University of Alberta

Strategy Choice as a Possible Mediator of the Effects of Phonological and Auditory Processing on Spelling Accuracy

by

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Abstract

Research studies regarding the effects of auditory processing on spelling ability have often been contradictory. While indications that linguistic auditory processing affects spelling ability have been strong, researchers have disagreed in terms of whether nonlinguistic auditory processing affects spelling. It has also been a common assumption that nonlinguistic auditory processing forms the basis for linguistic auditory processing. In this study, Grade 2 students, Grade 4 students, and adults completed tasks measuring nonlinguistic auditory processing, linguistic auditory processing, spelling strategy choice, and spelling ability. Correlations between nonlinguistic and linguistic auditory processing were tenuous and inconsistent, suggesting that nonlinguistic auditory processing forms, at best, a *partial* foundation for linguistic auditory processing. Nonlinguistic auditory processing was not consistently related to measures of spelling ability. Linguistic auditory processing was correlated to measures of spelling ability for Grade 2 students and adults, but only for individuals who depended more heavily on phonological strategies for spelling unfamiliar words. The difference between Grade 4 students and the other age groups was unexpected, but may be partially explained by their higher performance on tests of linguistic auditory processing. The results of this study suggest strategy choice as both an independent influence on spelling ability, and a mediator of the effects of linguistic auditory processing on spelling ability. Possible future directions for this line of research include fine-tuning of screening procedures for less accurate linguistic auditory processing and development of intervention programs for at-risk spellers.

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"It takes a village to write a dissertation."
-New Canadian Proverb

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Does what children hear affect how they spell? In some ways, this may appear to be a simple question. Certainly in an extreme case, such as mistaking one word for another, accurate spelling is unlikely. However, when one considers less extreme cases, the answer becomes a little less obvious. For instance, what should one expect from a child who does not distinguish between two different phonemes (the linguistic sounds that factor in linguistic auditory processing) as accurately as does another child? Will this affect the child's ability to spell words containing those phonemes? Will it affect the child's ability to spell in general?

If linguistic auditory processing, that is, people's ability to accurately process linguistic sounds, *does* affect spelling ability, the question remains as to whether problems that occur lie in the ability to detect, discriminate among, and manipulate phonemes, or in auditory processing that is not specific to, or restricted to, spelling. Considering this, one may wonder what should be expected of a child whose nonlinguistic auditory processing is less accurate than that of another child. For instance, if one child is better at discriminating among auditory frequencies than is another, does this give any information about the children's respective spelling abilities? The ability to distinguish between two tones may seem quite removed from the ability to perceive and spell phonemes. However, could it be representative of some lower level of processing? In this case, this processing may be considered a possible underlying cause for linguistic auditory processing difficulties and any resulting spelling difficulties. The goals of the current research were to determine whether or not there is a basic link between nonlinguistic and linguistic auditory processing, to look for links between these types of processing and spelling ability, and to determine whether or not spelling strategy choice mediates those links.

Linguistic Auditory Processing

The literature concerning the effects of linguistic auditory processing on spelling is largely clear and consistent, at least with regard to learning to spell in English. Does what children hear affect how they spell? The resounding answer appears to be yes. There have been many studies that support the idea that children, when they are first learning to spell, rely largely on phonological strategies, or sounding out words (e.g., Griffith, 1991; Nunes, Bryant, & Bindman, 1997; Treiman, 1993; Varnhagen, 1995). While this may imply that linguistic auditory processing affects spelling accuracy, however, it says nothing explicitly about differences between individuals. That is, it does not directly answer the question of how individual differences in processing may affect spelling.

Treiman, Goswami, Tincoff, and Leevers (1997) compared speakers of different English dialects to determine if their differing pronunciations of certain words would lead to differing spellings among beginning spellers. Specifically, they compared American children to Southern British children on words that were correctly spelled with an *r* that was not pronounced by the British children (e.g., *blur*). They also extended this to words that were correctly spelled without an *r*, but had pronunciations in the British dialect that were similar to words that were correctly spelled with an *r*. For instance, would children form analogies between words such as *bath* and words such as *card*, which have similar vowel pronunciations in the British dialect? Such analogies may lead children who spell *card* correctly to add an *r* to their spelling of *bath*. These researchers found that beginning British spellers were more likely to omit the *r* from their spellings of words in which it was not pronounced in their dialect. Further, more experienced spellers, who had learned that there was often an unpronounced *r*, were more likely to insert this letter into words that were correctly spelled without it.

Treiman (2004) has also found that this sort of effect may persist into adulthood. She compared a group of college students who spoke African American vernacular English (AAVE) to a group of Caucasian students. In AAVE, a final /d/ is often pronounced more like /t/ (Treiman, 2004). Treiman found that speakers of AAVE, even in adulthood, sometimes used *t*, rather than *d*, in spelling such words (e.g., to spell *rigid* with a *t* as in *ballot*). Also, as with the British children, she found that the opposite error sometimes occurred: presumably knowing the /t/ sound in AAVE is sometimes spelled with a *d*, some adults in Treiman's study used a *d* in words that should be spelled with a *t* (e.g., spelling *ballot* as *ballad*).

Treiman has also examined the effects of pronunciation on spelling in other contexts. For instance, she has studied children's spellings of syllabic consonants; that is, cases in which the rime of a syllable is similar or identical to the letter-name of the final consonant (Reece & Treiman, 2001; Treiman, Berch, Tincoff, & Weatherston, 1993). Treiman has found that beginning spellers often omit the preceding vowel in cases like this (e.g., spelling *car* without the *a*), presumably because the presence of the vowel is not clear to them in the pronunciation of the words.

Such research shows that there are conditions that can be present in dialect or in a word's structure that can cause letters to be inserted or omitted in spelling and pronunciation. How common is it, though, for two phonemes to be confused? In cases where the pronunciation of two phonemes differs only in one characteristic, such as voicing (whether or not the vocal cords vibrate during articulation), young children often have difficulty distinguishing between the two (Treiman, Broderick, Tincoff, & Rodriguez, 1998). Is it reasonable to assume, then, that these confusions affect their spelling? Varnhagen, Daniels, Rabiau, Gillingham, and Steffler (2000) designed a study to examine the effects of such confusions on spelling. Children were presented aurally with a phoneme and were then asked to choose the correct spelling for that phoneme from three provided choices, one of which was a similar, or confusable, phoneme (e.g., *tr* versus *tʃr*). They found that children who had difficulty discriminating between confusable phonemes had lower spelling accuracy, not only when attempting to spell words that contained those phonemes, but also with other words.

One conflict in the research comes from appropriate treatment for children who have difficulty with linguistic auditory processing. Tallal and her colleagues (1996) found that modification of speech sounds so that the stimulus was slower improved language comprehension (which could be expected to improve attempts at spelling what they hear) in children who were language-learning impaired. Habib and his colleagues (2002) found temporally modified speech to be a useful aspect of phonological training. Specifically, 5- to 12-year-old children who were exposed to speech that was slowed down, and was amplified in unstable portions (such as consonant-vowel transitions) showed more improvement in phonological skills than did those who received training that involved only unmodified speech. McAnally, Hansen, Cornelissen, and Stein (1997), however, failed to replicate this type of results with a group of 15-year-old participants. While this sort of modification did result in improvement for some individuals, there was no reliable pattern in terms of whether the improvement was for individuals with or without dyslexia. However, there is a general agreement that baseline linguistic auditory processing is lower in impaired individuals. In the case of nonlinguistic auditory processing, however, there is considerably less agreement.

Nonlinguistic Auditory Processing

Studies finding an effect. Researchers' lack of agreement concerning the effects of nonlinguistic auditory processing on spelling ability is not due to a lack of research in the field. Over 25 years ago, Tallal and her colleagues were investigating possible links between nonlinguistic auditory processing and reading and writing skills. Tallal (1980) compared 8- to 12-year-old-children with and without reading disabilities on the basis of their ability to perform auditory tasks involving computer-generated tones composed of frequencies within speech range. In one task, children's ability to discriminate between two rapidly presented tones was measured. In a second task, children were asked to give the sequence in which the tones had been presented. Performance on these tasks correlated with overall reading ability (i.e., children with reading disabilities could not perform them as well as could normal readers); however, these results were found only when the tones were presented rapidly. Children with reading disabilities performed as well as normal readers when the tones were presented more slowly.

Tallal, Stark, and Mellits (1985) investigated processing differences between 5- to 8 ½-year-old children who did or did not have language impairments. Children participated in a variety of both speech and nonverbal auditory tasks. The researchers found that performance on these tasks could be used to classify children as having or not having language impairments with near-perfect accuracy. Children who had language impairments almost always performed significantly more poorly on the task than did those who did not.

Both of the auditory impairments (i.e., discrimination and sequencing) that Tallal and her colleagues reported in children who had reading disabilities and language impairments have been replicated. Stein and McAnally (1995; McAnally, & Stein, 1996) found that adults with dyslexia were less able to discriminate between tones of differing frequencies; they required larger differences between two tones, on average, in order to detect a difference. France and his colleagues (France, et al., 2002) found that adults with dyslexia had more trouble with pitch discrimination tasks when the interstimulus interval (ISI) was brief. Bishop, Bishop, Bright, James, Delaney, and Tallal (1999) found that 7- to 13-year-old children who had language impairments were less accurate in their recollection of tone sequences than were unimpaired controls. Several other research groups have found similar impairments when, as in France et al.'s study, the ISI is brief (e.g., Booth, Perfetti, MacWhinney, & Hunt, 2000; Bretherton & Holmes, 2003). However, a closer look at Stein and McAnally's (1995; McAnally & Stein, 1996) results reveals that there were some mixed results in terms of which tasks elicited differential performance. Specifically, they did not find significant differences between readers with dyslexia and normal readers in the ability to detect very brief gaps between presentations of a tone, contrary to another of their predictions. Also, as discussed below, other researchers have reported evidence that contradicts their findings.

Studies finding no effect. Hill and his colleagues (Hill, Bailey, Griffiths, & Snowling, 1999) attempted to replicate McAnally and Stein's (1996) findings. They found that, once outliers were removed, most significant differences between participants with and without dyslexia disappeared; with the exception of a subgroup of participants with dyslexia, all of the differences disappeared. They concluded that any phonological deficit that may exist in dyslexia could not be reasonably connected to a low-level auditory deficit based on current evidence.

Schulte-Körne, Deimel, Bartling, and Remschmidt (1998), working with both children and adults, used a measure of auditory perception that differed from those used by other researchers. Like Tallal (1980), they had participants listen to tones that had frequencies that were within speech range and to determine whether they had heard one tone or two. However, instead of alternating frequencies, Schulte-Körne and his colleagues investigated gap detection—the participants' ability to detect a brief gap between presentations of the tones. They started with a 400 msec gap, and decreased the length of this gap each time the participant responded correctly twice. The researchers found no difference between the gap-detection threshold for groups with spelling disabilities and for control groups.

Morais, Cluytens, and Alegria (1984) investigated the ability of 6- to 9-year-old children with and without dyslexia to perform speech and non-speech segmentation tasks. The children with dyslexia, who were taught phonics at a school for people with dyslexia, performed significantly worse than did the control group children on speech segmentation, but not on the non-speech tasks.

Some of the contradictory results reported regarding the effects of nonlinguistic auditory processing on reading and spelling may be due to different measures of nonlinguistic auditory processing. Specifically, researchers who have operationalized nonlinguistic auditory processing in terms of frequency distinction have been more likely to find significant differences between individuals with and without dyslexia than have those who have operationalized it in terms of gap detection. However, there has not been complete agreement of results even when similar measures have been used. Hill et al. (1999), for instance, were unable to completely replicate McAnally and Stein's (1996) results. Their discovery of a subgroup of individuals with dyslexia for which there was a significant correlation, though, does suggest that the conflicting results could be explained, at least partially, by differences in participant groups. Specifically, participants who have less accurate nonlinguistic auditory processing may be compensating for this impairment to different degrees. Another possibility is that different ISI lengths contributed to different results, and that temporal issues, rather than simple discrimination are responsible for some of the results. While this issue is not explored here, it is one potential path of research.

Spelling Strategy as a Possible Mediating Variable

One salient feature of the nonlinguistic auditory processing literature is that it seems to focus exclusively on individuals who have reading and/or spelling impairments—individual differences among normally developing individuals have not been investigated. This focus is significant because there is some evidence for compensation among individuals with dyslexia. Kershner and Micallef (1992) found that 11-year-old children with dyslexia actually performed better than did normally developing children at left ear recall in a directed attention dichotic listening task. When asked to listen to only one ear at a time, children with dyslexia were better able to do this for the left ear than were normally developing children. Since stimuli to the left ear are directed to and interpreted by the hemisphere less strongly associated with hearing, this suggests that children with dyslexia may be lateralized more weakly than are normal readers, at least for this task. Kershner and Micallef (1992) hypothesized that something similar to between- hemisphere compensatory hypertrophy (an overdevelopment of areas of one hemisphere in response to early neurodevelopment aberrations in homologous areas of the other) may be occurring.

Compensation that may be used by individuals who have less accurate linguistic or nonlinguistic auditory processing is strategy choice. This idea is supported by findings obtained by Breznitz (1997). Breznitz had children with and without dyslexia (matched for reading level) read information from a computer screen at different speeds and in both a quiet condition and a condition in which auditory masking (that is, white noise presented via headphones) was used. Both auditory masking and reading acceleration can function to shift the reader's focus away from linguistic auditory processing and towards other strategies. These conditions combined served to enhance the reading performance of children with dyslexia only. It seems plausible that these children may have had less accurate nonlinguistic and/or linguistic auditory processing and that, given this less accurate processing, they may have performed better when using strategies other than phonology. Given the connection between reading and spelling, it also seems plausible that this phenomenon may generalize to spelling ability. Also, McAnally and Stein (1997) failed to find hypothesized significant differences between individuals with and without dyslexia in terms of amplitude modulation following response (AMFR; that is, a change in the potential recorded at the scalp following response to a tone stimulus) when the two groups of participants were matched for hearing sensitivity. Thus, the difference in their reading and spelling abilities must be assumed to stem from something other than auditory acuity. The possibility exists that it stems from differences in the strategies the participants were using to perform these tasks. In order to explore this possibility fully, it is necessary to understand the range of strategies that children have available to them for spelling.

Spelling strategies. A strategy is a conscious attempt to solve a problem. In the case of spelling, it is an attempt to determine the correct spelling of a word by means that are conscious (the speller is aware of what he or she is doing).

Phonological strategies, as discussed earlier, involve sounding out the word that is to be spelled. Here, phonemes (sounds) are matched to corresponding graphemes (letters). Beginning spellers often rely heavily on phonological strategies, and this reliance usually decreases with age (e.g., Varnhagen, 1995). It seems logical that phonological strategies may not be adaptive choices for individuals with less accurate linguistic and/or nonlinguistic auditory processing; that is, these strategies may not lead to the fastest and most accurate spelling. There are, however, several other possible strategies from which individuals may choose.

Forming analogies is often a better choice because part of the new word can be automatically retrieved. Analogy consists of comparing a new word to a known word that has a similar structure, such as using knowledge of the word *at* to spell the word *cat* (Goswami, 1992). There is evidence that even very young children can become adept at spelling words by analogy (Goswami, 1992; Laxon, Coltheart, & Keating, 1988; Sternberg & Rifkin, 1979; Marsh, Desberg, & Cooper, 1977). Children may also use orthographic knowledge, that is, conform to spelling rules, such as "*i* before *e* except after *c*" (e.g., Cassar & Treiman, 1997), or follow conventions, such as doubling a final consonant before adding *-ing* in order to keep a vowel short. As well, children use morphological knowledge in their spelling. This strategy involves using knowledge of the root word to aid in spelling a compound word or a word with a prefix or suffix, such as using knowledge of the word *signature* to spell the silent *g* in *sign* (Treiman, Cassar, & Zukowski, 1994). Finally, when children have used some strategy or combination of strategies to attempt the spelling of a word, they may write the word or spell it out loud to determine whether or not a particular spelling looks or sounds correct (Varnhagen, 1995; Tenney, 1980).

With the multiple strategies that children have to choose from, the question arises as to how they go about choosing. There is evidence that this question may be answered in one word: adaptively.

Adaptive choice among strategies. Although the area of study is relatively new, evidence has been accumulating that children choose adaptively among available strategies. Siegler has shown evidence of adaptive strategy choice in varied domains such as multiplication (Siegler & Lemaire, 1997), physics learning (Maloney & Siegler, 1993), and time-telling (Siegler & McGilly, 1989). While this adaptive choice is sometimes inferred simply in terms of when children choose to use back-up (i.e., non-retrieval) strategies, which are more time-consuming but usually result in greater accuracy for more difficult problems, Siegler (Siegler, 1991; Siegler & Lemaire, 1997) has proposed and supported a model of strategy choice in which there is also adaptive choice among alternative back-up strategies based on the accuracy of answers obtained using those strategies in the past.

Specifically in the domain of spelling, Rittle-Johnson and Siegler (1999) found that children were more likely to use a back-up strategy than retrieval for more difficult words. While these choices did not result in greater accuracy, they did allow the children to allot more of their cognitive energy where it may be most needed. Kwong and Varnhagen (2005) conducted a microgenetic study (i.e., one in which participants are observed frequently over a relatively short period of time in order to observe change in progress) of Grade 1 children's development of automaticity with novel words. They found that the children not only progressed as a group from less- to more-sophisticated strategies, but also chose adaptively as individuals. That is, individual children differed in which strategies worked best for them, and tended to gravitate toward those strategies. This is more speller-specific than some previous research. For instance Lemaire and Lecacheur' (2002a) found that children in Grades 3 and 5 are more likely to use dictionaries, when available, for words that they could not spell correctly without one. Lemaire has found adaptive choice by elementary school children and adults in other domains, usually taking into consideration problem characteristic (for example, problem difficulty) moreso than the strengths or weaknesses of the individual (Lemaire, Lecacheur, & Farioli, 2000; Lemaire & Lecacheur, 2002b; Messe & Lemaire, 2001). However, Siegler and Lemaire (1997) did consider skill and experience when comparing strategy preferences of a group of older adults (age 70) to a group of younger adults (age 20) in solving mathematical problems. Specifically, they found the older adults, who were often less experienced with calculators (and were slower when using one) were more likely than were younger adults to choose to use paper and pencil in problem-solving.

However, it seems unlikely that all individuals will choose adaptively all the time. There may also be situations in which more adaptive strategies have simply never been made available, through instruction, to individuals. Thus, the difference between an individual with less accurate auditory processing who is a poor speller and one who is not may lie in their choice of strategies.

Heavy reliance on phonological strategies has been associated with poor spelling and poor reading (e.g., Barron, 1980; Frith, 1980; Bruck & Waters, 1988; Bruck & Waters, 1990). It seems likely that this effect may be greater in the case of individuals who have less accurate auditory processing. Thus, those who continue to rely on phonological strategies may produce consistently less accurate spellings, and those who adaptively choose (consciously or not) to circumvent their auditory difficulties by using alternate strategies may produce spellings that do not betray those difficulties.

The extent to which both individuals who choose adaptively among spelling strategies and those who do not are included in a sample may have considerable implications for the results of that study. That is, a larger number of adaptive spellers may result in a study that shows no link between nonlinguistic auditory processing and spelling ability, whereas if more less-adaptive spellers are included, a link may be evident.

Relationships Among Variables

Taken together, previous research involving auditory processing, strategies, and spelling, paint a rather complex picture. Linguistic auditory processing reliably affects spelling performance, but studies comparing the two have not taken strategy choice into account. Studies of the effects of nonlinguistic auditory processing on spelling have been restricted to disabled-nondisabled comparisons, and have often produced conflicting results. Once again, strategy choice has not been taken into account, and there is a possibility that considering these may shed some light on the inconsistent results of previous studies. The influence of strategy choice on spelling ability has been studied, but again, never in conjunction with auditory processing. To obtain a more complete picture of the complex and multifaceted process of spelling, additional and expanded research is needed.

Research Needs

While there is a plethora of literature on the subject of auditory processing and its connection to reading and spelling accuracy, there are several conspicuous holes in the research. This study is an attempt to fill in some of this missing information in order to better understand the connection between auditory processing and spelling, as well as the limits of this connection and circumstances under which it occurs.

Particularly unclear is the relationship between linguistic and nonlinguistic processing. That is, it is unclear whether or not individuals with less accurate nonlinguistic auditory processing are also likely to have less accurate linguistic auditory processing.

Also, nonlinguistic auditory processing has been studied only in individuals who have reading and/or language impairments (e.g., France et al., 2002; Habib et al., 2002; Stein & McAnally, 1995; Tallal et al., 1996). The literature on linguistic auditory processing has been expanded to include individual differences within normally-developing populations. Varnhagen et al. (2000) found that linguistic auditory processing skills affect spelling even within normal readers and spellers. Light may be shed on the area of nonlinguistic auditory processing if such differences are investigated.

In addition, other variables may mediate the effect of auditory processing on spelling. It is possible that there is a mediating variable, such as spelling strategy use, influencing the link between auditory processing and spelling ability. As described above, an argument can be made for the viability of strategy choice as a means through which a person may circumvent auditory processing difficulties. It is also possible that there are other mediating variables that have not been explored.

Aims of Current Study

There were several aims of the current study. First, the link between linguistic and nonlinguistic auditory processing must be explored. Previous research has not clarified the extent to which these two are related. While some researchers (e.g., Tallal, 1980) appear to assume that nonlinguistic auditory processing forms the basis for linguistic auditory processing, this is not a certainty. Without this information, several questions remain unanswerable. Is testing *either* nonlinguistic *or* linguistic auditory processing sufficient for predicting spelling ability, or must both be tested? Can, or should, phonological difficulties be dealt with through treatments aimed at nonlinguistic auditory processing? Should these two types of processing be examined separately or as related functions? Thus, one aim of the current study was to establish the degree of relationship between nonlinguistic and linguistic auditory processing. How the other research questions are addressed (as aspects of all auditory processing, or separately for nonlinguistic and nonlinguistic auditory processing) must necessarily depend on the results of the current study.

A second aim was to explore the relationship between these types of processing and spelling ability. Linguistic auditory processing has been linked, in the past, to spelling ability (Varnhagen et al., 2000). Nonlinguistic auditory processing, however, has been studied mainly with regard to disabled readers and spellers (e.g., France et al., 2002; Habib et al., 2002; Stein & McAnally, 1995; Tallal et al., 1996). It is unclear at this point whether or not the already tenuous relationship will hold when a normal sample is studied. Also, assuming a relationship, a regression should make it possible to determine whether or not nonlinguistic auditory processing has any connection to spelling ability once linguistic auditory processing is taken into account.

A third aim was to explore age-related trends in the relationships among linguistic and nonlinguistic auditory processing and spelling ability. In addition to adults, children in Grades 2 and 4 were included in this study. Grade 2 students are beginning spellers. This level of spelling is associated with heavy reliance on phonological strategies. Also, as spelling is still explicit at this point, whatever strategies children use, or have been taught, are often fresh in their minds. The children in Grade 4 have had more experience. They have often learned more diverse strategies, but also may have had more opportunity to forget any direct teaching in spelling strategy. Spelling is more of an explicit task at this point, and specific strategies may be more difficult to access. Adults have often reached a point at which spelling most of the words they use involves retrieval from memory.

Finally, I explored spelling strategy as a mediating variable between nonlinguistic and linguistic auditory processing and spelling ability. Participants who show different strategy preferences were examined separately to determine whether or not strategy choice affects the degree of the relationship between hearing and spelling. If participants who choose less-phonological approaches to spelling show a lesser degree of spelling impairment with less accurate processing, this may have implications for teaching spelling to individuals with nonlinguistic or linguistic auditory processing difficulties.

Rationale for Measures.

Both auditory processing tasks were chosen largely for their simplicity. I wanted to measure processing in the simplest means possible. My interest in nonlinguistic auditory processing here was in tone discrimination, rather than temporal ability. In many studies of nonlinguistic auditory processing, ISI has not been reported. When it has (e.g., France et al., 2002), the studies have involved brief ISIs for study of temporal processing. This does not necessarily allow temporal processing effects to be teased apart from discrimination. For this reason, my measure (see below) involved two-tone stimuli with a relatively long ISI. A significant correlation between nonlinguistic auditory processing and spelling ability should clearly indicate an effect that is specific to nonlinguistic auditory processing. A lack of correlation may suggest that past findings have been based on temporal processing, rather than problems with frequency perception.

My test of nonlinguistic auditory processing was based on the tone discrimination task used by McAnally and Stein (1996), but unlike that study, I presented all tones to all participants, regardless of performance. McAnally and Stein used the method of limits, starting with larger frequency differences, decreasing the difference when participants answered correctly. However, in an initial pilot trial of this task, I noticed that participants sometimes erred on a judgment for a larger frequency difference, only to perform much better on subsequent trials with smaller differences. My method allows the analysis of results beyond a simple indication of a participant's just noticeable difference.

I measured linguistic auditory processing in terms of phoneme perception, in much the same way as was done by Varnhagen et al. (2000). Participants' scores were based on their percentage of correctly identified phonemes, to mirror the process used for nonlinguistic auditory processing. The "same-different" paradigm for nonlinguistic auditory processing was not used here because the sounds were recorded rather than generated by computer. Given this, the possibility of differences between sounds *other than* the articulation differences under study affecting children's responses made another paradigm seem more reasonable. Children completed training items before performing the task to ensure that they were familiar with the letters. This way, in-task errors could be more reliably attributed to auditory processing, rather than lack of alphabetic knowledge. They also completed three practice trials as part of the task, to help them adjust to the no-feedback format.

I obtained strategy reports to determine participants' preferred strategies. I expected that participants' preferences for phonological or nonphonological strategies would affect the degree to which their nonlinguistic and linguistic auditory processing skills influenced their spelling ability. Assignment to a preferred-strategy category was based on a median split for each group (i.e., Grade 2, Grade 4, adult), dividing them into phonological and nonphonological spellers. My previous research (Kwong & Varnhagen, 2005) demonstrated that most individuals, child and adult, have some clear preference in terms of spelling strategy.

I measured participants' spelling ability using two different tasks. The TWS 3 (Larsen & Hammill, 1994) provides lists of both predictable (TWSP) and unpredictable (TWSU) words, which can also be combined to calculate an overall, or total, spelling score (TWST). As predictable words are more likely to induce use of phonological strategies, individuals who have less accurate linguistic (and perhaps nonlinguistic) auditory processing are likely to show a greater disadvantage on these than on unpredictable words. For this reason, the test is considered a valuable tool in the proposed research. However, the TWS 3 does not allow for standard scores for individuals 19 years of age or above. Therefore, for adults, I also used the Diagnostic Spelling Potential Test (DSPT) (Arena, 1982) in order to obtain a standardized score.

Hypotheses

The literature has been far from clear regarding links between nonlinguistic and linguistic auditory processing, and between nonlinguistic auditory processing and spelling ability. Given that the present participants are not disabled, I expected that the links among these variables would be even more tenuous, and possibly nonexistent. I did expect to find a correlation between linguistic auditory processing and spelling. Other researchers have found that non-disabled individuals do sometimes make spelling errors based on what they hear (e.g., Treiman et al., 1993). I anticipated similar findings here. While it seems likely that the relationship between auditory processing and spelling will change with an individual's development, it is difficult to predict the pattern of these changes. While I anticipated less reliance on phonological strategies with each successively older group, this may or may not translate into significant changes in the auditory processing-spelling relationship. Finally, I anticipated that the correlation between linguistic auditory processing and spelling would be dependent on spelling strategy. Specifically, I expected that participants who relied heavily on phonological strategies would be more affected by their linguistic auditory processing skills than would those who relied on alternate strategies.

Method

Participants

Children. Participants were 39 Grade 2 students, 18 female and 21 male, with a mean age of 7 years, 4.6 months (*SD* = 3.56 months), and 45 Grade 4 students, 23 female and 22 male, with a mean age of 9 years, 5.3 months (*SD* = 3.96 months). The children came from three schools in Edmonton, Alberta, and had mixed racial backgrounds. Children with learning or hearing disabilities, or who did not have English as their first language, were excluded. Two additional Grade 2 males and two additional Grade 4 females were excluded from the study because data collection could not be completed, either due to the child's absence on a testing day or due to technical difficulties with data collection. The Grade 2 students were receiving instruction based on the Balanced Literacy Program. They received instruction in phonics, analogy, orthography, and whole word methods. Approximately half of the Grade 4 students were receiving this type of spelling instruction. The others were in classrooms in which the teachers chose not to use explicit spelling instruction. These children had previously been instructed using the Balanced Literacy Program, but now received instruction only in the form of feedback on spelling on written assignments.

Adults. Adult participants were undergraduate students enrolled in introductory psychology courses at the University of Alberta. Only individuals with normal hearing, reading, and learning development were included. There were 59 females and 15 males, with a mean age of 20 years, 2 months (*SD* = 3 years, 3.67 months). One additional male was excluded from the study, due to a failure to establish a basal on two of the three spelling lists (that is, due to measurement error, it was impossible to calculate a score for this individual). Several other participants did not establish a basal on one of the tests (test varied) and were excluded from only the analyses that included affected tests. The types of spelling instruction these participants received is not known.

Materials

Nonlinguistic auditory processing. Tones for the nonlinguistic auditory processing task were presented via headphones on computer, using Authorware (Macromedia). For each set of tones, the first tone was 1000Hz, 1500Hz, or 2000Hz. The second tone was the same as the first for two presentations within each block. For the children, there were two presentations of tones that differed from the first by 2Hz, two that differed by 4Hz, up to a maximum difference of 20Hz. At each difference level, one of these tones was lower than the baseline and one was higher. For adults, there were four presentations of tones that differed from the first by 2Hz, four that differed by 4Hz, up to a maximum difference of 20Hz. At each difference level, two of these tones were lower than the baseline and two were higher. Appendix A lists the tone pairs. The order in which the sets were presented was randomized for each participant. Within each set, the order in which the tone pairs were presented was also randomized. Two practice pairs were presented as well. One of these pairs consisted of two tones at 1000Hz; the other consisted of one tone at 1000Hz and one at 980Hz. Volume for the tones was between

60dB and 68dB, which is within the normal range of volume for speech. Appendix B shows the screens shown to the child participants, and the responses required.

Linguistic auditory processing. Phonemes were presented via headphones on computer, using Authorware (Macromedia). For each phoneme, participants chose among three spellings: one correct, one similar, and one dissimilar. The similar, or confusable, phoneme was always one that differed in only one feature of articulation. For most of these pairs, one phoneme was voiced (i.e., the vocal cords vibrate during pronunciation), and one was unvoiced. For one pair (/ʃ/-/tʃ/), the first (pronounced as the *sh* in *shout)*, is a fricative, meaning that air is forced through a small opening in the mouth; while the second (pronounced as the *ch* in *church)* is a lateral fricative, a fricative for which the sides of the tongue are lowered, forming two narrow openings through which air is forced. For two pairs (/θ/-/f/ and /ð/-/v/), the first phoneme (/θ/, pronounced as the *th* in *theme;* /ð/, pronounced as the *th* in *that)* is dental, meaning that the tongue is placed on or near the front teeth; while the second phoneme is labiodental, meaning that the upper front teeth are in contact with the lower lip. Volume was within normal speech range. See Appendix C for a complete list of phonemes and response options.

Training items, presented only to children, consisted of 30 sets in which phonemes were presented with nonconfusable choices. Children also completed three no-feedback practice trials, again with nonconfusable sets, before beginning the scored tasks. The confusable sets were repeated in such a way as that children completed 36 sets and adults completed 60 sets (see Appendix C). Children completed fewer sets to avoid loss of data due to wandering attention. Appendix D shows the screens shown to the child participants and the responses required.

Strategy choice. Words selected from the WRAT 3 (Wilkinson, 1993) were used to obtain strategy reports. For children, the words were presented on computer, using Authorware (Macromedia). For adults, they were read aloud by the researcher. For children, 15 consecutive words were used, starting below grade level, and continuing to above grade level. For adults, words from the beginning and the end of the WRAT 3 spelling list were used. In both cases, these words were selected to represent words whose spellings probably were and probably were not in participants' long-term memories (i.e., words that are quite common or very uncommon at a given age level). Appendix E shows a list of included words, and Appendix F shows the screens shown to the child participants, and the responses required.

Spelling ability. I administered both predictable (TWSP) and unpredictable (TWSU) word lists from the TWS 3 (Larsen & Hammill, 1994) to all participants, and also combined these two for an overall, or total, score (TWST). Adults also completed The Diagnostic Spelling Potential Test (DSPT) (Arena, 1982).

Procedure

Children. Participants began with the nonlinguistic auditory processing task. They wore headphones to ensure standardized noise and volume conditions. They first completed two practice trials, one in which the tones were the same, and one in which the tones were different, before beginning the task. Tones were presented in blocks (all 1000Hz tones, all 1500HZ tones, and all 2000Hz tones). I randomized tone order within the blocks, and presented the blocks in random order. Participants responded to each tone pair by pressing either "z" (labeled with two squares to represent sameness) to indicate that the tones were the same or "/" (labeled with a square and a circle to represent difference) to indicate that the tones were different. At the end of each block, participants were given the option of a short break.

Following completion of the nonlinguistic auditory processing task, in the same session, participants began the linguistic auditory processing task. Again, they wore headphones to ensure standardized presentation. Participants first completed training items in which choices did not include confusable phonemes, then practice trials, before beginning the task. Phonemes were presented in random order. For each phoneme, participants saw three spelling choices, also presented in random order. Participants used the mouse to select the spelling that they thought represented the presented phoneme. This session took approximately 20 minutes for each child to complete.

The third task was the strategy choice task. Children heard the word, a sentence containing the word, and then the word again, and typed the words on a laptop computer. After spelling each word, participants were asked to describe their strategies (e.g., "How did you decide how that word should be spelled?"). Non-leading probing was used for participants who did not give full explanations of spelling (e.g., "Is there anything else?", "That explains how you spelled the beginning of the word. Can you tell me how you figured out how to spell the end?"). Overt behavior was also considered. When children's overt behavior disagreed with their reports, the behavior was considered indicative of actual strategy use (if the behavior was very clear). For instance, if a child overtly sounded out a word *and* provided a phonological (and incorrect) spelling, but claimed to remember the word's spelling, a coding of "phonological" was used. However, it was extremely rare for a child's report to contradict his or her overt behavior. This session, usually a day or two after the auditory processing tasks, took each child approximately 20 minutes to complete.

The spelling ability tasks were presented last. These were conducted in a group setting. For each test, the experimenter read a word, a sentence containing the word, and then the word again. Participants were given time to complete each spelling before moving on to the next word. A second researcher checked children's papers at intervals and indicated when each child had misspelled five consecutive words. The spelling task ended when all children in a group had misspelled five consecutive words. This session took 20-40 minutes per group.

Adults. Adult participants completed all tasks in individual sessions that took approximately 45 minutes. Participants began with the nonlinguistic auditory processing task. They wore headphones to ensure standardized noise and volume conditions. Tones were presented in blocks (all 1000Hz tones, all 1500HZ tones, and all 2000Hz tones). Tone order was randomized within the blocks, and the blocks were presented in random order. Participants responded to each tone pair by pressing either "z" to indicate that the tones were the same or "/" to indicate that the tones were different. At the end of each block, participants were given the option of a short break.

Following completion of the nonlinguistic auditory processing task, participants began the linguistic auditory processing task. Again, they wore headphones to ensure standardized presentation. Phonemes were presented in random order. For each phoneme, participants saw three spelling choices, also presented in random order. Participants used the mouse to select the spelling that they thought represents the presented phoneme.

The third task was the strategy choice task. The experimenter read participants a word, a sentence containing the word, and the word again. Participants wrote the word using pencil and paper. After spelling each word, participants were asked to describe their strategies (e.g., "How did you decide how that word should be spelled?"). Non-leading probing was used for participants who did not give full explanations of spelling (e.g., "Is there anything else?", "That explains how you spelled the beginning of the word. Can you tell me how you figured out how to spell the end?").

The spelling ability tasks were presented last. For each test, the experimenter read a word, a sentence containing the word, and then the word again. Participants were given time to complete each spelling before moving on to the next word. The spelling task ended when participants had misspelled five consecutive words.

Results

Strategy Scoring

Strategy reports were assigned to one of eight categories (see Table 1). If a participant spelled a word based entirely on sounding it out (e.g., "I thought about the sounds and what letters made them."), the report was categorized as *phonology*. If a participant spelled a word based on its similarity to a known word (e.g., after spelling *heaven*, "It's kind of like *seven*."), the report was categorized as *analogy*. If a participant spelled a word based on knowledge of rules and spelling conventions (e.g., "I know there has to be an *e* for the vowel to say its name."), the report was categorized as *orthography*. If a participant spelled a word based on knowledge of its root or meaning (e.g., after spelling *auricular*, "I tried to use words I know, like *auricle*."), the report was categorized as *morphology*. If a participant spelled a word by trying a spelling and checking to see if it matched his or her visual memory (e.g., after several attempts, "Tried to see which letters go in the word and see if it looks right."), the report was categorized as *visual checking*. If a participant spelled a word from memory (e.g., "I just knew how to spell it."), the report was categorized as *retrieval*. If a participant reported using any combination of two or more strategies (e.g., after spelling *illogical*, "*ill*, like 'I'm ill', then *lodge*, then I sounded out the rest."), the report was categorized as a *combination*. If a participant did not appear to use any strategy to spell a word (e.g., "I guessed."), the report was categorized as *nonstrategic*.

A second rater categorized 20% of the reports, according to specific strategy choice, to check reliability. Agreement between raters was very good, yielding a Kappa of $k = 0.98$.

Table 1

Spelling Strategies

Strategy Coding	Sample Participant Description
Phonology	"I sounded it out."
Analogy	(after spelling *heaven*) "It's kind of like *seven*."
Orthography	"I know there has to be an *e* for the vowel to say its name."
Morphology	(after spelling *auricular*) "I tried to use words I know, like *auricle*."
Visual Checking	"Tried to see which letters go in the word and see if it looks right."
Retrieval	"I just knew how to spell it."
Nonstrategic	"I guessed."
Combination	(after spelling *illogical)* "*ill*, like 'I'm ill', then *lodge*, then I sounded out the rest."

Descriptive Statistics

Scores on the auditory processing tasks were reported in terms of percentage correct. This allowed comparisons between adults and children, who did not complete the same number of items.

Participants were, on average, good spellers. Grade 2 students, as measured by the TWS 3, were slightly above average ($M = 103.1$, $SD = 15.4$). Grade 4 students were also slightly above average ($M = 105.8$, $SD = 11.3$). Adults also scored above average, as measured by the DSPT ($M = 112.2$, $SD = 5.7$).

There was more variability in the participants' nonlinguistic auditory processing for Grade 2 students and adults (see Table 2 for mean scores and standard deviations) than on the linguistic auditory processing task. This difference was less for Grade 4 students. A single-factor ANOVA showed that Grade 4 students performed better on the linguistic auditory processing task than did the other two groups ($F(2, 155) = 3.98$, $p < .05$). A Tukey post-hoc test showed this difference to be significant between Grade 2 and Grade 4 students, $HSD = 2.6\%$, $p < .05$. The difference between Grade 4 students and adults approached significance, $HSD = 2.3\%$ (an alpha of .05 requires a difference of 2.5%).

Use of phonology (i.e., spelling words using phonology exclusively) decreased with age (see Table 2). A single-factor ANOVA showed significant differences among the groups ($F(2, 155) = 14.5$, $p < .01$). A Tukey post-hoc test showed a significant difference between the number of words Grade 2 children spelled using phonology and the number of words Grade 4 children spelled using phonology, $HSD = 2.0$, $p < .05$. The difference between Grade 4 children and adults approached significance, *HSD* = 1.7 (an alpha of .05 requires a difference of 1.8).

Table 2

Descriptive Statistics

	Grade 2	Grade 4	Adults
	M (SD)	*M (SD)*	*M (SD)*
Spelling (standardized)	103.1 (15.4)	105.8 (11.3)	112.2 (5.7)
Nonling. Auditory Proc. (% correct)	43.4 (14.7)	52.3 (7.4)	64.2 (18.7)
Ling. Auditory Proc. (% correct)	90.6 (6.3)	93.3 (3.7)	91.0 (4.8)
Use of Phonology (words, of 15)	8.2 (4.9)	6.2 (3.6)	4.5 (2.5)

Nonlinguistic-Linguistic Comparisons

Nonlinguistic auditory processing was not significantly correlated with linguistic auditory processing for Grade 2 children or Grade 4 children (see Table 3). There was a slight, but significant, correlation for the adults.

Nonlinguistic Auditory Processing

Nonlinguistic auditory processing was not significantly correlated with any measure of spelling ability for any group (see Table 3). In a stepwise regression, it was excluded for each group, indicating that it was not a significant predictor (see Table 4).

Table 3

Correlations of Group Measures With Auditory Processing and Use of Phonology

	Linguistic Auditory Processing	Nonlinguistic Auditory Processing	Use of Phonology
Grade 2			
Linguistic	--	.04	-.33*
Nonlinguistic	.04	--	.10
TWSP	.47*	-.06	-.50*
TWSU	.36*	-.18	-.35*
Grade 4			
Linguistic	--	.21	-.00
Nonlinguistic	.21	--	-.07
TWSP	.00	.08	-.14
TWSU	-.10	.07	-.24
Adult			
Linguistic	--	.34*	-.11
Nonlinguistic	.34*	--	-.00
TWSP	.36*	.19	-.45*
TWSU	.28*	.23	-.50*
DSPT	.45*	.19	-.41*

*significant at $p < .05$.

Linguistic Auditory Processing

Linguistic auditory processing correlated positively with all measures of spelling ability for Grade 2 children (see Table 3). Performance on this task correlated slightly more with the TWSP than with the TWSU (see Table 3). In Grade 4 children, linguistic auditory processing did not correlate with any of the measures of spelling ability. In adults, linguistic auditory processing correlated with all measures of spelling ability (see Table 3). The stepwise regression showed linguistic auditory processing to be a significant predictor of performance on the TWSP for Grade 2 children and a significant predictor of performance on both the TWSP and the TWSU for adults (see Table 4). It was not a significant predictor of any measure of spelling ability for Grade 4 children.

Use of Phonology

Use of phonology was a significant predictor of performance on both predictable and unpredictable spelling measures for Grade 2 children and for adults (see Table 4). In each of these cases, more reliance on exclusive use of phonology was associated with lower performance on spelling measures. For Grade 4 children, use of phonology was not, on its own, a significant predictor. However, its interaction with linguistic auditory processing was a significant predictor, and use of phonology was significantly negatively correlated with performance on the TWSP ($r(43) = -37, p < .05$), the TWSU ($r(43) = -54, p < .05$), and the TWST ($r(43) = -43, p < .05$) for Grade 4 children.

For Grade 2 students, use of phonology was negatively correlated with linguistic auditory processing (see Table 3). That is, participants who appeared to hear phonemes more accurately were actually *less likely* to use phonology than were those who appeared to hear phonemes less accurately. Use of phonology was not significantly correlated with linguistic auditory processing for Grade 4 students or adults.

Table 4

Stepwise Regression Results: Nonlinguistic Auditory Processing, Linguistic Auditory Processing, Use of Phonology, and Linguistic Auditory Processing X Use of Phonology Interaction as Predictors of Spelling Ability

Predictor	TWSP			TWSU		
	B	SE B	ß	B	SE B	ß
Grade 2						
Use of Phonology	-1.32	0.48	-0.39*	-1.12	0.46	-0.37*
Linguistic Aud. Proc.	2.43	1.03	0.34*			
R^2	0.32			0.11		
Grade 4						
Interaction	-0.04	0.01	-0.37*	no sig. predictors		
R^2	0.12					
Adults						
Use of Phonology	-0.55	0.13	-0.41*	-0.85	0.18	-0.48*
Linguistic Aud. Proc.	6.77	3.05	5.77*	0.35	0.15	0.23*
Interaction	-0.06	0.03	-5.45*			
R^2	0.32			0.28		

*significant at $p < .05$

Note. Reported here are the adjusted R^2 and the standardized ß.

Strategy Choice and the Link Between Linguistic Auditory Processing and Spelling

In Grade 2 students, a stepwise regression showed that linguistic auditory processing and use of phonology were both significant predictors of spelling performance, but the interaction between linguistic auditory processing and use of phonology was not (see Table 4). This result suggests that strategy choice did not mediate the influence of linguistic auditory processing on spelling ability. However, a median split that divided these children into phonological and nonphonological spellers suggested there was an effect (see Figure 1). There was a significant correlation between linguistic auditory processing and TWSP scores for phonological spellers ($r(19) = .49, p < .05$), but not for nonphonological spellers ($r(16) = .44$, *ns*). The lack of a statistically significant relationship between this interaction and spelling ability may be in part due to the fact that most Grade 2 children were highly phonological. In the median split, children who spelled up to 8 words using phonology alone (more than 50% reliance on phonology) were categorized as nonphonological spellers. Thus, it is possible that the results may have been different with a wider range of reliance on phonology.

In Grade 4 students, the interaction between linguistic auditory processing and strategy choice was a significant predictor of performance on the TWSP and the TWSU. Although it appeared to be the children who used more phonology who were the most affected by linguistic auditory processing, the relationship between linguistic auditory processing and spelling was slightly inverse for these students, and did not result in significant correlations for either the TWSP ($r(20) = .-29$, *ns* for phonological; $r(21) = .18$, *ns* for nonphonological) or the TWSU ($r(20) = -.38$, *ns* for phonological; $r(21) = .03$, *ns* for nonphonological) when a median split was used.

In adults, the interaction between linguistic auditory processing and strategy choice predicted performance on the TWSP only. A median split showed a correlation between linguistic auditory processing and spelling for phonological spellers ($r(35) = .48$, $p < .01$), but not for nonphonological spellers ($r(35) = .05$, *ns*) (see Figure 2).

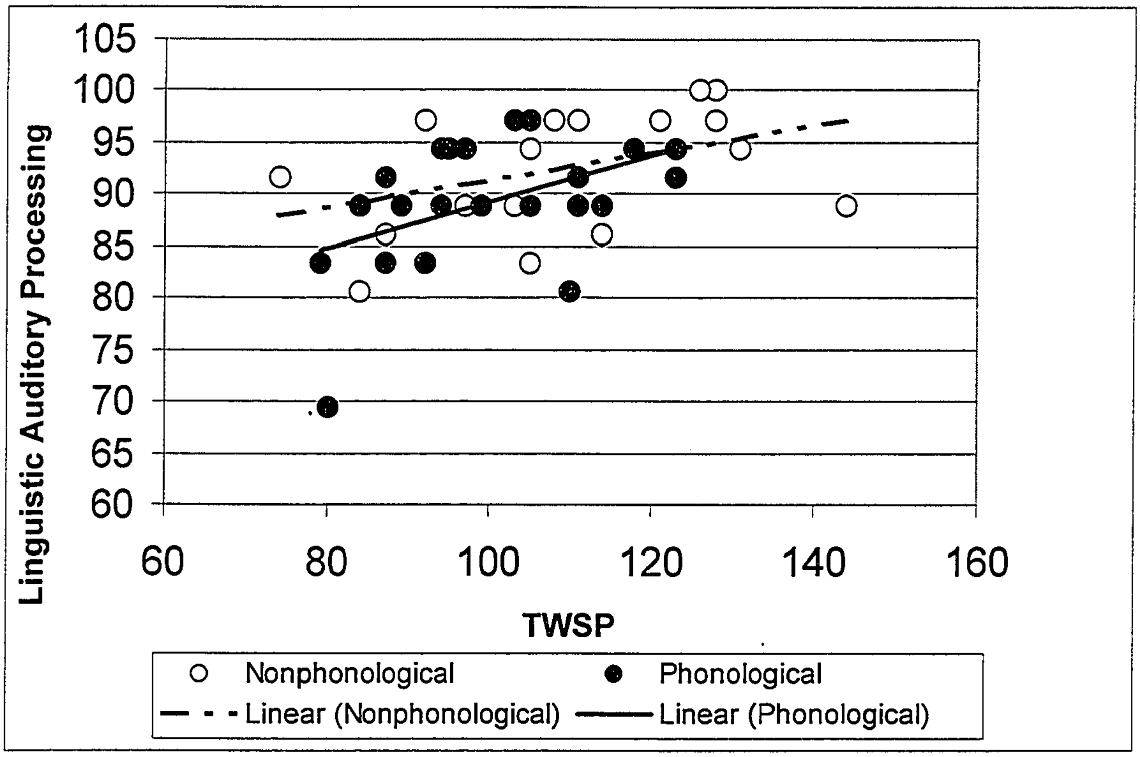

Figure 1. Correlation between linguistic auditory processing and the predictable word scale of the TWS for Grade 2 spellers, $r(20) = .46$, $p < .05$ (phonological); $r(16) = .42$, *ns* (nonphonological).

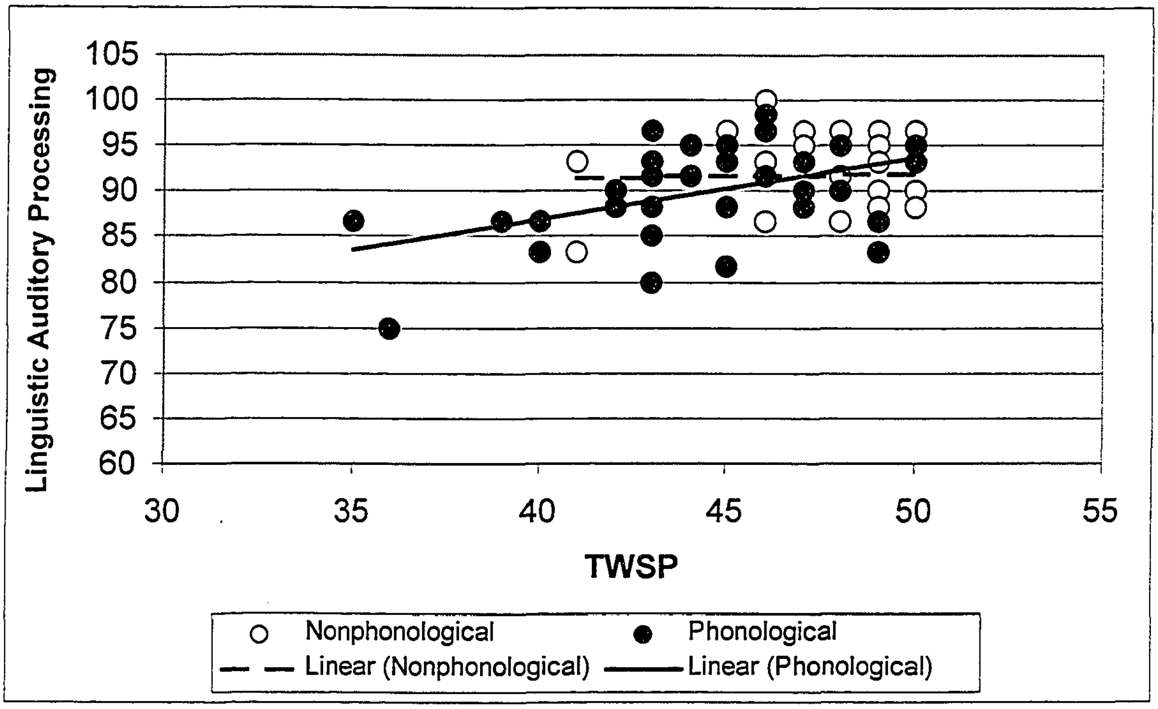

Figure 2. Correlation between linguistic auditory processing and the predictable word scale of the TWS for adult spellers, $r(35) = .48, p < .01$ (phonological); $r(35) = .05$, *ns* (nonphonological).

Discussion

The current study is the first in which both auditory processing and strategy choice are considered, and performance on both is compared. This study adds uniquely to the literature and serves as a basis for more integrated research in these areas in the future. However, the limited number of measures does somewhat restrict the potential to draw strong conclusions from this research alone. Other measures of auditory processing should be used (e.g., nonlinguistic measures involving temporal order, a linguistic measure with controlled recordings that allow a 'same-different' paradigm) to expand upon the current results. Also, future research may compare the effects of all different strategies used, rather than simply a linguistic-nonlinguistic paradigm.

Grade 2 students, Grade 4 students, and adults completed linguistic and nonlinguistic auditory processing tasks, spelling strategy choice tasks, and standardized spelling tests. The major goals in this study were to explore (a) possible associations between linguistic and nonlinguistic auditory processing, (b) possible associations between each type of auditory processing and spelling ability, (c) possible age-related trends in these associations, and in strategy choice, and (d) the possibility of spelling strategy choice mediating any associations between auditory processing and spelling ability. The relationship between linguistic and nonlinguistic auditory processing appeared tenuous at best, and only linguistic auditory processing appeared to be meaningfully associated with spelling ability. Interestingly, it was the Grade 4 students who differed from the other age groups. Neither linguistic auditory processing nor strategy choice was a significant predictor on its own, but the interaction between the two was a significant predictor of spelling ability for this group. Finally, strategy choice did seem to affect spelling ability for each age group. Heavy reliance on phonological strategies was associated with lower spelling ability. Use of phonology was a significant predictor of spelling ability for Grade 2 students and adults. Again, for Grade 4 students, the interaction between strategy choice and linguistic auditory processing was a significant predictor.

Use of Median Split

Methodologists tend to discourage the use of median splits in analyzing continuous variables (e.g., MacCallum, Zhang, Preacher, & Rucker, 2002; Maxwell & Delaney, 1993; McClelland & Judd, 1993). MacCallum et al.'s point about artificial dichotomies ignoring individual differences is well taken. The points that each of these research teams have made illustrating that use of median-splits to determine statistical significance and/or effect size can be misleading are also acknowledged. Note, however, that median splits are not used here to determine significance or effect size, but rather to elucidate and illustrate the nature of the interaction as measured by the regression analysis. Thus, the median split result for the Grade 2 children, which differs from the regression results, should be interpreted cautiously (particularly given the high use of phonology even in the group at the nonphonological end of the median split). For the other groups, in which a regression showed significant interaction effects, median splits are used to more clearly demonstrate the specific effects of the mediation (i.e., the specific influence of strategy choice; in this case, that participants using more phonology are relatively more affected by their linguistic auditory processing skills). As the median splits are not used for independent analyses here, their use in explaining the interaction should not detract from the reliability of the results.

Nonlinguistic-Linguistic Comparisons

Nonlinguistic auditory processing was correlated with linguistic auditory processing for adults, suggesting a relationship between the two types. It was not, however, significantly correlated for children. Since there were no floor or ceiling effects for the Grade 2 children on either task, it seems unlikely that the lack of correlation could have been entirely due to a restricted range. I find these results interesting, particularly in light of Scarborough's (Scarborough, Ehri, Olson, & Fowler, 1998) finding that adults often have poor phonological awareness. When considered in combination with my participants' linguistic auditory processing scores, one may have expected the Grade 4 participants (who outperformed both of the other groups in linguistic auditory processing) to be different, rather than the adults. It may be possible that there are factors that influence linguistic auditory processing that decrease with age, and that linguistic auditory processing becomes more dependent on baseline hearing ability (possibly shared with nonlinguistic auditory processing) as this occurs. Alternately, there may be some process common to linguistic and nonlinguistic processing, as-yet untapped by research, that is used in some strategic process that adults use more than do children. More research would be necessary to confirm the existence of this correlation, and to investigate the course and cause(s) of its development over time.

Nonlinguistic Auditory Processing

Nonlinguistic auditory processing was not a significant predictor of any measure of spelling ability for any group. This lack of a relationship suggests that spelling ability is affected by a component of linguistic auditory processing that is distinct from simple hearing ability. Even if the relationship between linguistic and nonlinguistic auditory processing may increase with age, it continues to be linguistic auditory processing alone that correlates with spelling ability. While my results do not support the work of researchers such as Stein and McAnally (1995; McAnally & Stein, 1996) and Tallal (e.g., Tallal, Stark, & Mellits, 1985), they also do not directly refute it. My results, when compared to those of Stein and McAnally, may suggest that the relation between nonlinguistic auditory processing and spelling ability is restricted to differences between disabled and non-disabled populations, as opposed to a relationship that is observable in a completely non-disabled sample. All available research on this issue to date (e.g., Booth, Perfetti, MacWhinney, & Hunt, 2000; McAnally & Stein, 1996; Stein & McAnally, 1995; Tallal, 1980; Tallal, Stark, & Mellits, 1985) has involved disabled populations. It is not possible, without further investigation, to reliably predict whether or not my results could be replicated with participants who have reading, writing, or language disorders. Much of the research that has been conducted (e.g., Booth, Perfetti, MacWhinney, & Hunt, 2000; Bretherton & Holmes, 2003; France et al., 2002) has involved considerably shorter ISIs than used in this study. If, as Tallal has suggested (Tallal, 1980; Tallal, Stark, & Mellits, 1985), the nonlinguistic auditory processing problems seen in these studies are due to difficulties with rapidly-presented stimuli, one would expect the lack of correlation found in the current study. Replication of the current study with disabled samples, and of Tallal's with non-disabled samples, would be necessary to begin to resolve this question.

Linguistic Auditory Processing

As previous research (e.g., Treiman, 2004; Treiman et al., 1997; Varnhagen et al., 2000) has indicated, there does seem to be a link between linguistic auditory processing and spelling ability. The stepwise regression showed linguistic auditory processing to be a significant predictor of performance on the TWSP for both Grade 2 students and adults. While it is not surprising to find that what people hear may affect their spelling, the differences in linguistic auditory processing tapped in this study are subtle enough to go largely undetected in a classroom setting, or any non-test situation. With the exception of Varnhagen et al. (2000), previous studies of linguistic auditory processing have generally not investigated differences in processing at this level (e.g., Treiman, 2004 and Treiman et al., 1997 focused on group differences in accent and dialect).

Use of Phonology

The negative relationship between use of phonology and spelling ability was not surprising. Heavy reliance on phonological strategies into adulthood has been associated with poor spelling and poor reading (e.g., Barron, 1980; Frith, 1980; Bruck & Waters, 1988; Bruck & Waters, 1990). While there is little, if any, evidence of such a link for children, my finding of such a relationship in child spellers is supported by Kwong and Varnhagen's (2005) findings of slightly slower speed and lower accuracy for children who used phonological strategies, as opposed to those who incorporated nonphonological strategies into their spelling attempts.

The lack of correlation between use of phonology and linguistic auditory processing ability in adults and Grade 4 students, and the negative correlation in Grade 2 students, was unexpected. This lack may be interpreted as a lack of adaptive strategy choice, which is counter to the findings of Kwong and Varnhagen (2005). It is possible that deficits in phonological skills led teachers to emphasize the development of these skills, at the expense of developing other strategies. However, it is equally possible that focusing on this area of weakness is adaptive, for future spelling development if not for present spelling performance. Longitudinal research is necessary to determine if this may be the case. If continued focus on phonology does not lead to gains in that area, this may suggest that individuals who have difficulty with linguistic auditory processing should be taught alternate strategies, perhaps in addition to focusing on developing their phonological skills.

It is notable, however, that adaptive strategy choice is measured differently in the current study than in Kwong and Varnhagen (2005). The previous study considered strategy choice on a per-word basis (i.e., will an individual who spelled a given word incorrectly previously try a different strategy when attempting that word in the future?), in a situation in which specific feedback was available. Essentially, Kwong and Varnhagen (2005) considered adaptive choice, not in terms of what worked best for a given participant in general, but what worked best for a given participant for a given word. The current study involves overall trends, not considered on a per-word basis. Does a participant's general tendency towards a particular strategy depend on his or her general abilities? It is possible that participants make adaptive choices for specific words, but do not generalize their trends when faced with novel words.

Strategy Choice and the Link Between Linguistic Auditory Processing and Spelling

The interaction between linguistic auditory processing and strategy choice was a significant predictor of spelling ability for all groups. In fact, the correlations between linguistic auditory processing and spelling ability for Grade 2 children and adults held only for the participants who used relatively more phonology (see the contrasts in Figures 1 and 2). This suggests that problems with linguistic auditory processing can be circumvented through the use of alternative strategies. Does this mean that linguistic auditory processing cannot be improved with practice? No, this does not seem to be the case. Research indicates that remedial phonological training can be successful (e.g., Lovett, Benson, & Olds, 1990; Olson, Wise, Rings, & Johnson, 1997). However, it does appear that strategy is an important part of spelling ability. The ability to use alternate strategies, if and when phonological strategies fail to result in accurate spelling, may still be highly advantageous. As Kwong and Varnhagen's (2005) results suggested adaptive strategy choice, this may serve as further evidence that teaching multiple strategies is of utmost importance, particularly in cases in which an individual may have difficulties in executing a given strategy.

Conclusions

It is clear that phonological skills are related to spelling ability both for beginning spellers and for adults. Indeed, less phonologically able intermediate spellers may well show similar patterns. Further, use of nonphonological strategies seems to be the key to improving spelling and circumventing less accurate linguistic auditory processing for beginning, and later, spellers.

Theoretical Implications

The results of the current study suggest that, while the possibility of linguistic and nonlinguistic auditory processing sharing a similar basis cannot be completely discounted, one process is not entirely dependent on the other. Foxton et al. (2003) found differences in perception of local pitch change (changes in pitch) and global pitch change (changes in pitch contour). Specifically, only global pitch change perception, which involves a change in pattern unrelated to frequency (i.e., two tones of different frequencies, but with the same contour, would be considered the same), correlated with reading skill in their participants. Would a person who is less skilled at this type of perception hear two voices say the same phoneme and perceive them as different? This is somewhat similar to Serniclaes, Van Heghe, Mousty, Carré, and Sprenger-Charolle's (2004) suggestion that many individuals suffering from dyslexia may continue to perceive phoneme differences that are not useful in their language; distinctions that are usually lost in the first year of life.

The finding that linguistic auditory processing is related to spelling ability corresponds with the findings of other researchers (e.g., Treiman, 2004; Treiman et al., 1997). However, the effects of strategy choice in the current study suggest that this relationship is malleable, which has not been considered in the literature to date. This suggests that strategy choice affects not only spelling ability, but also has the potential to influence the effects that other factors (in this case, linguistic auditory processing) have on spelling ability. One implication of this finding is that instructions in any spelling research should be worded carefully, and should be standardized. My results suggest that any differences in instructions that may influence spelling strategy choice may also systematically affect performance. Also, when discrepancies arise between research studies, the possibility exists that instruction differences or simple sampling differences have resulted in systematic differences in spelling strategy choice.

The different patterns of these results that I found for the different age groups suggest developmental change in these relationships. However, more detailed study would be necessary to specify the exact nature of these changes and to separate them convincingly from education-related changes.

Linguistic auditory processing, strategy choice, and spelling ability. The results of this study do not suggest that linguistic auditory processing has no independent effect on spelling performance, but that this effect is partially mediated by spelling strategy choice. Strategy choice, as well, seems to have an effect independent of its mediation of the link between linguistic auditory processing and spelling performance. Thus, both of these influences can be conceptualized as having independent effects, with the effect of linguistic auditory processing also being partially mediated by strategy choice.

Because spelling often (particularly for beginning spellers) involves hearing something and converting it to written form, linguistic auditory processing is a necessary part of the process. Even experienced spellers may make mistakes (e.g., spelling *free* when the spoken word was *three*) if they do not have highly accurate linguistic auditory processing. Thus, some independent effect of linguistic auditory processing is to be expected in dictated spelling tasks, even when an individual prefers nonphonological strategies. This may or may not be the case for words spelled under other circumstances (e.g., if the individual is writing a story, and thus does not have to interpret someone else's spoken words).

Strategy choice appears to both mediate the effects of linguistic auditory processing and contribute its own independent effects. The mediation of linguistic auditory processing occurs as strategy choices place more or less emphasis on phonological strategies. Individuals who rely heavily on phonological strategies are more dependent on their linguistic auditory processing to guide their spelling attempts. Individuals who rely more heavily on other strategies are less dependent on their linguistic auditory processing, and may instead rely on other processes (e.g., retrieval of a word or its root from memory) instead.

The independent effect of strategy choice may stem from multiple sources as well. Because English is an opaque language (i.e., phonemes do not map reliably onto graphemes in spelling), individuals who rely heavily on phonological strategies cannot be expected to correctly spell the many English words that violate expected phoneme-grapheme correspondences. This effect may not be seen in languages that are transparent (i.e., those in which phoneme-grapheme correspondences are reliable). It is also possible that strategy choice represents an index of an individual's level of practice and sophistication in reading and spelling. It is feasible that increased exposure to reading and writing leads both to increased flexibility in spelling strategy choice and increased spelling ability. Further research would be necessary to test this possibility.

Instructional Implications

Previous research (e.g., Kwong & Varnhagen, 2005) has suggested that teaching a variety of spelling strategies may be beneficial for children whose reading and spelling skills are developing normally. What should be done, though, for those who are experiencing difficulty and need instruction the most? Extrapolating from studies of normally-developing spellers is not ideal, and future research should be conducted with disabled and at-risk spellers. However, considering the results of the current study in conjunction with previous research involving individuals with disabilities, some tentative conclusions can be made.

Further research is required to determine the best route to improving spelling. Concentration on nonphonological strategies is one means that should be investigated. It is also important to determine the extent to which linguistic auditory processing skills may be improved.

Lovett and her colleagues (Lovett et al., 1990; Lovett, Lacerenza, Borden, Frijters et al., 2000) have conducted intervention studies utilizing both phonological remediation and strategy training. As part of their phonological training program, correspondences between sound and letters and letter clusters are taught directly (Lovett, Lacerenza, & Borden, 2000). Children are taught to blend sounds and to analyze sounds that have been blended. Their strategy training involves direct phonological training, but also training in the use of analogy and morphological strategies in decoding words (Lovett, Lacerenza, & Borden, 2000). For instance, children learn to look for known words in a new word and to drop prefixes and suffixes in a multisyllabic word). This strategy training also includes discussions concerning which strategies are appropriate for which words (Lovett, Lacerenza, & Borden, 2000) and how to generalize strategies from one situation to the next (Lovett, Lacerenza, Borton, Frijters et al., 2000). Their phonological programs have resulted in improved reading skills for children with reading disabilities (Lovett et al., 1990). The improvements seemed to be larger, though, and to generalize better when phonological training was combined with strategy instruction (Lovett, Lacerenza, Borden, Frijters et al., 2000). Olson et al. (1997) found that children whose phonological decoding skills improved after training did not necessarily show improved word recognition. This fits with Lovett's findings that children must often be explicitly taught to generalize these skills to new words.

Findings in reading research, combined with the spelling patterns observed in the current study, suggest that intervention for children at risk for spelling problems should be three-fold. First, both Lovett's (Lovett et al., 1990; Lovett, Lacerenza, Borden, Frijters et al., 2000) and Olson's (Olson et al., 1997) research suggests that remedial phonological training, while it may not be enough on its own, can be successful, and should be implemented. Second, these studies indicate that children may not automatically or instinctively generalize their skills, so intervention should include explicit instruction in skill generalization. Third, the current study indicates that the effects linguistic auditory processing on spelling may be circumvented through use of nonphonological strategies. Combined with previous research supporting the advantages of learning multiple strategies (e.g., Kwong & Varnhagen, 2005), this suggests that intervention should also include training in a variety of alternate strategies that may be used instead of, or in combination with, phonological strategies.

Future Directions

Screening for At-Risk Spellers

Research to date has focused on improving reading and/or spelling in individuals who are experiencing difficulty. It may be possible, however, to identify some of these individuals before they begin to experience problems. A longitudinal study, following the spelling achievement of children who have been screened using my linguistic auditory processing task would be necessary to determine its usefulness as a screening tool. Do the children who score more poorly on the linguistic auditory processing task continue to perform more poorly on spelling tasks? Do their abilities deteriorate further? Or do they eventually catch up to their peers? Following the achievement of screened children before intervention is implemented would provide answers to these questions. Also, it may be possible to fine-tune the task in a way that allows it to be shortened, without sacrificing precision. Finally, some sort of cut-off must be determined. Are children with less than 75% accuracy at risk? Are children with less than 80% accuracy at risk? Again, a longitudinal study would be helpful in determining this.

Intervention Development

If screening children before the onset of difficulties becomes possible, intervention can also be implemented before the onset. Perhaps the most persistent question in intervention research is "how much intervention is necessary?" A good intervention study would implement phonological and strategy training both separately and together for comparison purposes. Based on the results of the current study, use of alternate strategies may circumvent the detrimental effects of less accurate linguistic auditory processing. For instance, an individual who learns to use analogy efficiently, or who learns to memorize often-used words, may find that backing up phonological strategies with nonphonological strategies decreases the impact of the lower accuracy of linguistic auditory processing. However, this does not mean that remedial phonological training cannot improve spelling further. Lovett's (Lovett et al., 1990; Lovett, Lacerenza, Borden, Frijters et al., 2000) research suggests that phonological training is useful, if not necessarily sufficient, for spelling improvement. It may also be necessary to experiment with the duration of sessions in order to achieve maximum results with minimum disruption of other classroom activities. A final question to be addressed is "when should intervention end?" Ideally, research would seek the shortest possible duration of intervention that would still allow children to retain their improved skills

Final Thoughts

This study addresses several issues that have not been addressed, or not addressed thoroughly, in previous research. One of these issues is that of a link between linguistic and nonlinguistic processing. While this link has often been assumed, my research indicates that this relationship may be tenuous, and is certainly more complex than one simply forming the foundation for the other. Another issue is that of the effect of linguistic auditory processing on spelling ability. While this issue has been explored in the past, the study of subtle, individual differences in linguistic auditory processing is still in its infancy. Also, this study represents the first real evidence that strategy choice can mediate the effects of other influences. In doing this, it also offers a potential explanation for discrepancies that may be found within this area of research. Practically, this study may inform research practices, in terms of how instructions for spelling tasks are worded. It also forms the foundation for later research on screening for, and intervening against, potential obstacles to spelling achievement.

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Appendix A

Tone Pairs Presented

1000Hz Block

1000Hz-1000Hz

1000Hz-1002Hz (X 2 for adults)

1000Hz-1004Hz (X 2 for adults)

1000Hz-1006Hz (X 2 for adults)

1000Hz-1008Hz (X 2 for adults)

1000Hz-1010Hz (X 2 for adults)

1000Hz-1012Hz (X 2 for adults)

1000Hz-1014Hz (X 2 for adults)

1000Hz-1016Hz (X 2 for adults)

1000Hz-1018Hz (X 2 for adults)

1000Hz-1020Hz (X 2 for adults)

1000Hz-998Hz (X 2 for adults)

1000Hz-996Hz (X 2 for adults)

1000Hz-994Hz (X 2 for adults)

1000Hz-992Hz (X 2 for adults)

1000Hz-990Hz (X 2 for adults)

1000Hz-988Hz (X 2 for adults)

1000Hz-986Hz (X 2 for adults)

1000Hz-984Hz (X 2 for adults)

1000Hz-982Hz (X 2 for adults)

1000Hz-980Hz (X 2 for adults)

1500Hz Block

1500Hz-1500Hz X 2

1500Hz-1502Hz (X 2 for adults)	1500Hz-1498Hz (X 2 for adults)
1500Hz-1504Hz (X 2 for adults)	1500Hz-1496Hz (X 2 for adults)
1500Hz-1506Hz (X 2 for adults)	1500Hz-1494Hz (X 2 for adults)
1500Hz-1508Hz (X 2 for adults)	1500Hz-1492Hz (X 2 for adults)
1500Hz-1510Hz (X 2 for adults)	1500Hz-1490Hz (X 2 for adults)
1500Hz-1512Hz (X 2 for adults)	1500Hz-1488Hz (X 2 for adults)
1500Hz-1514Hz (X 2 for adults)	1500Hz-1486Hz (X 2 for adults)
1500Hz-1516Hz (X 2 for adults)	1500Hz-1484Hz (X 2 for adults)
1500Hz-1518Hz (X 2 for adults)	1500Hz-1482Hz (X 2 for adults)
1500Hz-1520Hz (X 2 for adults)	1500Hz-1480Hz (X 2 for adults)

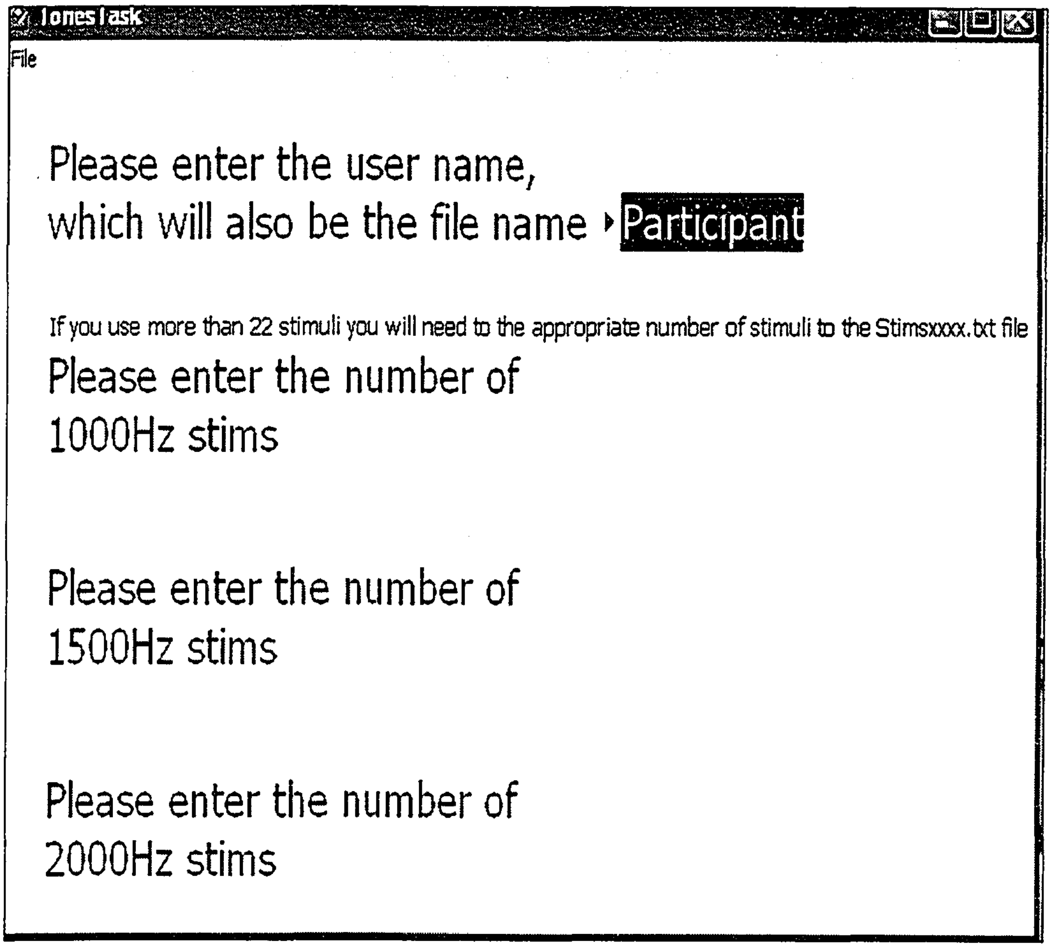
2000Hz Block

2000Hz-2000Hz X 2

2000Hz-2002Hz (X 2 for adults)	2000Hz-1998Hz (X 2 for adults)
2000Hz-2004Hz (X 2 for adults)	2000Hz-1996Hz (X 2 for adults)
2000Hz-2006Hz (X 2 for adults)	2000Hz-1994Hz (X 2 for adults)
2000Hz-2008Hz (X 2 for adults)	2000Hz-1992Hz (X 2 for adults)
2000Hz-2010Hz (X 2 for adults)	2000Hz-1990Hz (X 2 for adults)
2000Hz-2012Hz (X 2 for adults)	2000Hz-1988Hz (X 2 for adults)
2000Hz-2014Hz (X 2 for adults)	2000Hz-1986Hz (X 2 for adults)
2000Hz-2016Hz (X 2 for adults)	2000Hz-1984Hz (X 2 for adults)
2000Hz-2018Hz (X 2 for adults)	2000Hz-1982Hz (X 2 for adults)
2000Hz-2020Hz (X 2 for adults)	2000Hz-1980Hz (X 2 for adults)

Appendix B

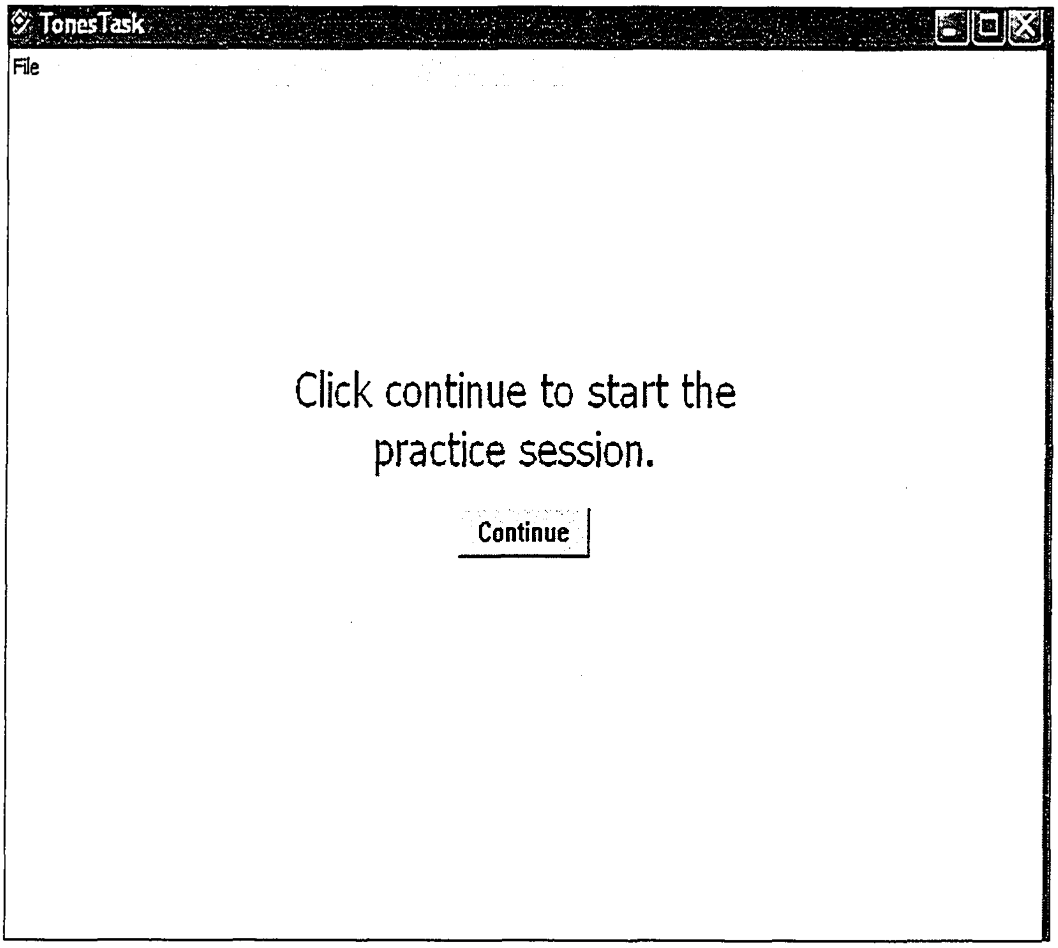
Screens and Responses for the Nonlinguistic Auditory Processing Task



↓

Researcher enters Participant Code and number of tone pairs at each level.

↓



↓

Participant clicks 'Continue'

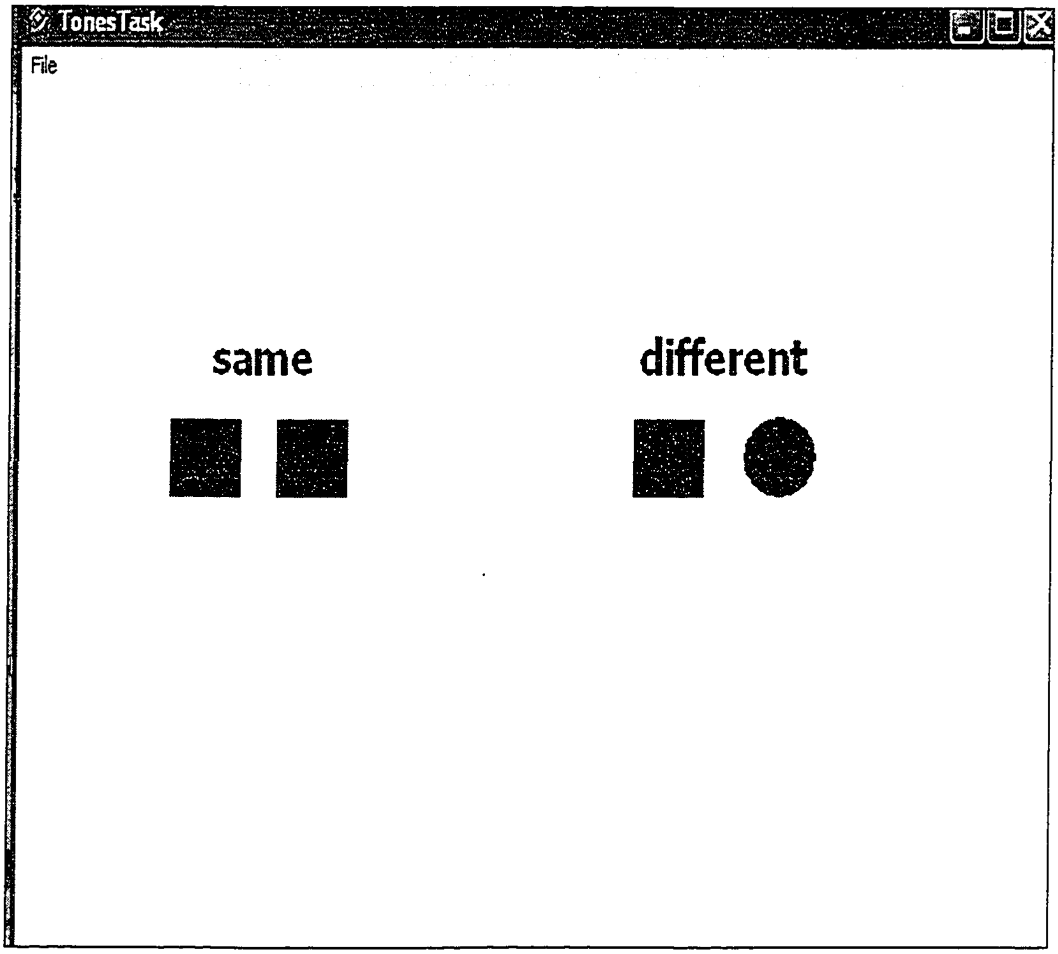
↓ (0.5 sec)

Tone 1 (1 sec)

↓ (0.5 sec)

Tone 2 (1 sec)

↓



↓

Participant hits key labeled with one of the images on the above screen

↓

for an incorrect response; participant clicks ‘Continue’

↓ (0.5 sec)

For a correct response; participant clicks 'Continue'

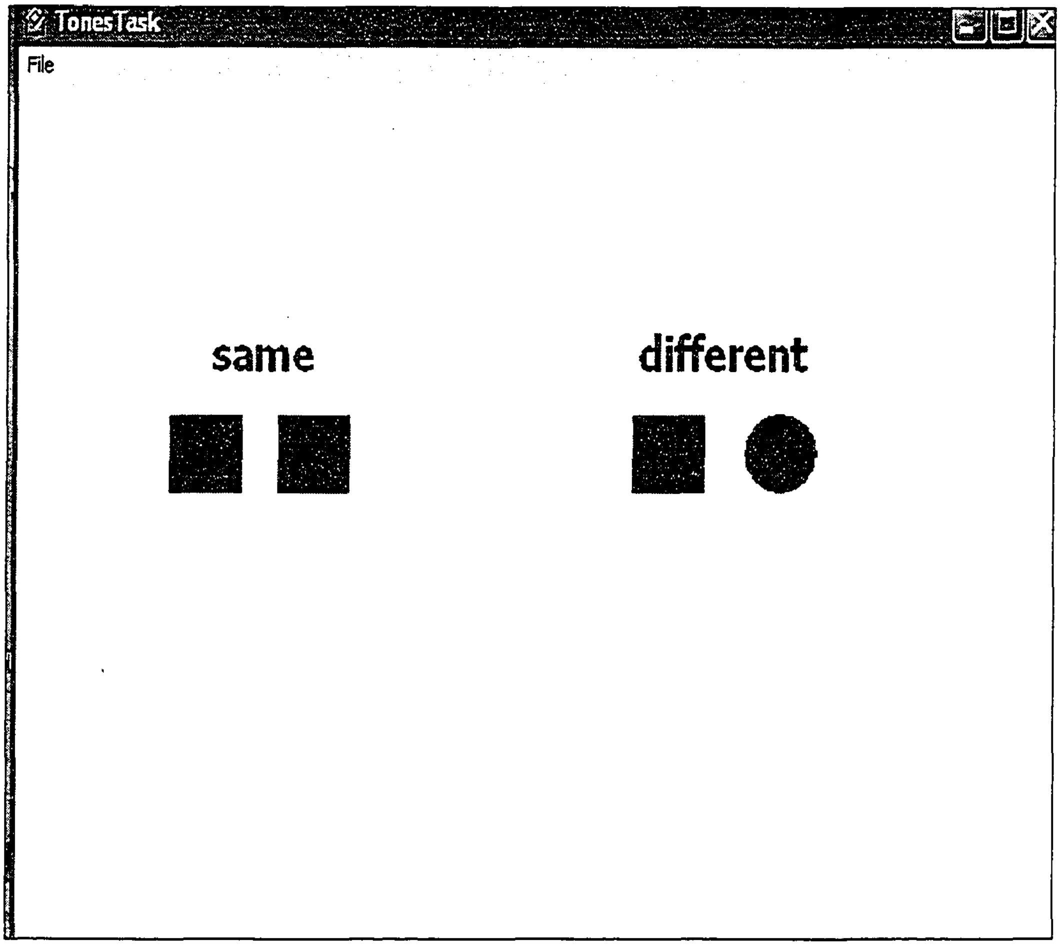
↓ (0.5 sec)

Tone 1 (1 sec)

↓ (0.5 sec)

Tone 2 (1 sec)

↓



↓

Participant hits key labeled with one of the images on the above screen

↓ (0.5 sec)

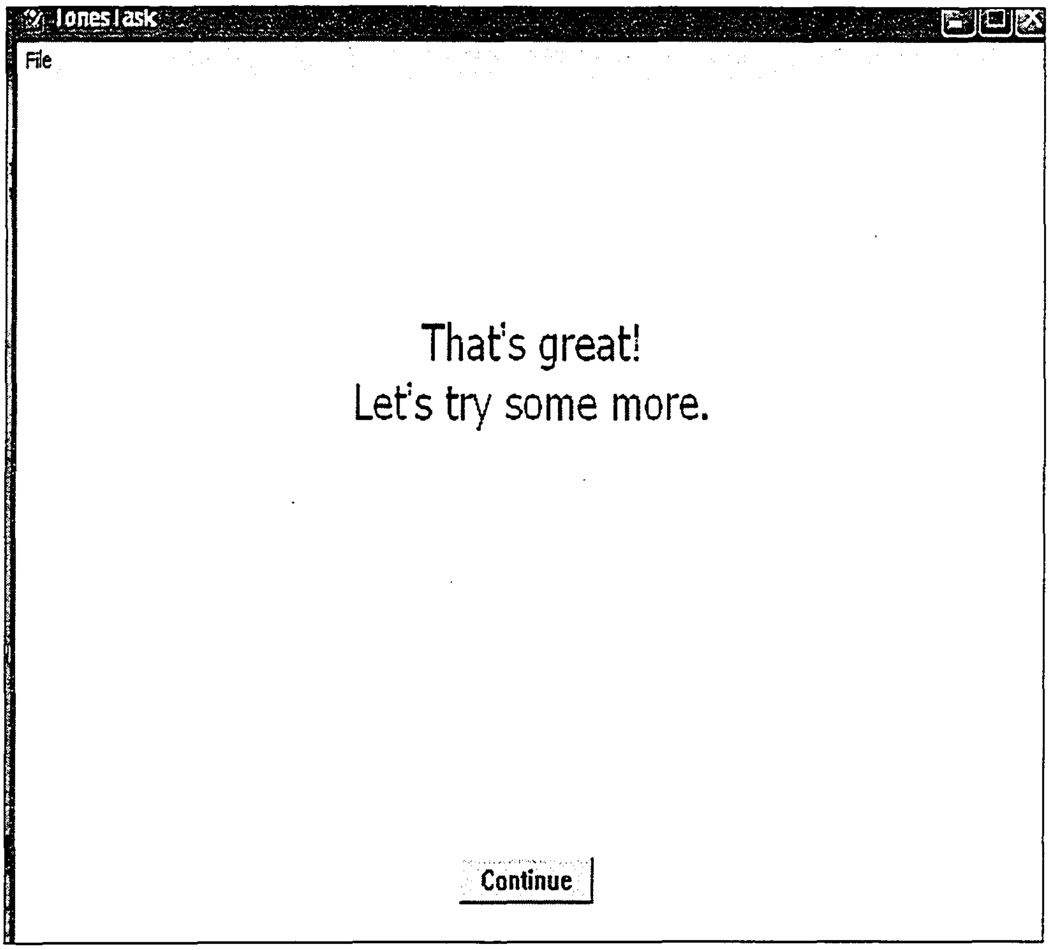
Next tone pair presented; continues until all tone pairs in that set have been completed

↓

↓

Next block of tone pairs presented in same fashion

↓



↓

Next block of tone pairs presented in same fashion


TonesTask
File
BYE!

Appendix C

Phoneme Task Sounds and Response Options

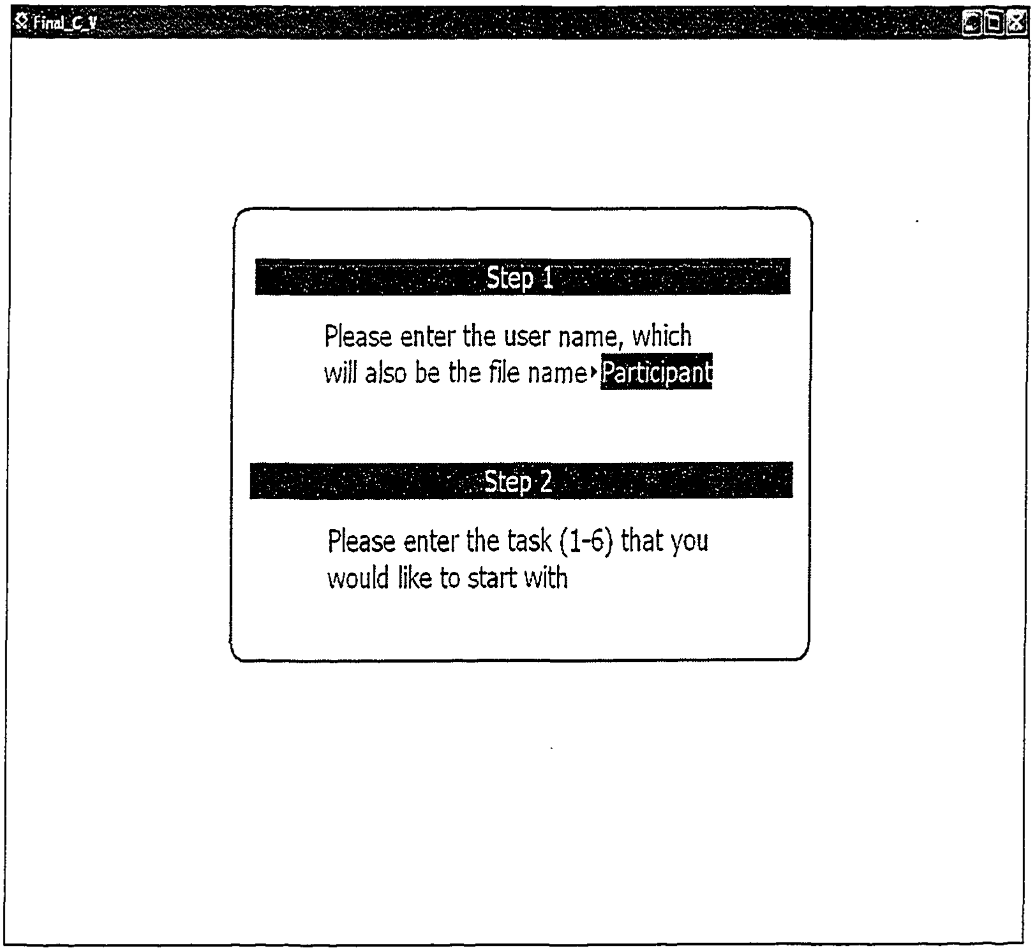
Each set was presented twice during child testing and three times during adult testing.

Sound:		k/k/	
Options:	k	g	s
Sound:		g/gʌ/	
Options:	g	k	f
Sound:		b/b/	
Options:	b	d	ch
Sound:		d/d/	
Options:	d	b	sh
Sound:		z/z/	
Options:	z	s	th
Sound:		s/s/	
Options:	s	z	f
Sound:		v/v/	
Options:	v	f	d
Sound:		f/f/	
Options:	v	f	t
Sound:		ch/tʃ/	
Options:	ch	sh	p
Sound:		sh/ʃ/	
Options:	sh	ch	b
Sound:		f/f/	
Options:	f	th	t
Sound:		th/θ/	
Options:	th	f	d
Sound:		d/d/	
Options:	d	t	j
Sound:		t/t/	
Options:	t	d	ch
Sound:		j/dʒ/	
Options:	j	ch	v
Sound:		ch/tʃ/	
Options:	ch	j	th
Sound:		p/p/	
Options	p	b	z
Sound:		b/b/	
Options:	b	p	sh
***Sound:**		v/v/	
Options:	v	th	k
***Sound:**		/ð/	
Options:	th	v	g

*Used in adult testing only.

Appendix D

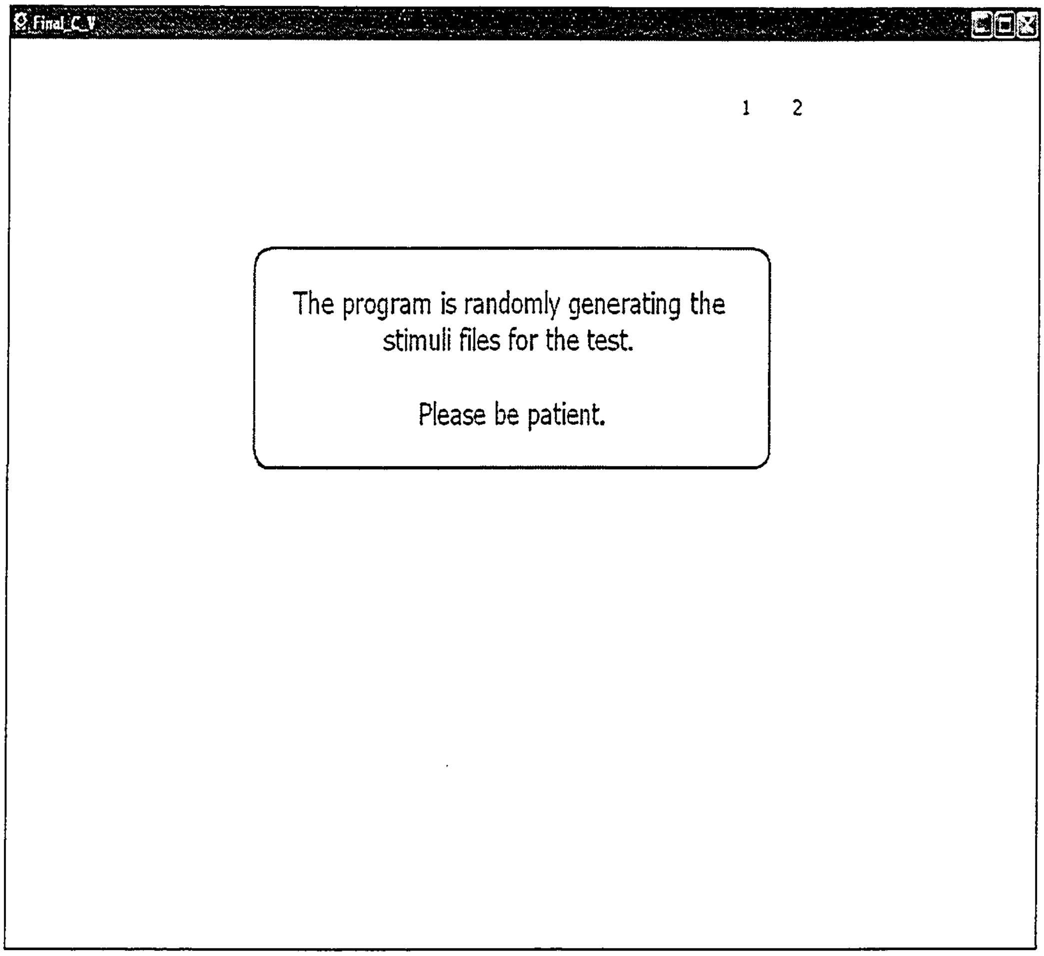
Screens and Responses for the Linguistic Auditory Processing Task



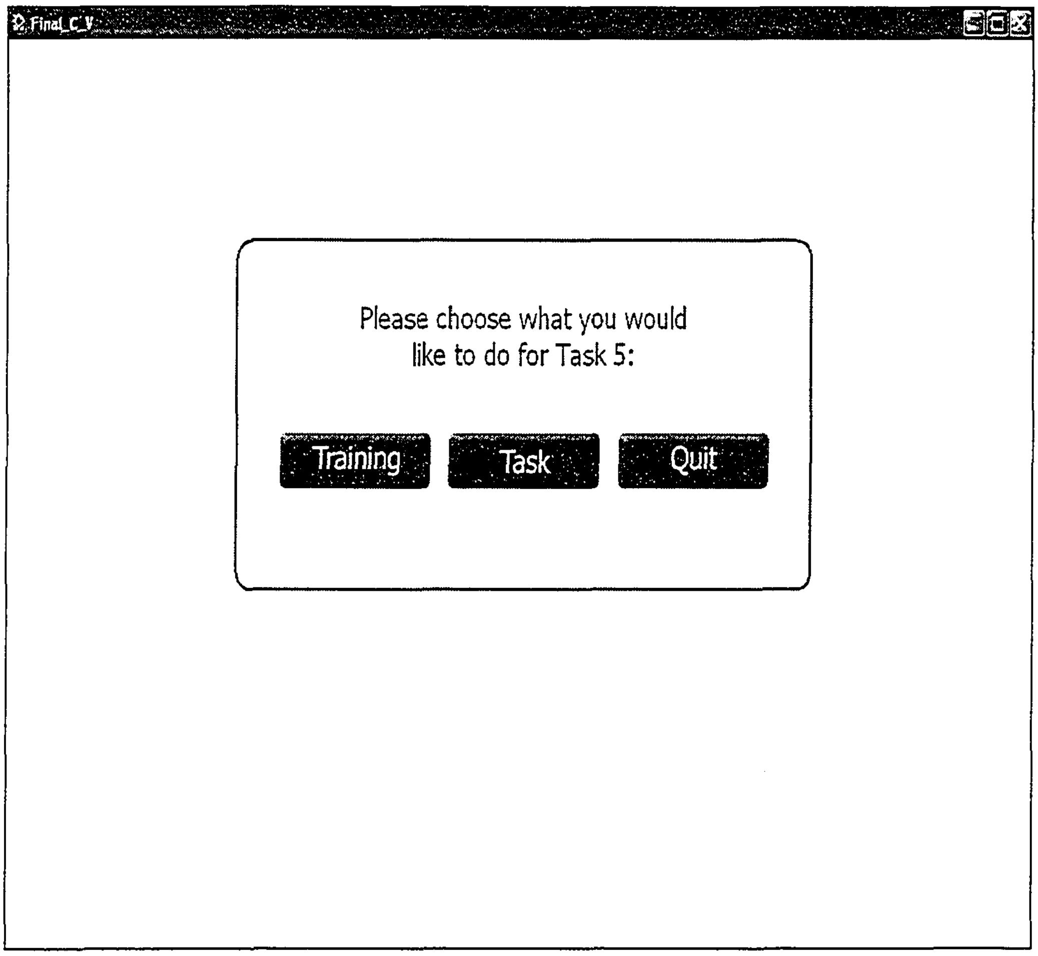
↓

Researcher enters Participant Code and task number.

↓


Final_C_V
1 2
The program is randomly generating the stimuli files for the test.
Please be patient.

↓



↓

Participant clicks “Training”.

↓

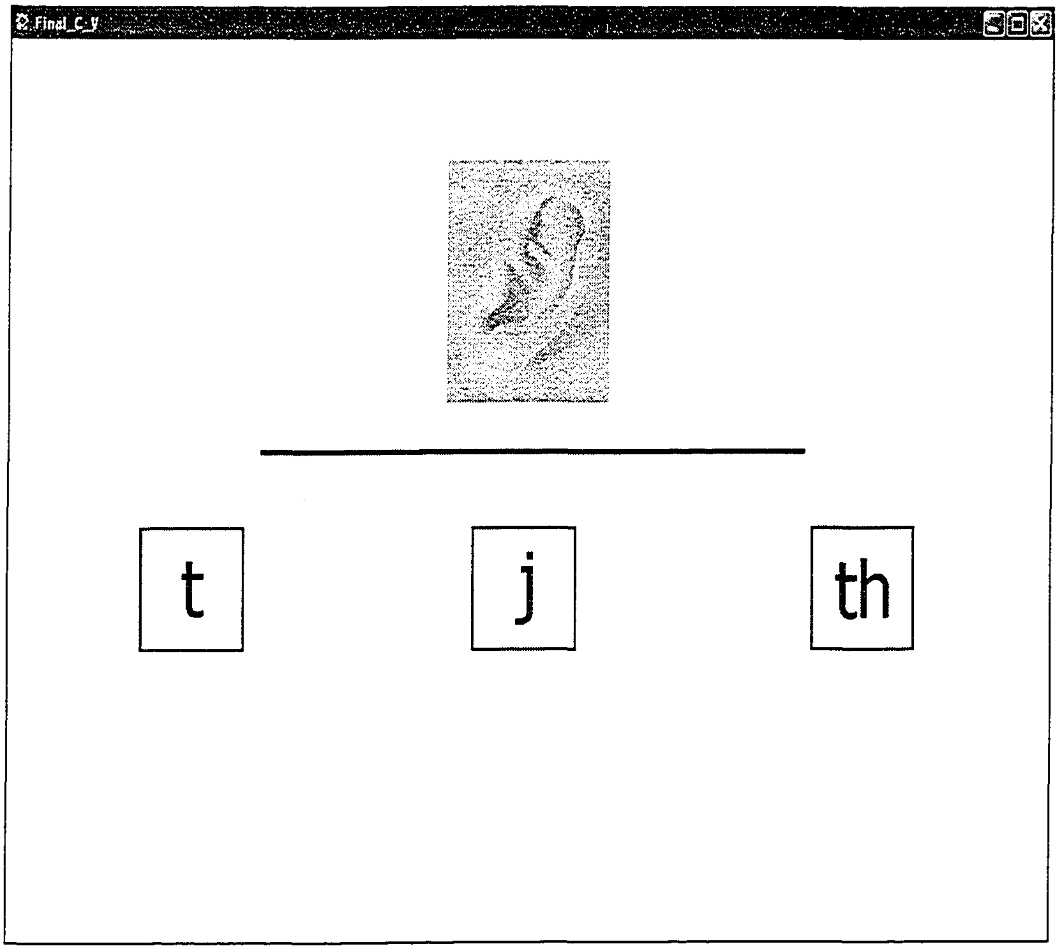
↓

Participant clicks "Continue".

↓ (0.5 sec)

Phoneme

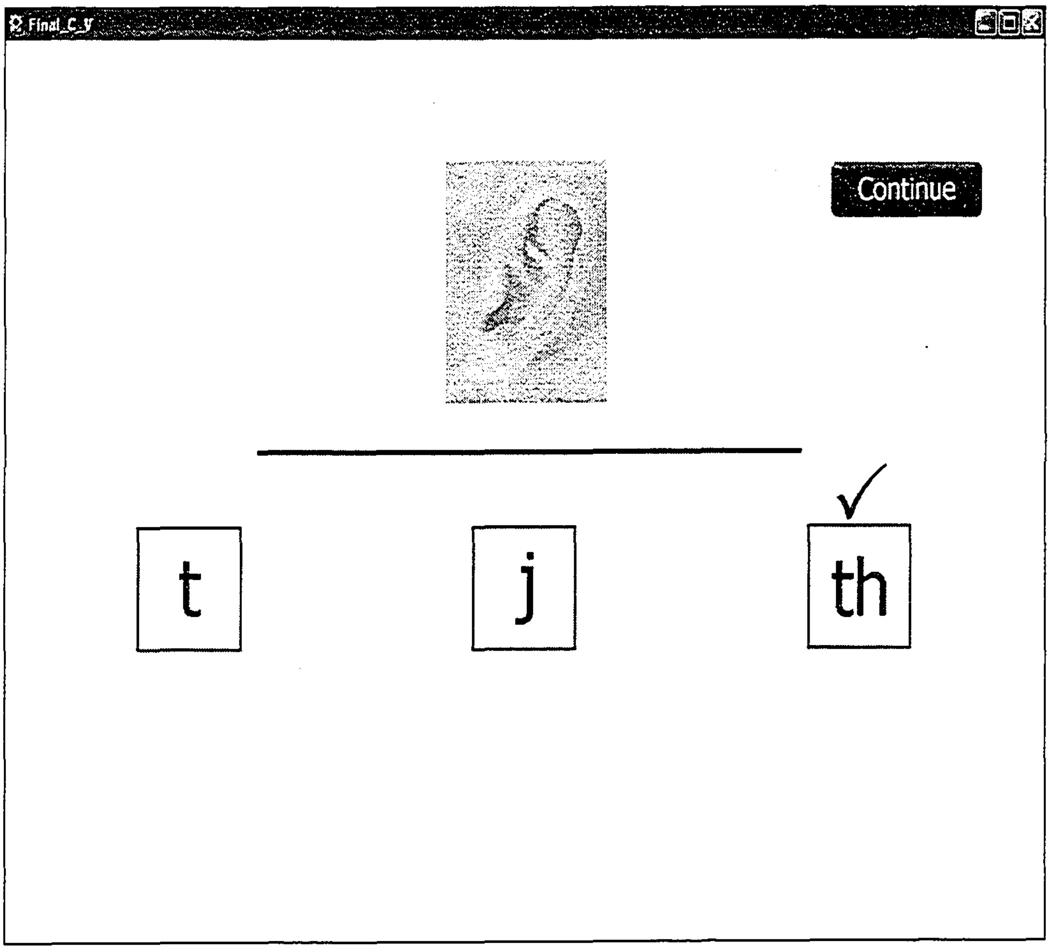
↓



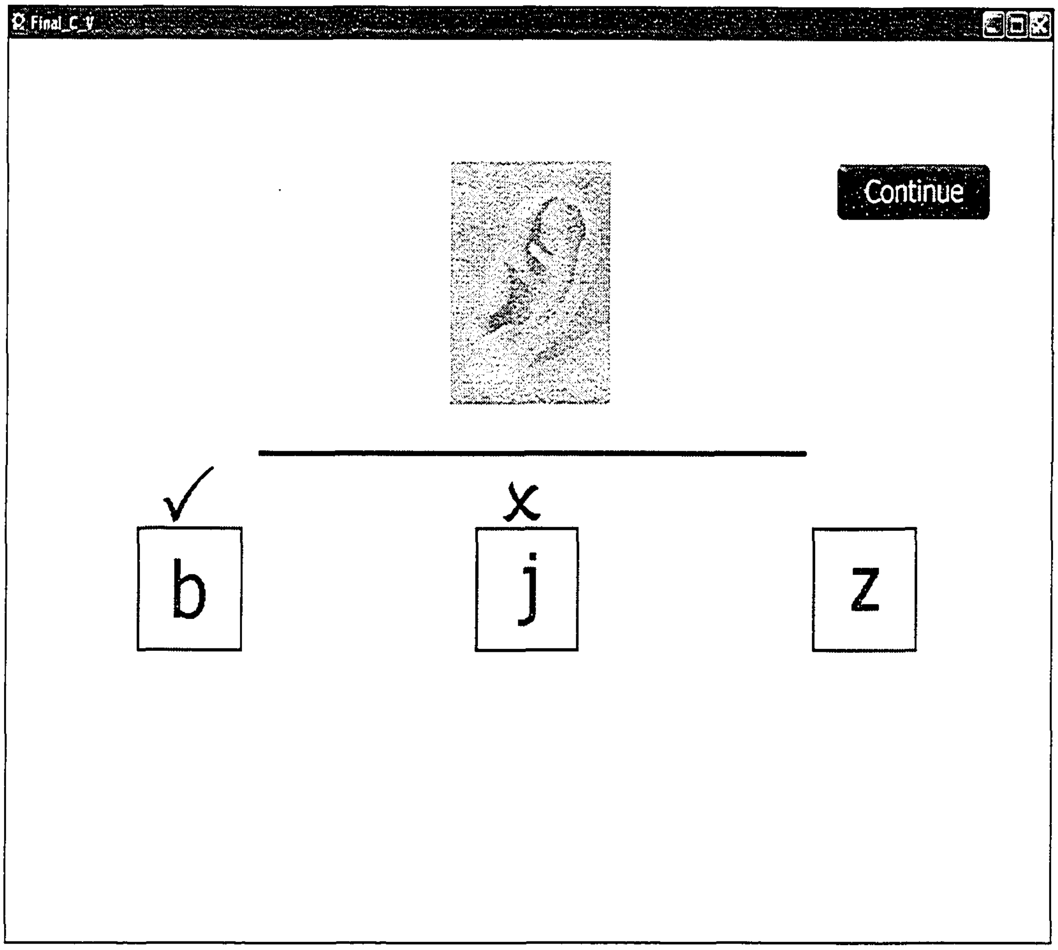
↓

Participant clicks the ear to hear the sound again or a letter to indicate which sound was heard.

↓



For a correct response; or

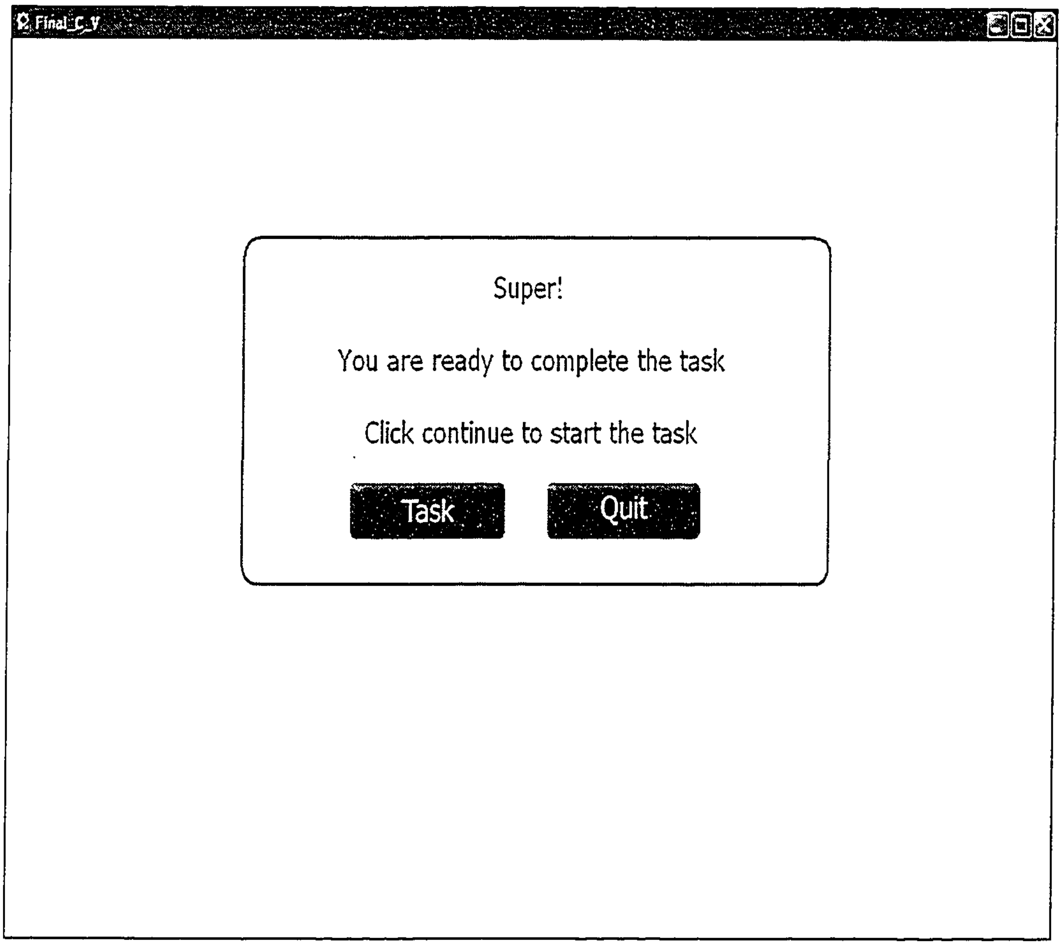


for an incorrect response.

↓

Participant clicks "continue"; this continues for 30 training trials.

↓ (0.5 sec)



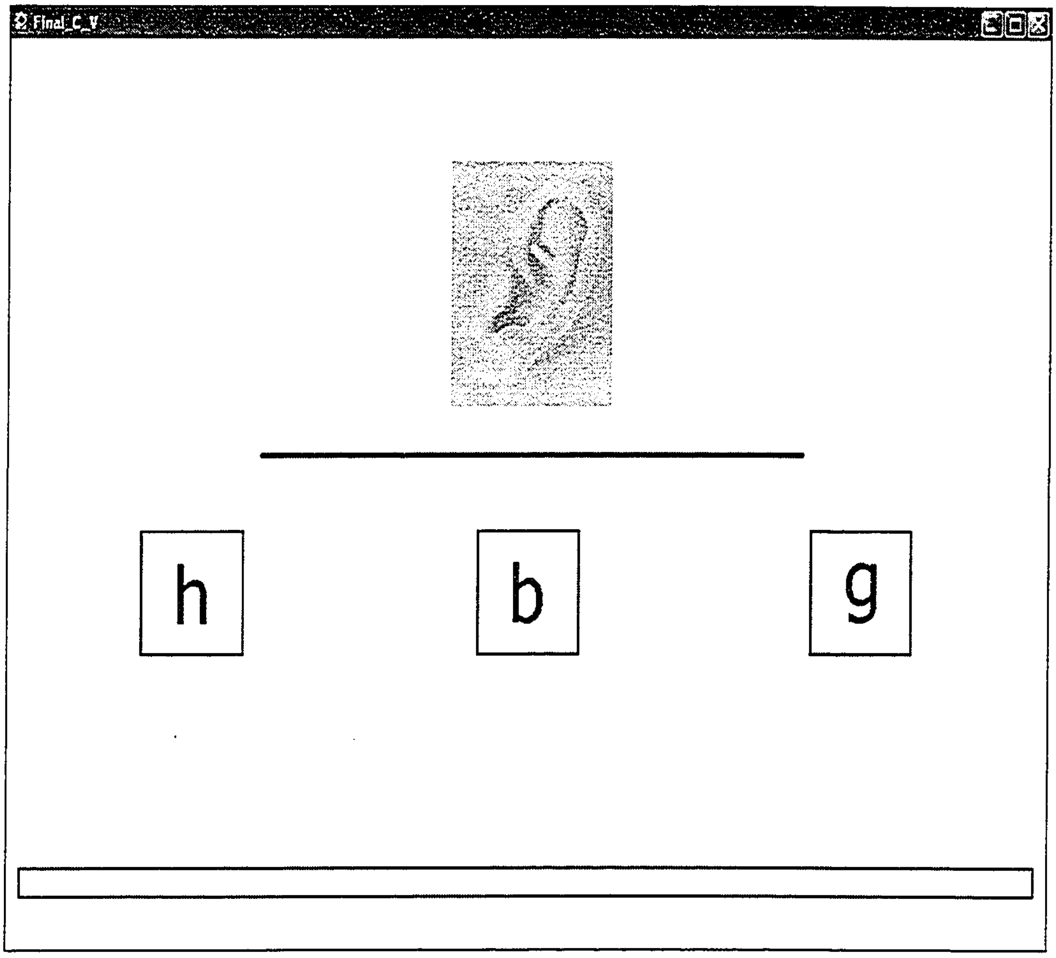
↓

Participant clicks "Task".

↓ (0.5 sec)

Phoneme

↓ (0.5 sec)



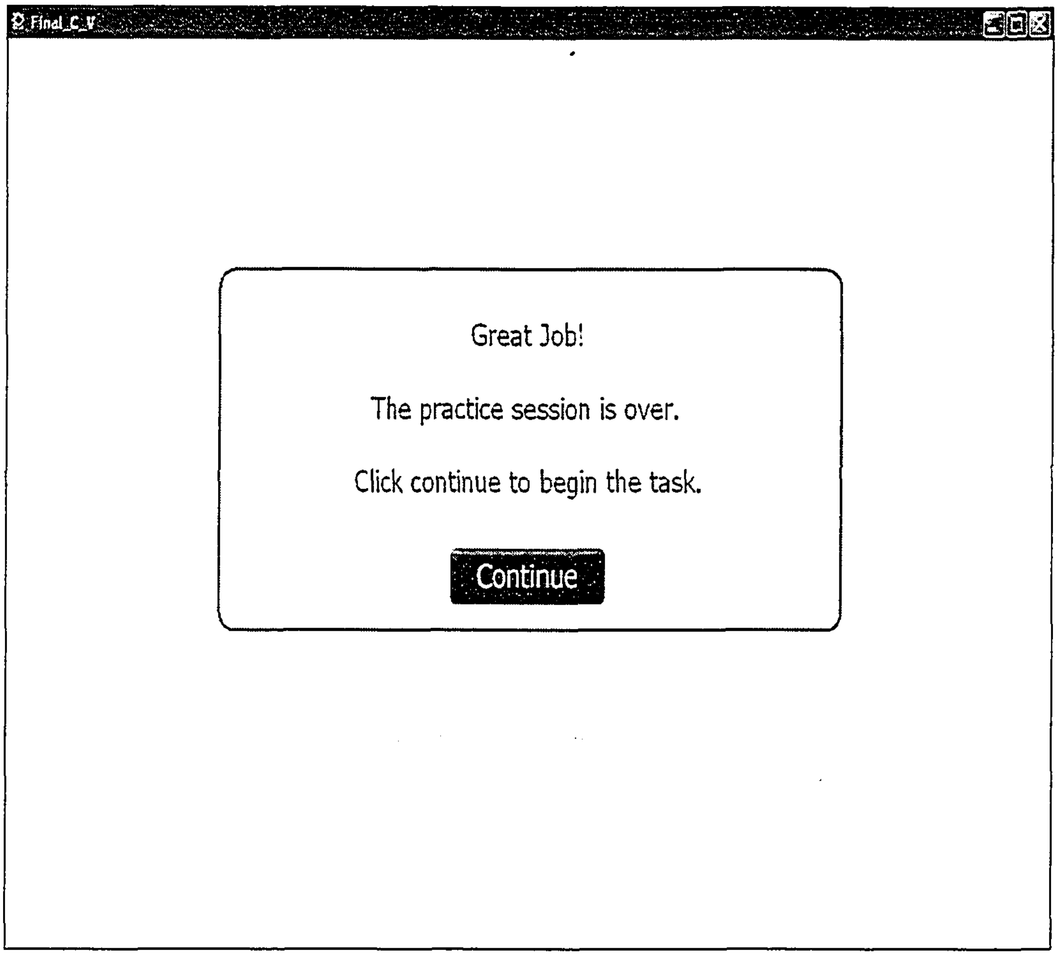
↓

Participant clicks the ear to hear the sound again or a letter to indicate which sound was heard.

↓ (0.5 sec)

Phoneme; for two more no-feedback practice trials.

↓



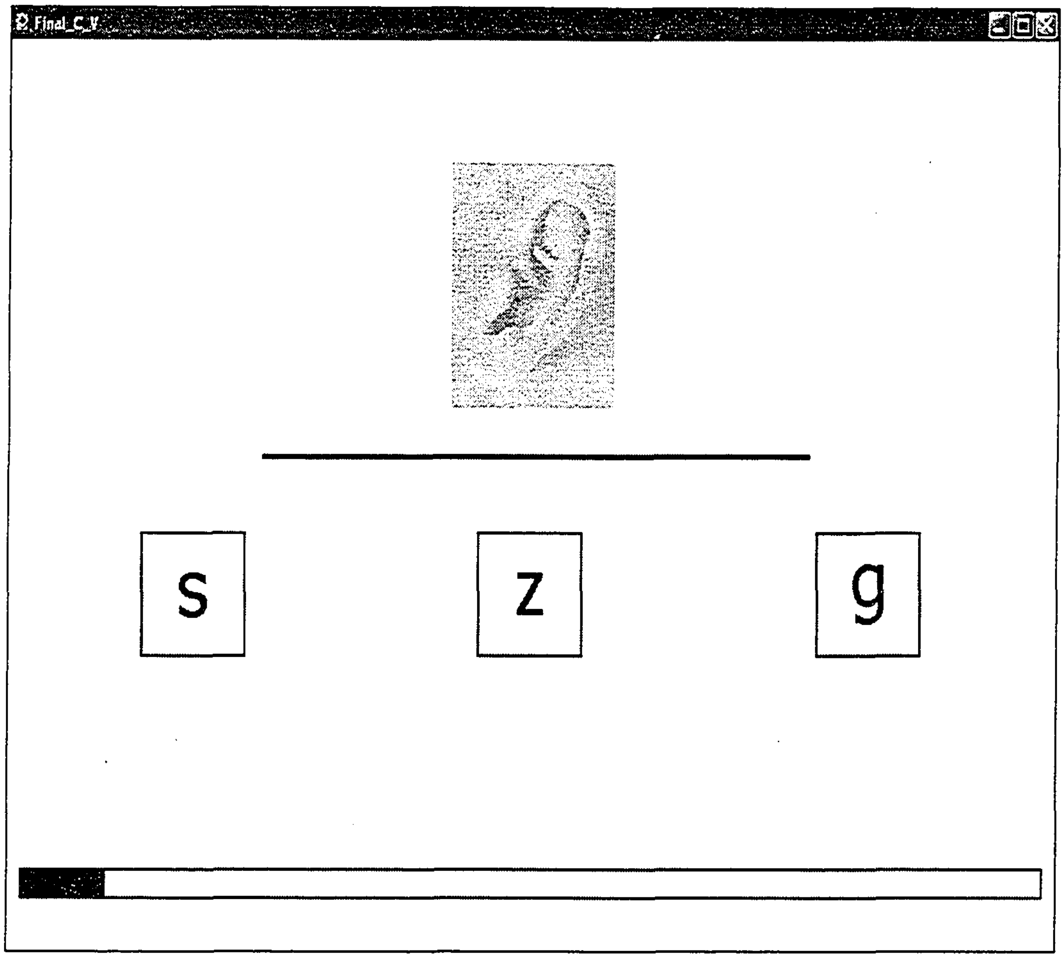
↓

Participant clicks “Continue”.

↓ (0.5 sec)

Phoneme.

↓



↓

Participant clicks the ear to hear the sound again or a letter to indicate which sound was heard; this continues for 36 confusable pairs.

↓

↓

Participant clicks “Quit”.

Appendix E

Selected Words and Sentences from the WRAT 3

Grade 2

1. Run.	Jenn can run fast.
2. Will.	They will wait for you.
3. Cut.	Mother will cut the cake.
4. Arm.	His arm hurt.
5. Dress.	The dress fits well.
6. Train.	The train was on time.
7. Shout.	If you shout, he'll hear you.
8. Watch.	My watch is fast.
9. Grown.	Potatoes are grown in the field.
10. Kitchen.	Our kitchen is small.
11. Result.	The result of your work is good.
12. Heaven.	Heaven surrounds the Earth.
13. Educate	Parents educate their children.
14. Purchase	He did not purchase the car.
15. Institute	The art institute held and exhibit.

Grade 4

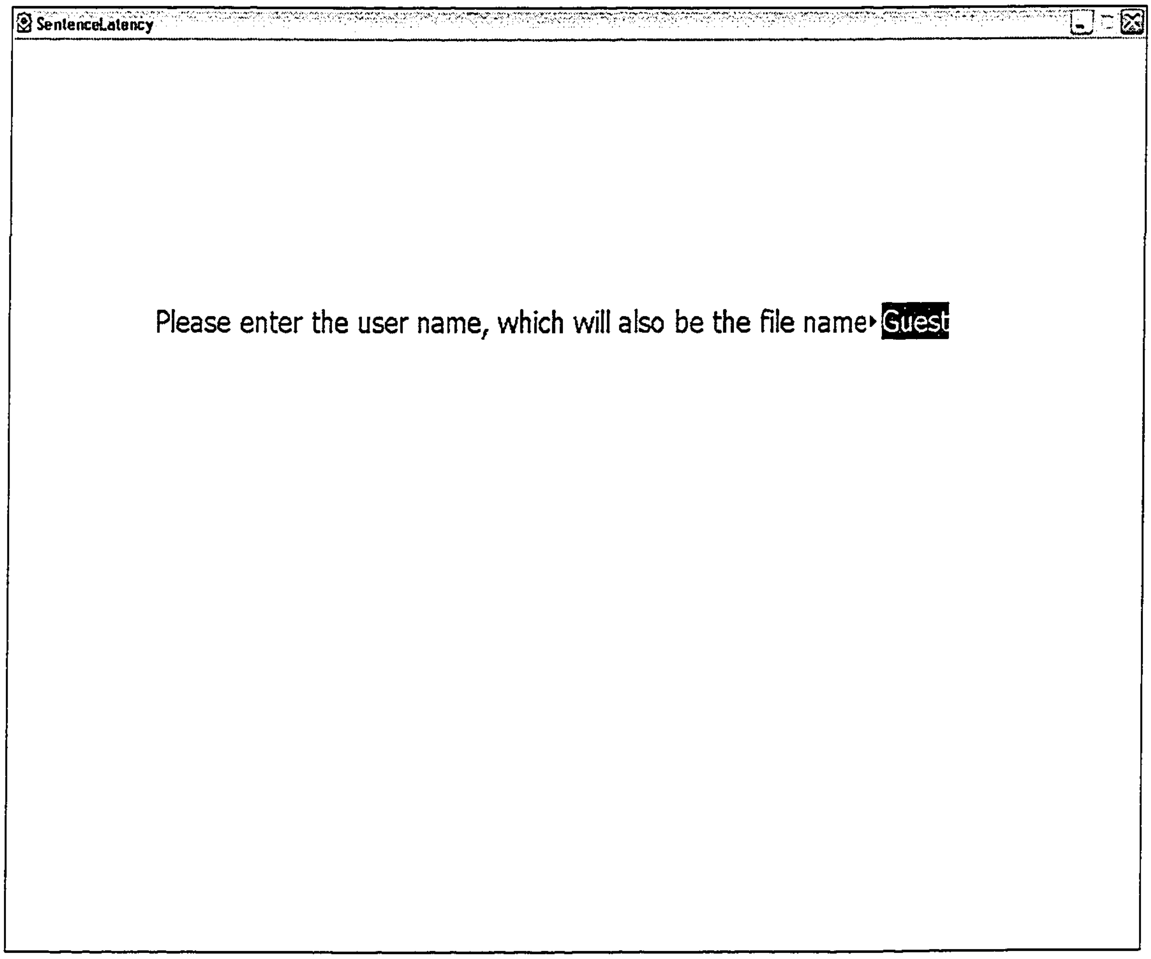
1. Train.	The train was on time.
2. Shout.	If you shout, he'll hear you.
3. Watch.	My watch is fast.
4. Grown.	Potatoes are grown in the field.
5. Kitchen.	Our kitchen is small.
6. Result.	The result of your work is good.
7. Heaven.	Heaven surrounds the Earth.
8. Educate	Parents educate their children.
9. Purchase	He did not purchase the car.
10. Institute	The art institute held and exhibit.
11. Suggestion	My suggestion was followed.
12. Equipment	The office got new equipment.
13. Museum	We went to the museum for the afternoon.
14. Occupy	We occupy a small apartment.
15. Illogical	His thinking was illogical.

Adult

1. Arm.	His arm hurt.
2. Dress.	The dress fits well.
3. Train.	The train was on time.
4. Shout.	If you shout, he'll hear you.
5. Necessity.	Food is a necessity.
6. Commission.	The commission reported to the mayor.
7. Assiduous.	Assiduous effort gets results.
8. Loquacious.	He was loquacious during the interview.
9. Sovereignty.	The country kept its sovereignty.
10. Irresistible.	His idea was irresistible.
11. Occurrence.	War is a tragic occurrence.
12. Auricular.	An auricular defect pertains to the external ear.
13. Imperturbable.	Her imperturbable attitude was reassuring.
14. Iridescence.	Iridescence is a play of colours.
15. Mnemonic.	It is easier to learn a long list of words by using a mnemonic trick.

Appendix F

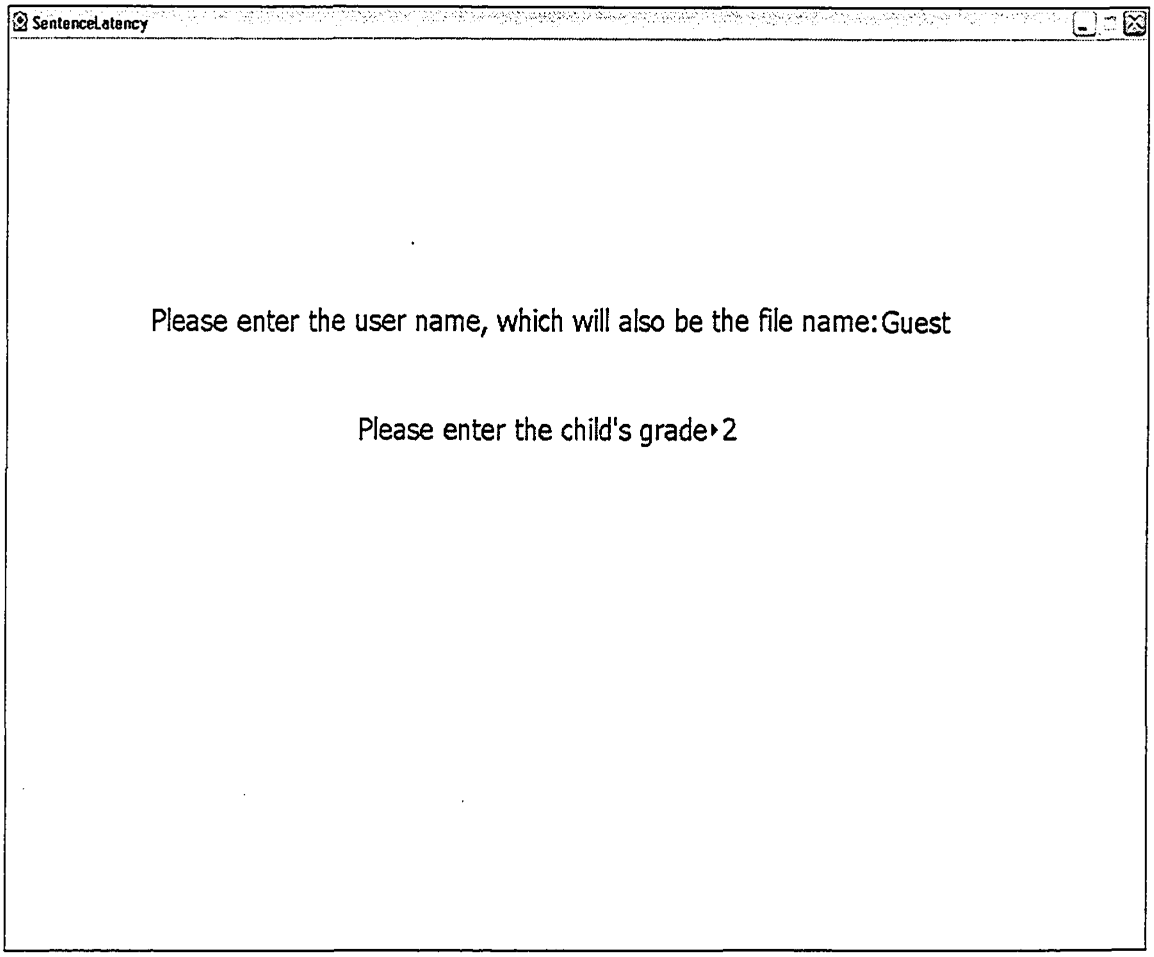
Screens and Responses for the Spelling Strategy Task



↓

Researcher enters Participant Code.

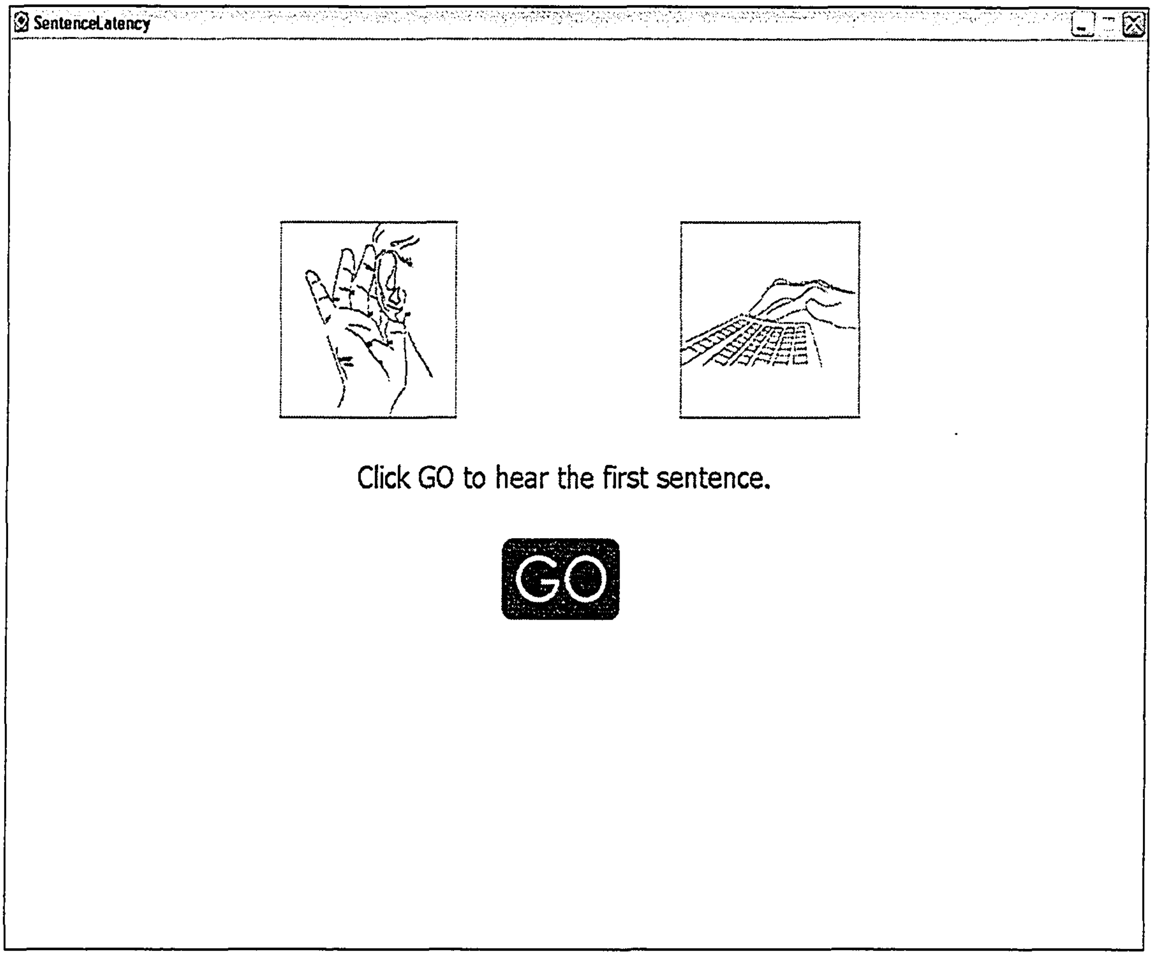
↓



↓

Researcher enters participant's grade.

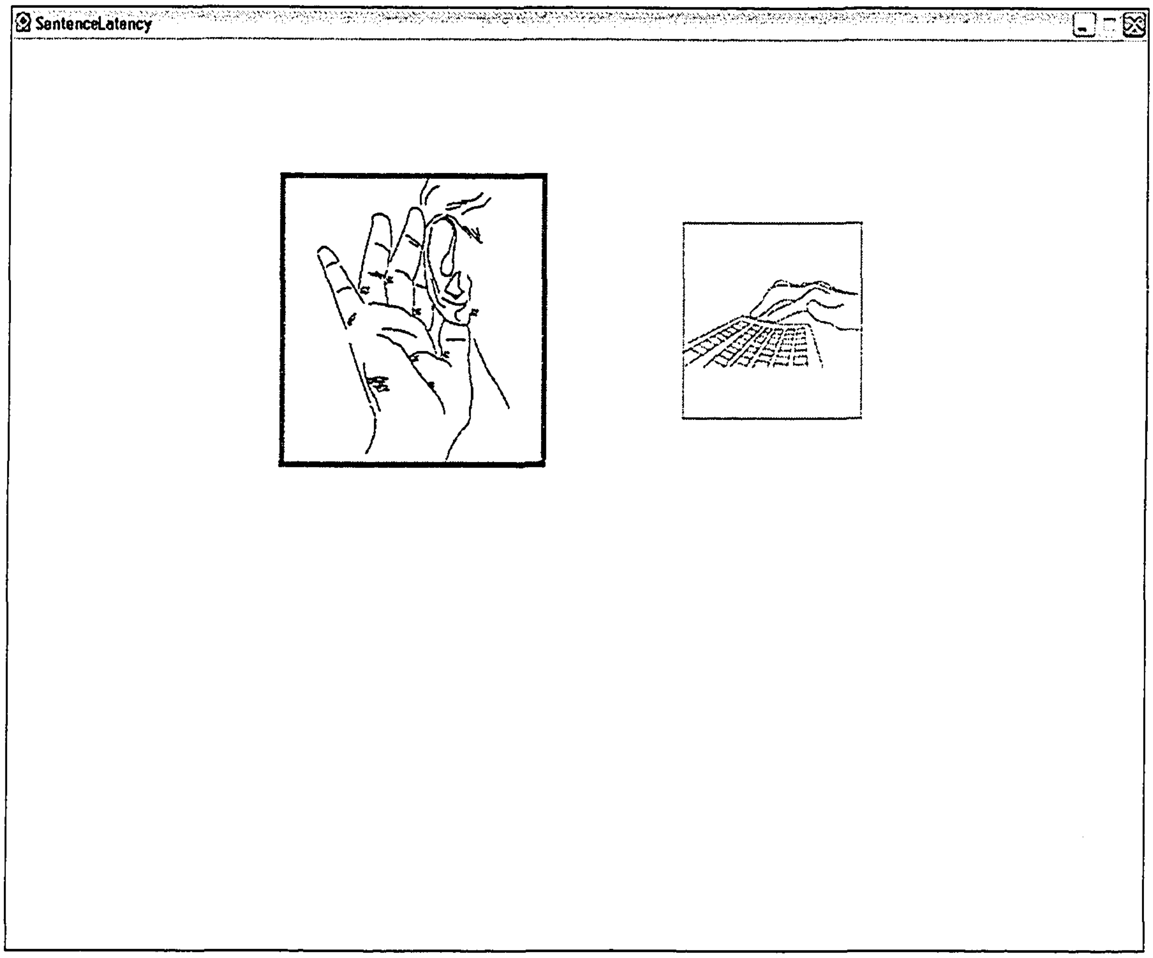
↓ (0.5 sec)



↓

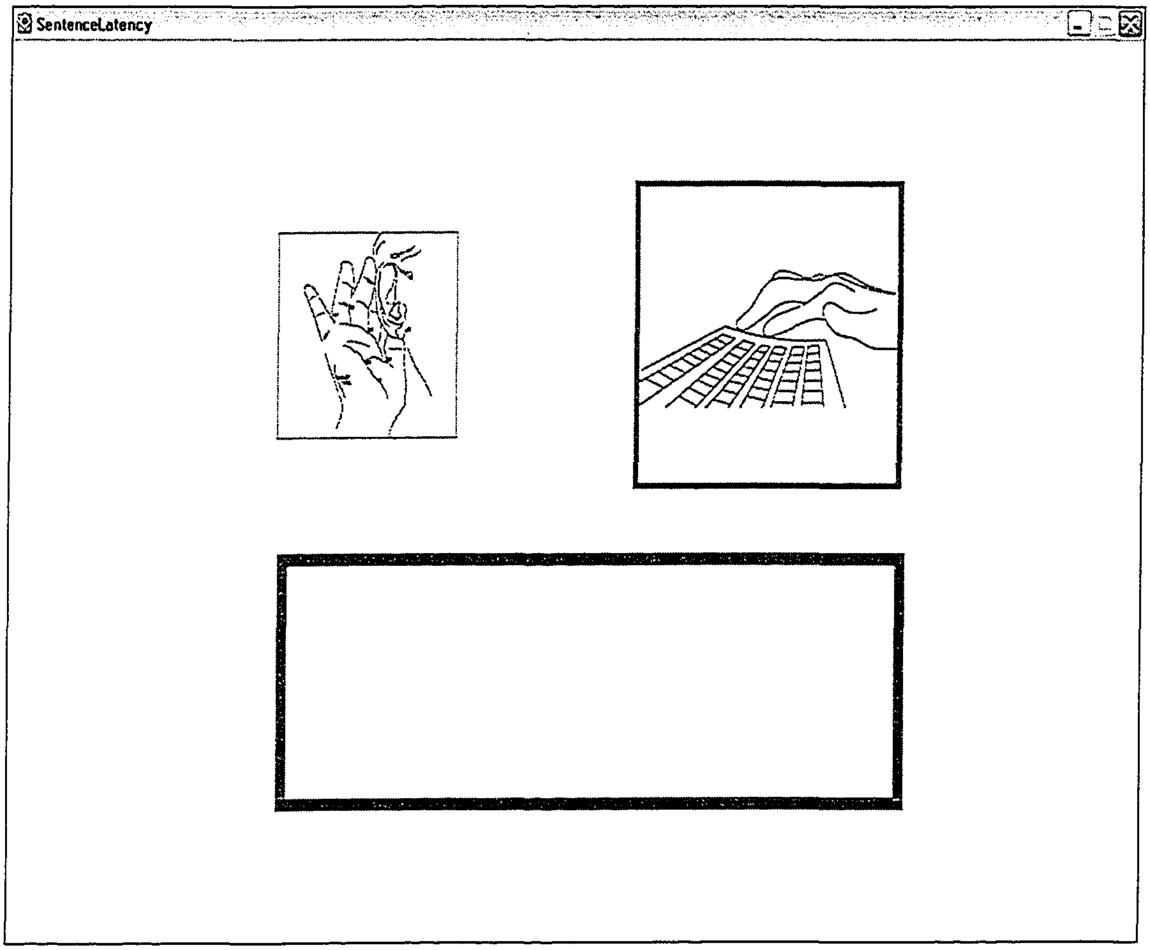
Participant clicks “Go”.

↓ (0.5 sec)



Screen remains while sentence is presented

↓



↓

Participant types word and hits “Enter”; this is repeated for 15 words.

↓


SentenceLatency
Great job!