of processing as measured by the Digit-Symbol task, which is from the Wechsler Adult Intelligence Scale—Third Edition (Wechsler, 1997), is highly sensitive to both brain damage and dementia, and to normal age-related declines in cognition, although the locus of the deficit in the brain is not well defined by performance on this task. Working memory deficits have similarly been implicated in frontal dysfunction (Gabrieli, Singh, Stebbins, & Goetz, 1996; Smith, Geva, & Marshuetz, in press), Alzheimer's disease, and normal cognitive aging (Belleville, Peretz, & Malenfant, 1996; Reuter-Lorenz, 2000).

Although age-related declines in speed of processing and working memory are well documented (Salthouse, 1991), there has been little research on developing cross-cultural instruments to measure these important functions. A substantial literature has examined the validity of dementia screening devices across cultures (e.g., Salmon et al., 1989), but this research has not focused on the applicability of basic cognitive measures cross-culturally. Indeed, Chinese researchers have noted that neuropsychological test batteries are infrequently used in China (Chan & Lee, 1993). In the present study, we examined the potential cross-cultural applicability of spatial and verbal measures of speed of processing and working memory. Such measures would be extremely useful for neuropsychological assessment and for direct comparisons of the cognitive performance of younger and older adults in East Asian and Western cultures.

The measurement of perceptual speed of processing and working memory capacity is straightforward. Many perceptual speed tasks involve having participants make a series of same–different judgments as rapidly as possible about strings of digits or simple geometric figures. Commonly used measures of immediate and working memory capacity are the Forward and Backward Digit Span tasks from the Wechsler Adult Intelligence Scale—Revised (WAIS–R, Wechsler, 1981).

Trey Hedden, Denise C. Park, Richard Nisbett, and Li-Jun Ji, Department of Psychology, University of Michigan; Qicheng Jing and Shulan Jiao, Institute for Psychology, Chinese Academy of Sciences, Beijing, China.

Li-Jun Ji is now at the Department of Psychology, Queen's University, Kingston, Ontario, Canada.

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Correspondence concerning this article should be addressed to Trey Hedden, Department of Psychology, University of Michigan, 4422 East Hall, Ann Arbor, Michigan 48109. E-mail: hedden@umich.edu

The Forward Digit Span requires participants to repeat back a list of digits, and the maximum number that participants can repeat without error is recorded. This is an estimate of short-term storage capacity and is sensitive to left hemisphere damage (Lezak, 1995) but less sensitive to aging (Craik & Jennings, 1992) and dementia (Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986). The Backward Digit Span would typically be viewed as a working memory task that involves both storage and manipulation of information. Participants listen to digits and repeat them back in the reverse order from presentation. Backward Digit Span is sensitive to left hemisphere damage and also to frontal lobe damage because this task requires ordering and sequencing. It is also an indicator of dementia (Lezak, 1995) and displays consistent, though relatively small, age effects (Kausler, 1991). The Corsi Blocks Task (Milner, 1971), sometimes called the Spatial Span Task, is also an estimate of working memory and is very similar to the Forward and Backward Digit Span except that it is visuospatial in nature. Participants are presented with an array of 10 blocks, and the experimenter points to them in a predetermined order. The participant's task is to point to the blocks in the same order as the experimenter (forward condition) or in the reverse order (backward condition). Forward and Backward Corsi Blocks tasks are sensitive to frontal lobe and right hemisphere damage as well as to normal aging effects and dementia (Rahman, Sahakian, Hodges, Rogers, & Robbins, 1999; Roth & Crosson, 1985). On the basis of a review of studies, Luciana and Nelson (1998) indicated that the right ventrolateral prefrontal cortex is a neural correlate of performance on the Forward Spatial Span task.

Separate estimates of the visuospatial and verbal aspects of working memory are important because the influential Baddeley (1986) model of working memory includes separate visuospatial and verbal subsystems (measured by Forward Corsi Blocks and Forward Digit Span) that are under the control of the central executive function (measured by the sequencing and organizational aspect of Backward Digit and Backward Corsi Blocks). There has been some success in localizing these visuospatial and verbal subsystems with neuroimaging technology (Courtney, Ungerleider, Keil, & Haxby, 1996; D'Esposito, Aguirre, Zarahn, Ballard, Shin, & Lease, 1998; Smith & Jonides, 1997) as well as localizing the central executive function (Smith & Jonides, 1997, 1999). Studies using positron emission tomography and functional magnetic resonance imaging have indicated that executive function is localized in the dorsolateral prefrontal cortex, whereas storage systems are located more ventrally in the frontal cortex, with spatial information more localized in the right hemisphere and verbal information in the left hemisphere (D'Esposito et al., 1998; Smith & Jonides, 1997, 1999).

The specific neurobiological underpinnings of age-related changes of speed of processing are not as well understood but are usually attributed to global changes in neurological function, as in the information-loss model of cognitive aging (Myerson, Hale, Wagstaff, Poon, & Smith, 1990). Salthouse (2000) noted that "reductions in processing efficiency could result from decreases in the number of functional neurons, in the extent of dendritic branching or myelin sheathing for surviving neurons, in the quantity of particular types of neurotransmitters, etc." (p. 43). Other candidates for the neurological basis of processing speed include a decrease in dopamine receptors and declines in brain weight (Raz, 2000). It is interesting to note that global views of processing speed would hold that the type of information, that is, visual versus verbal, being processed makes little difference to the estimate of a participant's perceptual speed. However, as neuroimaging and neuropsychological studies have demonstrated, different neurological pathways are used when operating on visual and verbal modalities of information, even in seemingly simplistic processing tasks (Sergent, Zuck, Levesque, & MacDonald, 1992). Therefore, one might expect that age-related declines in speed of processing could have modality-specific effects.

Interest in cultural variability in behavior has been growing, with provocative findings challenging the assumed cultural universality of many phenomena (Fiske, Kitayama, Markus, & Nisbett, 1998). Culture-specific variables that may influence performance on cognitive tasks include differences in linguistic factors, approaches to learning, value placed on education, availability and organization of educational institutions, child-rearing practices, and degree of emphasis on innate characteristics versus situational constraints (Gow, Balla, Kember, & Hau, 1996; Stevenson & Lee, 1996; Stevenson, Lee, Chen, Stigler, Hsu, & Kitamura, 1990; Wu, 1996). Culture itself is composed of a host of interrelated variables, each of which provides a context into which cognition must be placed. Nevertheless, little research has been aimed specifically at examining basic cognitive processes, such as speed and working memory, across cultures. We believe that the potential effects of culture are so pervasive that even some tasks that measure the building blocks of cognition, such as speed and working memory, may be culturally biased (Park, Nisbett, & Hedden, 1999). We explored this issue in the present study.

Establishing cross-cultural equivalence on tests of basic cognitive processes is fundamental to further investigations of cultural differences in higher cognitive function, an increasingly important area of inquiry. To understand any differences in cognitive behavior across cultures, it is necessary to establish that the populations being examined are equivalent on fundamental aspects of cognition that may predict or influence performance on the behavior of interest. Without such a reference point, the understanding of cultural differences is subject to many competing interpretations. Because of the importance of speed of processing and working memory as measures of fundamental cognitive function, the present study investigated visual and verbal measures of these constructs in two cultural settings: the United States and China.

Prior cross-cultural studies of cognitive function in younger adults have found evidence of cultural variation on basic cognitive tasks. For example, Stigler, Lee, and Stevenson (1986) and Chen and Stevenson (1988) reported Chinese superiority on the digit span task because of the shorter pronunciation duration of digits in the Chinese language as compared with in the English language rather than superiority in general ability, strategy, or educational differences. Chincotta and Underwood (1997), in a comparison study among speakers of six different languages, found that Chinese speakers had the largest digit spans. However, this advantage was eliminated with articulatory suppression, suggesting that differences in the pronunciation duration of digits were responsible for the Chinese advantage. Cheung and Kemper (1993) found that English–Chinese bilinguals had larger verbal working memory spans in Chinese than in English and that these differences could be accounted for by phonological properties of the two languages.

Little research has investigated age-related cognitive effects across cultural settings. Two studies reported differences in arithmetical ability between Chinese and American adults across the life span but concluded that this was due to educational differences in which the American younger adults demonstrated underdeveloped arithmetical skills (Geary et al., 1997; Geary, Salthouse, Chen, & Fan, 1996). The lack of data is somewhat surprising given that older adults, because of their lengthy exposure to the culture, should provide strong examples of cultural strategies, norms, and knowledge structures. In addition, aging could provide a window on the manner in which biologically driven declines in cognition interact with these strategies, norms, and structures (Baltes, 1987, 1993). As outlined in the theoretical framework presented by Park et al. (1999), when a task relies heavily on processing-intensive mechanisms, one should expect that cultural effects observed in a younger age group should be diminished in an older age group. This occurs because the neurobiological constraints of cognitive aging cause declines in basic processing that, in turn, limit an older adult's ability to effectively use culturally prescribed strategies or knowledge structures that may be advantageous to performance on the task. The limitations imposed on the application of strategic processing may be particularly pronounced when the prefrontal executive function deficits associated with aging (Reuter-Lorenz, 2000) are required for successful task performance. The current study presents evidence for this pattern of cultural convergence across age groups.

In the present study, we investigated cross-cultural differences in younger and older adults on speed of processing and working memory tasks that are numerically based versus visuospatial in their processing requirements. Both Americans and Chinese represent number concepts and perform mathematical computations using Arabic numerals. Given that number-based cognitive tasks are left-hemisphere tasks that rely on the same written symbols across the two cultures, one might conclude that such tasks provide an ideal medium for studying cross-cultural differences in cognitive processes. Linguistic differences, however, may appear in left-hemisphere tasks involving the processing of numbers or other symbolic material. We anticipated that cultural differences would be found on the numerically based tasks but not on the visuospatial tasks in younger adults primarily because of linguistic differences in the pronunciation duration of digits (Chen & Stevenson, 1988; Chincotta & Underwood, 1997). For older adults, we expected performance to decrease with age on visuospatial and verbal tasks within both cultures but anticipated that cultural differences observed in younger adults would be diminished in older adults as processing demands increased. As outlined in Hedden and Park (2001), this second prediction stemmed from the cultural convergence hypothesis of Park et al. (1999) that biological declines in cognitive functioning that accompany aging may limit cultural differences in strategy use and knowledge structures under cognitively demanding conditions, resulting in greater similarity across cultures in late adulthood.

Method

Participants

One hundred twenty-eight participants in two age groups from America and China were sampled. The younger Americans (18 men, 14 women) were undergraduate students at the University of Michigan, and the younger Chinese (18 men, 14 women) were students at Beijing Normal University. The older Americans (17 men, 15 women) were active, community-dwelling residents of the Ann Arbor, Michigan area who had volunteered to participate in the research. The older Chinese adults (15 men, 17 women) resided in Beijing, China, and were recruited from the pool of retired faculty and staff associated with the universities near the Institute of Psychology, where the research was carried out. Younger and older American participants were tested in laboratories at the University of Michigan. The younger Chinese participants were tested in laboratories at Beijing Normal University, and the older Chinese participants were tested at laboratories at the Institute of Psychology in Beijing.

Details about the sample are presented in Table 1. Although the samples were generally equivalent, it should be noted that the Chinese undergraduates were primarily undergraduate upperclassmen, whereas the American undergraduates were primarily freshmen. Hence, there were small but significant age, $t(62) = 3.63$, $p < .005$, and education, $t(62) = 4.93$, $p < .001$, differences between the two younger groups. Also, the average age of the older Americans was higher than that of the older Chinese, $t(62) = -6.36$, $p < .001$, consistent with other studies that have examined age differences in China and in the United States (Geary, Bow-Thomas, Liu, & Siegler, 1996; Geary et al., 1997). Demographic data show that in 1999 adults above the age of 65 constituted 6% of the population in China compared with 12% in the United States (Central Intelligence Agency, 1999). Because of these factors, we

Table 1
Demographic Information for Younger and Older Chinese and Americans

		Age[a]		Education[a]		Vocabulary[b]	
Group	*n*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Chinese							
Younger	32	21.94	1.74	15.31	1.31	14.53	0.80
Older	32	64.56	3.39	15.81	1.38	14.03	1.36
Americans							
Younger	32	20.44	1.56	13.87	1.01	13.06	1.22
Older	32	71.25	4.89	15.56	2.47	13.25	2.50

[a] In years. [b] Vocabulary is the scaled score for the vocabulary subtest of the Wechsler Adult Intelligence Scale—Revised (Americans) or the Wechsler Adult Intelligence Scale—Revised in China (Chinese).

believe that the age discrepancies in our sample were representative of the populations of the two countries. The education levels of the older American adults and the older Chinese adults were equivalent, $t(61) = 0.61$.

All participants completed the Vocabulary subtest of the WAIS–R or the Revision of Wechsler's Adult Intelligence Scale in China (WAIS–RC; Gong, 1983). This intelligence scale provides a previously validated set of norms within each culture. These norms were used to provide scaled scores that placed each participant's performance on a scale relative to the reference population within that culture. Comparisons between the younger and the older groups within each culture indicated no significant age differences in either culture. To further address issues of equating participant abilities, we report analyses using education and WAIS–R and WAIS–RC scores as covariates in the Results section.

Neuropsychological Tests Administered

Speed of processing. Two measures of speed of processing were used: a verbal and a visuospatial measure. The verbal task was the Digit Comparison Task, adapted from the Letter Comparison Task of Salthouse and Babcock (1991). The Digit Comparison Task is a paper-and-pencil test involving same–different judgments of digit strings. The test is divided into three sections, with each section consisting of digit strings of one length. The first section involves three-digit strings, the second section involves six-digit strings, and the third section involves nine-digit strings. Participants were given 45 s for each section to make as many comparisons as possible.

The Pattern Comparison Task (Salthouse & Babcock, 1991) is a figural analog to the Digit Comparison Task, with each section involving comparisons among figures consisting of three-, six-, or nine-line segments. Scores on both the Digit and the Pattern Comparison Tasks were calculated as the number correctly marked minus the number incorrectly marked for each level of complexity (three-, six-, or nine-line segments). In addition, a total adjusted item score was computed by summing the scores for each level of complexity and dividing them by three. Although these measures of processing speed are not standardized neuropsychological tests, these measures may provide a cleaner estimation of processing speed than the WAIS–R Digit–Symbol task. These two tasks were used instead of the Digit–Symbol task because the processing requirements of each individual task are distinct, whereas the Digit–Symbol task mixes both visuospatial and numerical stimuli in a single task. The Pattern Comparison Task correlates .63 with the Digit-Symbol task, whereas the Letter Comparison Task (on which the Digit Comparison Task was based) correlates .64 with the Digit-Symbol task (Salthouse, 1993b).

Working memory. There were two verbal and two visuospatial measures of working memory collected in the study. The Forward and Backward Digit Span tasks from the WAIS–R were used to measure verbal working memory. Beginning with a series of two digits in length, each digit string was read aloud at an approximate rate of one digit per second. Two trials at each series length were given. Participants repeated the digits in either the same order (forward version) or the reverse order (backward version). If either trial of a given length was correctly recalled, then the series length was increased by one, up to a maximum of 10 digits. The task was terminated when a participant missed both trials of a given length. The total trials correct score was used (Randhawa, Pershad, & Verma, 1981), providing a larger range and more precision than the usual standard span score.

The visuospatial measure of working memory was the Corsi Blocks Task (Milner, 1971). It was given in both forward and backward versions. This task consists of a board with 10 blocks in fixed locations. The experimenter tapped on a series of blocks, which the participant then repeated either in the same order (forward version) or in the reverse order (backward version). The series became progressively longer in length, with two trials of each series length being administered until the participant was unable to correctly repeat any trials of a given length. Scoring was identical to that of the Forward and Backward Digit Span Task.

Translations. Two native Chinese speakers translated all instructions and task materials from English into Chinese. Any disagreements were resolved through discussion between the two translators.

Procedure

Participants provided informed consent and completed a demographics questionnaire. Participants were then administered the Forward Corsi Blocks task, the Backward Corsi Blocks task, the Forward Digit Span task, and the Backward Digit Span task. Participants next completed the Digit Comparison Task and the Pattern Comparison Task. The vocabulary subtest of the WAIS–R (for Americans) or the WAIS–RC (for Chinese) was then administered. All participants received the tasks in the same order. Participants were debriefed and compensated 10 U.S. dollars per hour in the United States or 20 Chinese yuan per hour in China. One Chinese participant's data was discarded for the Pattern Comparison task because the participant inadvertently skipped one section of the task.

Results

The analysis of the speed of processing and working memory data provided strong evidence for cultural invariance on the visuospatial measures of speed and working memory, but the numerically based versions of both tasks showed evidence of superior performance by Chinese compared with American participants. In addition, there was evidence that cultural differences were larger on the numerically based tasks for younger adults compared with older adults.

Speed of Processing

Separate analyses of variance (ANOVA) were conducted on the Pattern Comparison Task and the Digit Comparison Task. For each analysis, age (younger–older) and culture (Chinese–American) were between-groups variables, and complexity (the number of elements in the comparison: three, six, or nine) was a within-subjects variable. We report the more conservative analyses, which include education and vocabulary score as covariates. When these covariates were removed from the model, the pattern of results was unchanged. Because of the mean age difference between the two older groups, we also conducted follow-up analyses on all comparisons between these two groups using age as a covariate. The results of those analyses were substantially and statistically the same as the presented results.

For the Pattern Comparison data, the ANOVA yielded a significant main effect of age, $F(1, 121) = 101.75$, $p < .001$, because younger adults made more comparisons than older adults (28.78 vs. 21.19). There was a significant interaction of Age × Complexity, $F(2, 242) = 5.31$, $p <$

.01, with age differences being larger on less complex items (younger *M*s = 37.33, 26.66, and 23.22; older *M*s = 27.20, 19.91, and 15.94 for three-, six-, and nine-element comparisons, respectively). The effects of culture are displayed in the left panel of Figure 1. It is important to note that the analysis did not yield a significant main effect of culture nor any interaction of culture with other variables, suggesting that the Pattern Comparison Task measured speed of processing equivalently across the two cultures.

The analysis of the Digit Comparison Task yielded a somewhat different pattern of findings, as shown in the right panel of Figure 1. As in the Pattern Comparison analysis, there was a main effect of age (27.39 items completed for younger vs. 17.78 items completed for older participants), $F(1, 122) = 178.38$, $p < .001$. There was also a main effect of complexity, $F(2, 244) = 3.11$, $p < .05$, as items with more elements had a lower completion rate (*M*s = 35.42, 19.56, and 12.78 for three-, six-, and nine-element comparisons, respectively). Similar to the Pattern Comparison results, there was an interaction of Age × Complexity, $F(2, 244) = 38.53$, $p < .001$, with age effects larger on less complex items (younger *M*s = 42.78, 24.23, and 15.67; older *M*s = 28.06, 14.88, and 9.89 for three-, six-, and nine-element comparisons, respectively). Although there was no culture main effect, the Age × Culture interaction was significant, $F(1, 122) = 9.43$, $p < .005$. The interaction, depicted in the right panel of Figure 1, achieved significance because younger Chinese participants performed better on this task than did younger American participants, $t(62) = 2.32$, $p < .05$, but the reverse was true for older Chinese and older American participants, $t(62) = -2.24$, $p < .05$. This interaction suggests that younger Chinese are more facile with digit-based comparisons than younger Americans, but that this pattern is not maintained in older adults. More definitive evidence of numerical facility in the younger Chinese group occurred in the working memory data presented next.

Working Memory

Separate analyses were conducted on the Corsi Blocks and Digit Span data. For each analysis, age and culture were between-groups variables and task order (forward or backward) was a within-subject variable. The working memory analyses yielded findings similar to the analyses of speed of processing. The visuospatial measures of working memory appeared to be culture-invariant measures of capacity and processing, but the digit span measures appeared to be culturally saturated, with better performance by Chinese participants on digit span measures under conditions described below. Education and vocabulary scores were included as covariates; removing these from the model did not affect the pattern of results. In addition, results of follow-up analyses on all comparisons between the two older groups using age as a covariate were substantially and statistically the same as the presented results.

In the ANOVA on the number of correct trials in the Corsi Blocks Task, only a main effect of age was observed (*M*s = 9.26 and 7.24 for younger and older participants), $F(1, 122) = 68.38$, $p < .001$. No other effects were significant in this analysis because of the nearly identical performance on this task across cultures, as evidenced in the left panels of Figure 2.

The ANOVA on number of correct trials for digit span yielded a different pattern of results. As in the Corsi Blocks analysis, there was a main effect of age, $F(1, 122) = 17.18$, $p < .001$, because of the better performance by younger adults compared with older adults (*M*s = 10.89 and 9.22, respectively). There was also a main effect of culture, $F(1, 122) = 21.59$, $p < .001$, with better performance by Chinese ($M = 11.02$) compared with American ($M = 9.09$) participants. There was also a Culture × Order interaction, $F(1, 122) = 20.29$, $p < .001$, and a Culture × Age effect, $F(1, 122) = 5.29$, $p < .05$. These effects were qualified by the critical three-way interaction of Culture × Age × Order, $F(1, 122) = 9.26$, $p < .005$. This interaction can be seen in the right panels of Figure 2. Simple effects tests indicated that the younger Chinese participants outperformed the younger American participants in both the forward, $t(62) = 5.97$, $p < .001$, and the backward, $t(62) = 3.63$, $p < .005$, versions of the task, whereas the older Chinese participants were superior to the older American participants in

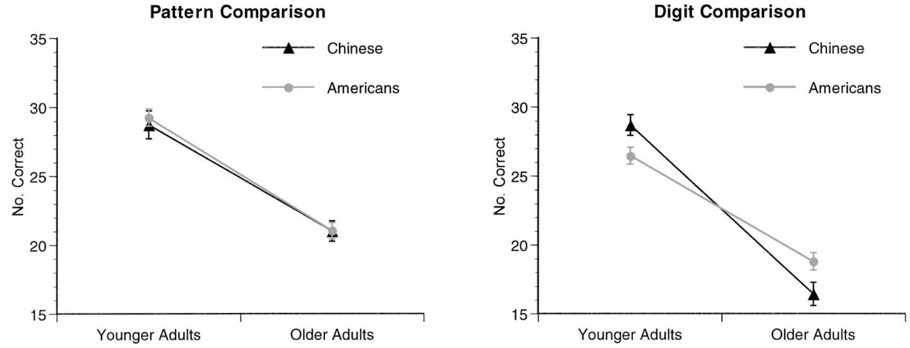

Figure 1. Performance on a visuospatial and verbal measure of speed of processing by younger and older American and Chinese adults. Left: Cultural equivalence on the visuospatial measure (Pattern Comparison). Right: Cultural differences in the numerically based measure (Digit Comparison).

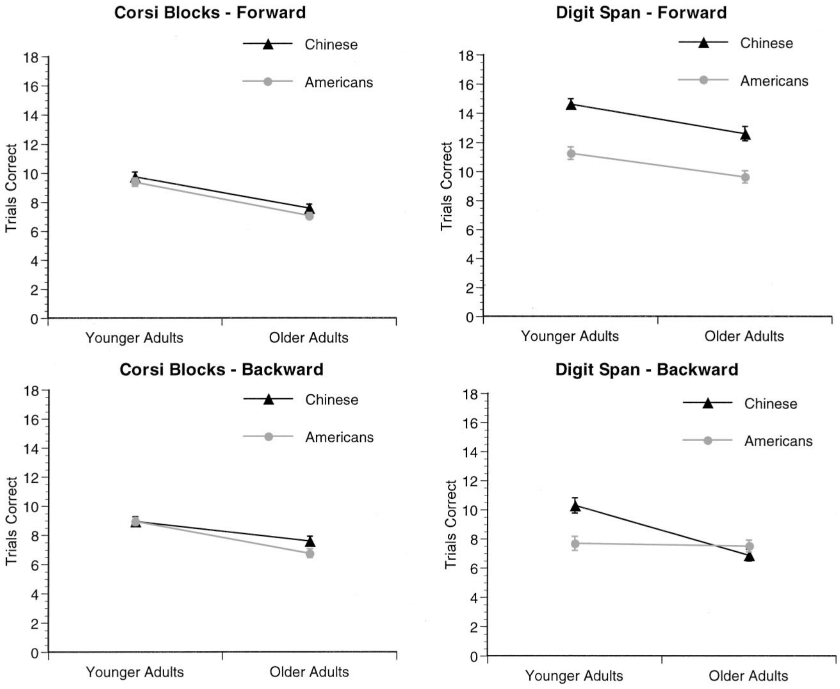

Figure 2. Performance on forward and backward versions of working memory tasks by younger and older American and Chinese adults. A visuospatial measure (Corsi Blocks) shows cultural equivalence. Chinese superiority is observed on the forward version of the Digit Span, but this effect is mitigated with age in the backward version.

the forward, $t(62) = 4.57$, $p < .001$, but not the backward, $t(62) = -1.12$, $p > .25$, version of the task.

Discussion

The main findings from this study are as follows. First, we observed cultural invariance on speed of processing and working memory tasks that involved visuospatial processing. There were no main effects or interactions involving the culture variable on the Pattern Comparison Task or on the Corsi Blocks Tasks. Second, cultural differences did emerge when digits were used as stimuli, despite the fact that both cultures use Arabic numbers to represent quantities and mathematical constructs. Third, cultural differences on the numeric tasks observed in the younger group were attenuated in the older age group. Chinese superiority on the Digit Comparison Task in younger adults was not maintained by Chinese older adults. Similarly, cultural differences among the younger participants were not observed among the older participants on the Backward Digit Span task. Each of these findings will be discussed in turn.

The first finding that visuospatial measures of speed of processing and working memory were culture-invariant suggests that these tasks provide a means for equating members of various cultures on visuospatial functioning. Robust age differences were observed in these tasks as well, indicating that they measure age-sensitive declines in cognitive functioning, while remaining unaffected by cultural differences. Similarly, Geary et al. (1996) found no culture differences between younger and older adults in America and China on tasks involving spatial orientation, further indicating the possibility of developing culture-invariant measures within the visuospatial domain. Further investigation should yield normative measures that may be useful in diagnosing neuropsychological function for nonverbal processing in both older and younger adults across cultures. This is an important finding because such culture-invariant functional measures can be useful for interpreting differences on other tasks between cultures.

The second finding of cultural differences on the digit-based tasks was likely due to linguistic differences between spoken Chinese (Mandarin or Putonghua) and spoken English, despite the fact that the Arabic numbers are visually represented identically in the two languages. Cheung and Kemper (1993, 1994) reported better memory performance in Chinese–English bilinguals when the Chinese language was used due to a lower processing load imposed by Chinese syllables compared with English syllables. Chinese syllables are less dense and are pronounced more quickly than English syllables. This appears to be the case particularly for Chinese digits, as there are no two-syllable digits, whereas *zero* and *seven* both have two syllables in English. In addition, because of the density of the syllabic structure in English compared with Chinese (e.g., *three* and *eight* in English vs. *san* and *ba* in Chinese), the articulation rate for American digits is longer than for Chinese digits. This explanation is further strengthened when the Culture ×

Order interaction observed for Digit Span is considered. As shown in the right panels of Figure 2, the effect of culture is most pronounced on Forward Digit Span, a task where items that have a longer articulation rate would result in fewer items being held in memory (Baddeley, Thomson, & Buchanan, 1975; Ellis & Hennelley, 1980; Naveh-Benjamin & Ayres, 1986). In contrast, Backward Digit Span requires more than the rehearsal and recitation of digits. Participants must actively manipulate the array of digits in memory, and this addition of processing requirements renders the linguistic elements of the task somewhat less important, resulting in a smaller cultural bias on this task. Although the culture effect is observed in both the Forward and the Backward Digit Span tasks for the younger age group, the mean difference is somewhat smaller in the backward than in the forward version, though not statistically so. For younger adults, the processing demands imposed by even the backward version may not be taxing enough to eradicate the advantage that the Chinese gain from the structure of their language. The mitigation of cultural or linguistic differences with the addition of processing requirements demonstrates the tension between the mechanics (process) and the pragmatics (knowledge structures) associated with cognition (Baltes, 1987). As processing requirements of a task increase, cognitive mechanics may become more important than culturally based knowledge to performance. Although these digit-based tasks would have appeared to be likely candidates to isolate culture-invariant measures of left-hemisphere function, the differences in syllabic structure between Chinese and English result in evidence of culturally saturated rather than culture-invariant performance on these tasks.

The third important finding was that cultural differences between the younger groups were not always maintained in the older groups. This pattern of attenuation of cultural effects with age was observed in the data of both the Digit Comparison Task, as portrayed in Figure 1, and the Backward Digit Span task (see lower right panel of Figure 2). The superiority of younger Chinese participants on these digit-based tasks was not maintained when older adults were tested. Park et al. (1999) postulated that neurological declines associated with aging may impose constraints on an older adult's ability to apply strategies and knowledge structures specified by his or her culture when task demands are high. In an extension of this hypothesis to communicative domains, Hedden and Park (2001) reviewed the linguistic influences on digit-based working memory and hypothesized that such linguistic differences would be diminished with age in conditions involving high processing loads. The pattern of results observed on the digit-based tasks is consistent with this hypothesis. The cultural effect continues to be observed in the older groups in the Forward Digit Span task because this task involves a relatively low working memory load. Supporting this interpretation, a study of kindergarten through third-grade children in China and the United States found that Chinese children outperformed American children on the Forward Digit Span task at all grade levels, even though working memory continues to develop during this time frame (Geary et al., 1996). In the Backward Digit Span task, in which processing demands increase, the culture effect is mitigated with age. It is likely that the lack of an age effect in the American sample on the Backward Digit Span task also contributed to this mitigation. Although the younger Chinese were able to continue to outperform their American counterparts on the backward version of the task, the older Chinese were not able to do so. The linguistic properties of the Chinese language and the culture's emphasis on mathematical skill may be more difficult for older Chinese adults to successfully apply as processing demands increase because of the declines in basic cognitive mechanisms associated with aging. This would suggest that even low-level cognitive differences between younger and older adults have an impact on cultural differences in any task in which the processing demands are high. Alternatively, the observed convergence with age could reflect cohort differences, such that younger Chinese have more exposure to mathematics and numbers than older Chinese. In line with this possibility, Geary and colleagues (Geary et al., 1996, 1997) described evidence that younger Chinese were superior to younger Americans on mathematical tests despite equivalent abilities on other tasks, but that older Chinese and older Americans were comparable in performance. Geary et al.'s (1996, 1997) interpretation, however, does not consider whether linguistic influences may also be operative in mathematical fluency tasks or whether older Chinese do not display higher mathematical skill than their American counterparts because of cognitive processing constraints. Further research is necessary to elucidate these issues.

In summary, the present research illustrates the plausibility of developing neuropsychological and cognitive instruments that can be used cross-culturally but also demonstrates the hazards of assuming that even simple neuropsychological tasks (such as digit span tasks) that measure basic cognitive function are culture invariant. In addition, the findings demonstrate that cultural or linguistic variation observed in younger adults may be attenuated in older age groups under process-intensive conditions because of the neurobiological constraints of cognitive aging. Further work may result in an understanding of tasks in which younger and older East Asians and Westerners process information similarly and under what conditions they process information differently.

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