2006

Emotion perception in speech: Discrimination, identification, and the effects of talker and sentence variability

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EMOTION PERCEPTION IN SPEECH: DISCRIMINATION, IDENTIFICATION, AND THE EFFECTS OF TALKER AND SENTENCE VARIABILITY

by

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A Capstone Project
Submitted in partial fulfillment of the
Requirements for the degree of:

Doctor of Audiology

Washington University School of Medicine
Program in Audiology and Communication Sciences

May 11, 2006

Approved by:
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Abstract:* *The primary goal of this project is to study the ability of adult cochlear implant users to perceive emotion through speech alone. A secondary goal of this project is to study the development of emotion perception in normal hearing children to serve as a baseline for comparing emotion perception abilities in similarly-aged children with impaired hearing.

PURPOSE:

The primary purpose of this project is to study the ability of adult cochlear implant users to perceive emotion through speech alone. Emotion perception will be evaluated using two types of experiments: emotion discrimination and emotion identification. The effects of variation in talker and in sentence script on emotion perception ability will also be determined. A secondary goal of this project is to study the development of emotion perception in normal hearing children. Their performance may then serve as a baseline for comparing emotion perception abilities in similarly-aged children with impaired hearing.

BACKGROUND:

Speech perception can be divided into two main groups: linguistic and nonlinguistic. The linguistic aspects of speech include the properties of the speech signal and word sequence. Linguistic aspects deal more with what is being said, not how it is said. The nonlinguistic properties of speech have more to do with talker attributes such as age, gender, dialect, and emotion. Cues to nonlinguistic properties can also be provided in non-speech vocalizations, such as laughter or crying.

The main nonlinguistic attribute that was examined in this study was that of emotion. In a communication situation the true meaning of the communication is transmitted not only by the linguistic content but also by how something is said, how words are emphasized and by the speaker's mood and attitude toward what is said. The speaker's 'tone of voice' often provides a listener with as much information about the speaker's emotional state as does the semantic content of his/her utterances (Most et al., 1993). The perception of emotion in the vocal expressions of others is vital for an accurate understanding of emotional messages (Banse & Scherer, 1996). In general, emotion has been described in a three dimensional space where arousal (activation), valence (pleasure) and control (power) represent each dimension (Yildirim et al., 2004). Listeners seem to use these three dimensions to understand what is being emoted by a speaker. This understanding is developed from birth. Adults may use a form of speech called motherese or infant-directed speech when talking to infants to help them understand mood. This infant-directed speech exhibits modifications from the typical prosody of speech. Prosodic modifications include higher overall pitch, wider pitch excursions, more distinctive pitch contours, slower tempo, longer pauses, and increased emphatic stress. Interest in the structure and function of this specialized form of infant-directed speech stems from the possibility that such speech may enhance the young child's language learning (Cooper & Aslin, 1990). Infant-directed speech typically has a slower tempo, is higher pitched, and is more modulated in both frequency and amplitude (Cooper & Aslin, 1990). Infants attend more to speech when prosodic features are exaggerated (DeCasper & Fifer, 1980; Cooper & Aslin, 1990) and infants show this preference even as neonates.

Some critics question the utility of speaking to infants in this way i.e., with exaggerated prosody. One possibility is that exaggerated prosody might be used to obtain or maintain an infants' attention (e.g., Fernald, 1991); Werker & McLeod, 1989). A second possibility is that infant-directed speech aids language learning by exaggerating lexical and grammatical structure (e.g., Fernald & Mazzie, 1991; Kemler Nelson, Hirsh-Pasek, Jusczyk, & Wright Cassidy, 1989; Shatz, 1982; Snow & Ferguson, 1977). A third possibility is that the prosodic features somehow communicate information to the infant (e.g., Fernald, 1991; Papousek, 1992; Stern et al., 1982; Trainor et al., 2000). The widespread use and language-independent nature of prosodic modification in speech to infants suggest that parental prosody could serve several important functions in the development of communication. The use of exaggerated intonation in the early preverbal period may function primarily to engage the infant's attention and to maintain social interaction (Garnica, 1977; Sachs, 1977; Fernald, 1989).

The intonation patterns of adult speech to infants differ dramatically from those of normal adult conversations (Fernald, 1989). Intonation carries considerable information about speaker affect in adult-to-adult speech (e.g., Scherer, 1986), and several prosodic cues are associated with positive affect. Prosody also encodes information about the syntactic and discourse structure of language (e.g., Nooteboom & Kruyt, 1987; Fernald 1989). Prosodic patterns are evident in adult speech and Cicero and Aristotle suggested that each emotion is associated with a distinctive tone of voice (Bachorowski & Owren, 2003).

Prosody has been widely studied in the psychological literature. One main area of research is where prosody is processed in the brain. According to Friederici and Alter (2004), the verbal content and prosody of a sentence are processed primarily in different hemispheres. The verbal content is processed in a left-hemisphere temporo-frontal pathway that includes separate circuits for decoding syntactic and semantic information from the auditory signal. In contrast to the verbal content, sentence-level prosody is processed in a right-hemisphere temporo-frontal pathway (Berckmoes & Vingerhoets, 2004). Baum and Pell (1999) have also studied this area and have developed four hypotheses. The most straightforward contends that all aspects of prosody are processed in the right hemisphere and then integrated with verbal information via interhemispheric connections (Klouda et al., 1988). A second hypothesis claims that emotional prosody is processed by the right side of the brain, whereas the left hemisphere is specialized for linguistic prosody (Van Lancker, 1980). A third hypothesis is that comprehension and production of prosody are not lateralized to one or the other side of the brain, but are controlled largely by deeper structures, which are referred to as subcortical (Cancelliere & Kertesz, 1990). Finally, the fourth hypothesis is that the various acoustical cues in prosody (e.g., pitch, amplitude, and rhythm) are processed independently and can be localized in separate areas of the brain (Van Lancker & Sidtis, 1992; Berckmoes & Vingerhoets, 2004).

Commonly analyzed acoustic parameters for emotion in speech are pitch, durations of phonemes or syllables, inter-word silence duration, voiced/unvoiced duration ratio in utterances, energy in the waveform envelope, the first three formant frequencies and spectral moment or balance. These parameters are related to speech prosody, vowel articulation and spectral energy distribution (Yildirim et al., 2004). The clearest most consistent factors in signaling the speaker's emotional state were found to be the mean value of the fundamental frequency, the range of the fundamental frequency, and the rate of its changes. The duration of the production and changes in the intensity of the voice were described as important parameters as well (Williams & Stevens, 1972; Scherer, 1982, 1986, 1992; Siegman & Feldstein, 1987; Most et al., 1993). Another research team found that the most important factor in signaling the speaker's mood is the mean fundamental frequency and the range, but that other factors also contribute (Oster & Risberg, 1986). There can be little doubt, however, that the following acoustic variables are strongly involved in vocal emotion signaling: (a) the level, range, and contour of the fundamental frequency (referred to as F0 below; it reflects the frequency of the vibration of the vocal folds and is perceived as pitch); (b) the vocal energy (or amplitude, perceived as intensity of the voice); (c) the distribution of the energy in the frequency spectrum (particularly the relative energy in the high vs. the low-frequency region, affecting the perception of voice quality or timbre); (d) the location of the formants (F1, F2…Fn, related to the perception of articulation); and (e) a variety of temporal phenomena, including tempo and pausing (Banse & Scherer, 1996).

Nonverbal behaviors can also aid in determining emotion. Information about a speaker's intonation, facial expression, and gestures can add to or change the meaning of spoken discourse. Such nonverbal actions are considered to have multiple functions, including the expression of emotion (Bavelas & Chovil, 2000; Feldman, Tomasian, & Coats, 1999; Patterson, 1995; Creusere et al., 2003). Visual information can definitely aid in determining a speaker's emotion in addition to auditory-only information. When hearing subjects were asked to identify different emotional expressions presented either auditorily or visually, it has been shown that the visual mode was always superior to the auditory one. The combined auditory-visual mode was also better than the auditory mode alone but not always significantly better (Most et al., 1993). Having both auditory and visual information can help a listener especially when sarcasm is used. Most of the time, the verbal and vocal channels convey the same emotion, but even in everyday speech, incongruities sometimes occur. For example, the humor of sarcasm and irony is built on such discordant constructions (Berckmoes & Vingerhoets, 2004). This can be especially hard for children or people with hearing impairment who either may not have developed the ability to understand sarcasm, or cannot do so without visual input. Children have a limited understanding of the role of vocal emotion in communication (Levy, 1982). As a result, they fail to consider its relevance to the speaker's feelings. Despite their ability to decode nonlinguistic cues, children may not treat such cues as a basis for qualifying or even overriding the propositional content of a literal message. Explanations such as these can account for children's difficulty with irony (Ackerman, 1986) and sarcasm (Capelli, Nakagawa, & Madden, 1990), both of which require the integration of contextual or nonlinguistic cues with opposing literal messages (Morton & Trehub, 2001). As children get older, they become better at correctly identifying emotion and sarcasm. According to Dimitrovsky (1964), children 5 to 12 years of age become increasingly accurate at labeling affect. Younger children were simply unable to label the nonlinguistic cues that they detected (Morton & Trehub, 2001). Children also tend to focus more on what a speaker says, while adults listen more to how a speaker says something (Morton & Trehub, 2001).

Persons with hearing impairment are at a greater disadvantage than those with normal hearing at understanding emotion because of all of the subtle changes that convey emotion. Among the profoundly hearing impaired persons, some can perceive acoustical changes that occur in the frequency, time, and intensity components of the speech signal, whereas others can only perceive changes in the time and intensity components (Erber, 1972, 1979; Marklein, 1981; Boothroyd, 1982; Most et al., 1993). The results of one study suggest that implant users perceive mood by using intensity as the primary cue, fundamental frequency as a strong secondary cue, and spectral and voice source characteristics as weak secondary cues (House, 1994). These cues can, however, be misinterpreted, especially when the emotions are similar. Emotions with a similar level of arousal, and sometimes a similar level of power, share acoustic characteristics in terms of F0 range and mean, and particularly intensity mean. Similar acoustic characteristics of emotions contribute to their perceived similarity and consequent confusion, especially in the hearing impaired (Pereira, 2000). Davitz (1964) concluded that emotions with a similar level of arousal sound similar in loudness, pitch, timbre and rate, and this is why listeners confuse them (Pereira, 2000).

The ability of listeners to identify emotion depends on whether the listener is a child, adult, or a person with a hearing impairment. The main focus for this study was to see how well adults with cochlear implants could identify emotion in spoken sentences. The four emotions that we tested were anger, fear, happiness, and sadness. On average, listeners do best in identifying anger, fear, and sadness (Bachorowski & Owren, 2003). Banse and Scherer proved quite helpful in describing acoustic characteristics of various emotions. Anger generally seems to be characterized by an increase in mean F0 and mean energy. Additional anger attributes are increases in high-frequency energy and downward-directed F0 contours. The rate of articulation usually increases also. There is considerable agreement on the acoustic cues associated with fear. High arousal levels would be expected with this emotion, and this is supported by evidence showing increases in mean F0, in F0 range, and high-frequency energy. Rate of articulation is reported to be speeded up. As with fear, acoustic characteristics are in general agreement across several studies that have examined sadness. A decrease in mean F0, F0 range, and mean energy is usually found, as are downward-directed F0 contours. There is evidence that high-frequency energy and rate of articulation decrease. Joy is one of the few positive emotions studied, most often in the form of elation rather than more subdued forms such as enjoyment or happiness. Consistent with the high arousal level that one might expect, we find strong agreement on increases is mean F0, F0 range, F0 variability, and mean energy. There is some evidence for an increase in high-frequency energy and rate of articulation (Banse & Scherer, 1996).

SIGNIFICANCE:

As discussed earlier, speech perception can be divided into two groups: linguistic and nonlinguistic aspects of speech. The linguistic aspects of speech include the properties of the speech signal and word sequence. Linguistic aspects deal more with what is being said, not how it is said. The nonlinguistic properties of speech have more to do with talker attributes such as age, gender, dialect, and emotion. Recent studies have shown that cochlear implant users have difficulty with the perception of nonlinguistic or indexical information. The ability to use indexical information to discriminate between the utterances of different talkers is often taken for granted in communicative situations. For both normal hearing and hearing-impaired persons, this task becomes more difficult when visual cues are unavailable (Cleary & Pisoni, 2002). Some studies have investigated the ability of cochlear implant users to discriminate differences between talkers. For example, the listener would need to determine if two different sentences were spoken by the same talker or by different talkers.

It has been shown that listeners with moderate to severe hearing loss have difficulties in identifying the mood of speakers in recorded test sentences (Oster & Risberg, 1986; House, 1990). These listeners typically confuse happy with angry and sad. Only two studies have examined cochlear implant users' perception of emotion, and only one of those was done using English. Cochlear implant users demonstrate a similarly confuse happy with angry and sad (House, 1991, 1994). However, these two studies only examined cochlear implant users' ability to identify emotion not their ability to discriminate emotion. Also, both of these studies are ten or more years old, and hence employed listeners with older cochlear implant technology. In our study, we used English and we looked at emotion discrimination as well as emotion identification in a variety of conditions. We wanted to find out how well adults with cochlear implants could perceive emotion in a variety of conditions, incorporating both identification and discrimination. From these experiments, we hope to understand more clearly the differences between cochlear implant users and normal hearing people, particularly for perceiving emotions in speech. Without visual cues, it seems apparent that cochlear implant users might have difficulties identifying different emotions.

METHODS:

This study was approved by the institutional review board at Washington University in St. Louis School of Medicine. All subjects gave informed consent prior to participation.

Study Populations:

Subject Group Normal Hearing Adults:

In the initial experiments, three normal hearing adults were selected (2 female and 1 male). The normal hearing adults were recruited by the experimenter from personal contacts. The normal hearing adults were coded in the experiment as NHA followed by the number 1, 2, or 3 based on the order that they were seen. The ages of these subjects ranged from 24 years to 55 years with a mean age of 36. NHA1 listened to 1756 presentations over the course of two sessions, each lasting about two hours. After data was collected from NHA1, it was determined that it would not be necessary to have as many stimulus presentations. The amount of presentations was cut approximately in half to 960 presentations for all other subjects in this study. For NHA2 and NHA3, testing took between 1 and 1¼ hours per session, for two sessions. An overview of our study design can be seen in Table 1.

Subject Group Normal Hearing Children:

Four normal hearing children were also selected to participate in this. The age range that we selected spans the age range during which emotion is developed. The normal hearing children were recruited from staff members in the Program in Audiology and Communication Sciences at Washington University. Two female and two male subjects participated. This subject group was coded as NHC followed by a number between 1 and 4. The children ranged in age between 6 years 1 month to 12 years 4 months with a mean age of 8 years 8 months. For this subject group, 960 presentations total were made and testing took approximately 1½ hours in each of two sessions as more breaks were allowed for these younger participants.

Subject Group Cochlear Implant Adults:

Sixteen adult cochlear implant (CI) users (7 female and 4 male) were recruited from the Adult Cochlear Implant Department at Washington University School of Medicine. Of those, eleven chose to participate in our study. For participation in this study, subjects were required to have at least one year experience with their device and to have a newer CI device. The implanted adults were coded in the experiment as CIA followed by a number between 1 and 11. The subjects ranged in age between 34 years and 75 years with a mean age of 57. Nine of the eleven subjects were implanted in the right ear and two were implanted in the left ear. Seven subjects wore a Cochlear Corporation device and four subjects wore an Advanced Bionics Corporation device, as shown in Table 2. Subject experience with the device ranges from two years to 5½ years. Also, six of the subjects wore a hearing aid on the opposite ear and five did not. However, during testing, hearing aids were removed. Subjects were asked to wear their CI device using their typical everyday program. The CI volume and/or sensitivity setting were recorded. The second experimental session was conducted using these same device settings.

Each subject in this group listened to 960 presentations, and testing took approximately 1½ hours per session depending on the number of breaks needed and the amount of difficulty the subject had. Testing of all of the subjects took place between January 5 and April 13, 2006.

Test Materials:

Three semantically neutral sentences were used. These sentences were appropriate in vocabulary and syntax for the children in the study, as well as the adults. Each talker said the sentence in the four emotions, three times each (to produce three tokens). Two female talkers' speech stimuli were used. All of the sentences were digitized and normalized in level before presentation. The three sentences were:

1. It's time to go.
2. Give me your hand.
4. Take you what you want.

Stimuli were presented in a sound-treated room at a level of 65 dB SPL through an Anchor AN-100 speaker. The speaker was located directly in front of the subject, about 4 feet away (Shinall, 2005). The APEX software program (Laneau et al., 2005) controlled the identification and discrimination tasks. The test battery was completed twice by each subject; once during one session, and then repeated entirely during a second session, most often within one week. The normal hearing adult and children completed the identification task followed by the discrimination task during the first session. In the second session, they completed the discrimination task, followed by the identification task. For the implanted adults, the subjects coded with an even number (e.g., CIA 2, CIA 4, etc) completed the tasks in this same order. The implanted adults coded with an odd number (e.g. CIA1, CIA3, etc) completed the discrimination task followed by the identification task in the first session and the identification task followed by the discrimination task in the second session.

Identification Task: For the identification task, a board with photographs of a girl's face portraying the emotions of angry, scared, happy, and sad was placed in front of the subjects. The subject would listen to the sentence and then was instructed to point to the photo associated with the emotion that he or she thought was being expressed by the talker. Alternately, the subject could simply say which of the four emotions he or she thought was being expressed by the talker.

Discrimination Task: For the discrimination task, a board with two pictures was placed in front of the subject. One picture represented the "same" feelings (two red triangles) and the other picture represented "different" feelings (one yellow square and one blue circle). The subject was asked to listen to two sentences and determine if the feelings being expressed by the talker in the two sentences were the same or were different. That is, for a trial in which emotion was the "same," the sentences in each interval would both have the same intended emotion—though the talker and/or sentence may be different. For example, a "happy" utterance followed by another "happy" utterance. For a trial in which emotion was "different," the emotion in the first and second interval would be different, though again the talker and/or sentence script may also be different. For example, a "sad" utterance followed by a "happy" utterance. The listener was instructed to point to, or say, "same" or "different."

For both the identification and discrimination experiments, talker and sentence (script) variation, within blocks of trials, was carefully controlled. To examine talker effects, talker was fixed in some groups of trials and then varied in others. (See Table 1). Similarly, to examine sentence script effects, sentence script was fixed in some groups of trials and then varied in others.

RESULTS:

Overview:

These results can be seen in Figure 1. Overall, NHA performed best followed by NHC and then by CIA subjects. Both NHA and NHC performed well in both the emotion identification and discrimination tasks, while the CIA subjects, on average, were correct 69% and 76% in these tasks respectively.

Subject Group NHA:

The raw data for this group can be seen in Tables 3-5 and the results of the statistical analysis are in Tables 6-9. The purpose of testing this group was to make sure that the two talkers had accurately conveyed the emotions in the three sentences. If this group did not do well on these tasks, then the sentences would not be suitable stimuli for examining emotion perception. The number of correct responses to the presentations ranged between 97.4% and 99.3%. This group proved the accuracy of the emotions being presented and that modifications were not needed.

Subject Group NHA Identification:

Talker Variations: These results can be seen in Figure 2. NHA1 and NHA3 were able to identify Talker 1 more accurately than they were able to identify Talker 2. NHA2 performed the same with both talkers. Overall, NHA1 did best when listening to Talker 1. Both NHA2 and NHA3 did best when the talkers were varied. However, there are no statistically significant differences in identification performance by these NHA listeners for the three talker conditions (T1, T2, and VarT). (See Table 6).

Sentence Variations: See Figure 3 for these results. These listeners did not show a preference for a certain sentence based on their performance. Each of the three subjects did their worst on different sentences. Surprisingly, the varied sentence condition was not the most difficult for these listeners. However, there are no statistically significant differences in identification performance by these NHA listeners for the four sentence conditions (S1, S2, S4, VarS). (See Table 8)

Subject Group NHA Discrimination:

Talker Variations: These results can be seen in Figure 4. For all three subjects in this group, Talker 1's productions seemed to be easiest to discriminate emotion. Listening to Talker 2 proved to be the second easiest for both NHA1 and NHA3. When the talkers were varied, discrimination tended to be worse than the other two conditions, except for NHA2. However, there are no statistically significant differences in discrimination performance by these NHA listeners for the three talker conditions (T1, T2, and VarT). (See Table 7).

Sentence Variations: See Figure 5 for these results. For NHA1, Sentence 2 seemed to be the most difficult, while NHA2 and NHA3 performed the worst in the varied sentence condition. However, there are no statistically significant differences in discrimination performance by these NHA listeners for the four sentence conditions (S1, S2, S4, VarS). (See Table 9).

For the NHA listeners' results, listener was a not a statistically significant factor in either identification or discrimination tasks, and had no effect on either talker or sentence conditions.

Subject Group NHC:

The raw data for this group can be seen in Tables 3-5 and the results of the statistical analyses are in Tables 10-13. The purpose of testing this group was to see how well normal hearing children between the ages of 6 and 13 could identify emotion. Results from normal hearing children might then serve as a baseline for comparing emotion perception abilities in similarly-aged children with impaired hearing. The number of correct responses to the presentations ranged between 90.7% and 98.6%.

Subject Group NHC Identification:

Talker Variations: These results can be seen in Figure 6. The most interesting finding in this group was that three of the four subjects did the best in the varied talker condition. It would seem as though this would be a more difficult condition since the listener has to not only identify which emotion is being expressed, but also how each talker expresses that emotion. It is impressive that children as young as six can already do this. However, there are no statistically significant differences in identification performance by these NHC listeners for the three talker conditions (T1, T2, and VarT). (See Table 10).

Sentence Variations: See Figure 7 for these results. Sentence 1 and Sentence 4 were the most difficult for identifying emotion for these subjects. However, there are no statistically significant differences in identification performance by these NHC listeners for the four sentence conditions (S1, S2, S4, VarS). (See Table 12).

Subject Group NHC Discrimination:

Talker Variations: These results can be seen in Figure 8. For most of the subjects, there was not much difference in performance between Talker 1 and Talker 2. NHC3 seemed to prefer Talker 2, but there is not much of a difference. The varied talker condition proved not to be any more difficult for NHC1, but NHC2, NHC3, and NHC4 all did worse in this condition than when listening to each talker separately. NHC1 may have done best in this condition due to the age of this subject (See Table 3). Talker effect is significant at the .05 level, but not at the .01 level ($p=.04$). (See Table 11).

Sentence Variations: See Figure 9 for these results. Three of the four subjects did best on Sentence 3, while they each performed their worst on different sentences. There is no statistical significance of sentence on discrimination performance by NHC subjects. See Table 13).

Just like for NHA, listener does not have a statistically significant effect on identification or discrimination results, for either talker or sentence conditions.

Subject Group CIA:

The raw data for this group can be seen in Tables 3-5 and results of the statistical analysis are in Tables 14-17. This group was the population of interest in this study. The primary goal of this project was to study the ability of adult cochlear implant users to perceive emotion through speech alone. It can be seen from the results that there is a wide range of performance amongst users. The number of correct responses to the presentations ranged from 40.7% to 92.8%.

Subject Group CIA Identification:

Talker Variations: The results can be seen in Figure 10. When these subjects were asked to identify the emotions in the sentences, ten of the eleven subjects did better when listening to Talker 1. CIA5 was the only listener who performed better when listening to Talker 2. Some of the listeners seemed to perform much better when listening to Talker 1, but others performed similarly no matter which talker was speaking. When the talkers were varied, subjects CIA1 and CIA11 performed best in that condition. Both the main effects, listener and talker-conditions are statistically significant at the .001 level (See Table 14).

Sentence Variations: See Figure 11 for these results. Sentence 3 elicited the highest performance in the identification task for this subject group. Eight of the eleven subjects performed best with this sentence. What is surprising is that the varied sentence condition was not the hardest for the identification task. Sentence 2 seemed to be the hardest sentence for these subjects to accurately identify emotion. Both talker and sentence conditions have a statistically significant effect on CIA subjects for both identification and discrimination tasks. Again, both the main effects, listener and sentence-condition are statistically significant at the .001 level (See Table 16).

Subject Group CIA Discrimination:

Talker Variations: The results can be seen in Figure 12. Four of the subjects performed better when listening to Talker 1, another four subjects performed better when listening to Talker

2, and three of the subjects performed the same when listening to the talkers. However, the main conclusion from this group is that every single one of the subjects performed worse in the varied talker condition. The decrease in performance ranges from approximately 7 to 15 percentage points between the conditions. These results are to be expected because this was the hardest condition, especially when the talkers as well as sentences were varied. As found for identification results, both listener and talker-condition are statistically significant effects at the .001 level (See Table 15).

Sentence Variations: See Figure 13 for these results. Sentence 3 was the easiest condition for 10 of the 11 subjects. The varied sentence condition was the hardest condition for seven of the eleven subjects, while Sentence 1 was the hardest for three of the subjects. Again, both listener and sentence-condition are statistically significant effects at the .001 level (See Table 17).

Analysis By Emotion:

Subject Group CIA Emotion Confusion Matrices:

Confusion matrices were only completed for the CIA subject group. The NHA and NHC subject groups performed so well that an analysis of errors or confusions would not be enlightening.

Identification Confusion Matrix:

See Figure 14 for these results. Raw data for this figure can be seen in Tables 18-19. Overall, these subjects correctly identified the emotions 69% of the time. The emotion that was most correctly identified was anger (86%) followed by sadness (75%), then happiness (64%), and finally fear (54%). Fear and happiness were the emotions that these subjects had the most difficulty identifying. However, these two emotions were rarely confused with angry or sad. Angry and sad were relatively rarely confused with the other emotions.

Discrimination Performance:

See Figures 15-16 for these results. Raw data for these figures can be seen in Tables 20-21. For discrimination, there were ten different types of trials that were presented to the subjects. In the first four types, the same emotion was presented twice to the listener. For the remaining types, the emotions presented were different in each presentation. Here are the types of trials that the subjects heard:

Type 1: Angry versus angry

Type 2: Scared versus scared

Type 3: Happy versus happy

Type 4: Sad versus sad

Type 5: Angry versus scared

Type 6: Angry versus happy

Type 7: Angry versus sad

Type 8: Scared versus happy

Type 9: Scared versus sad

Type 10: Happy versus sad

Of the same trials, anger was the easiest emotion to determine that both utterances (or intervals) were the same (80%) while sadness was the hardest (70%). But, overall there was not much difference amongst the four emotions. The subjects did fairly well when the emotions were the same. When the emotions were different across the intervals, the subjects also performed well, with the exception of type 8. When the emotions were fear and happiness, the subjects responded “same” 50% of the time, which is essentially chance-level performance. Consistent with the results, the CIA subjects also performed the worst when these two emotions were presented in the identification task.

Subject Group CIA Listener Characteristics

Age: Raw data for these figures can be seen in Table 22. See Figures 17-18 for these results. For Identification (r= -.81), age seems to play a big role in how well these subjects could identify the four emotions. There were a couple of outliers, but overall, performance tends to decrease as a function of age. For discrimination (r= -.71), there is not as big of a correlation between age and performance on this task. There is a decrease as a function of age, but it is not as evident as in the identification task.

Duration of deafness: See Figure 19 for these results. Duration of deafness results show somewhat of an opposite pattern than one might expect. It seems that, for the most part, the longer the duration of deafness, the better the performance, and the shorter the duration of deafness, the poorer the performance.

Experience with CI Device: See Figure 20 for these results. These results show no correlation between the number of years experience with a device and listener emotion identification performance.

DISCUSSION:

Only two previous studies examined emotion perception by cochlear implant subjects. Pereira (2000) studied how well hearing aid users, cochlear implant users, and bimodal users (meaning a cochlear implant worn on one ear and a hearing aid on the opposite ear) could identify emotion. House (1994) looked at how well cochlear implant users performed in identifying emotion at two-weeks, at six months, and at one-year post activation. The Pereira study used English, while the House study used Swedish. The Pereira study used two speakers, one male and one female, while the House study used one female speaker. In our study, we used two female speakers with English. Also, the Pereira and House study only used two sentences or utterances, while we used three in this study. The emotions studied in the Pereira and House studies were anger (divided into hot and cold anger for the Pereira study), happiness, sadness, and neutrality. In our study, since it involved children who probably would not understand neutrality, we substituted neutrality with fear. In all three of these studies, the utterances were semantically neutral. All three studies have normalized the intensity of the utterances, while Pereira also did another experiment to see how the subjects would perform if the utterances were not normalized for intensity. The results from our study are similar to those of both House and Pereira in that there is large variation in CI user performance across individuals. Also, overall performance was worse for CI users in all studies compared to either normal hearing adults or HA users. Finally, the same emotions seem to be easier to perceive than others, especially anger.

FUTURE DIRECTIONS:

This study proved that adults with cochlear implants show very individualized results. However, more research needs to be done to determine how these individuals are interpreting emotions. It would be useful to have an acoustic analysis of the speech stimuli to see if there are significant differences in each of the emotions' productions. If it is determined that there are significant differences, then investigations should be undertaken to see why CI users are not performing as well as normal hearing people in identifying and discriminating emotions. It can be determined which formants or Fo contours are the most difficult for CI users. In particular, the presence of acoustic differences between happy and fearful emotions could be enlightening, as those were often confused by CI users. Also, more research should be completed in the area of talker differences. Fu et al. reported that some studies have shown that voice gender identification is possible in conditions of reduced spectral resolution for normal-hearing listeners. Cleary and Pisoni (2002) tested whether children who had used a CI for at least four years could discriminate between two female voices. In general, the results suggested that speaker discrimination was difficult for CI patients. McDonald et al. (2003) examined adult CI users' ability to discriminate talkers as a function of the linguistic content of the stimuli and the talker's gender. When different talkers produced the tokens in the stimulus pair, they found that performance was significantly better for male-female talker contrasts than for within-gender talker contrasts. These results suggest that, while CI patients may have difficulty in identifying talkers, they are somewhat capable of voice gender discrimination (Fu et al., 2004). Although some research has been done in this area, more should be done to see why there is such difficulty in within-gender talker contrasts. Further acoustic analyses of stimuli used in both gender and emotion experiments may be fruitful, and may lead to improvements in CI processing strategies. Emotion perception is a very important part of everyday communication and CI users should not be denied this important aspect of speech.

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IDENTIFICATION-NEW

Condition				PER SESSION			
Talker	Sentence	Runs	No. of waveforms	No. of possible Stimuli for use	No. of Trials to be presented	No. of Minutes	IDN Filename(
Fixed	Fixed	T1 x S1	12 = 1T x 1S x 4E x 3W	12	12	2	IFixT1-FixS1-xx
		T1 x S2	12 = 1T x 1S x 4E x 3W	12	12	2	IFixT1-FixS2-xx
		T1 x S4	12 = 1T x 1S x 4E x 3W	12	12	2	IFixT1-FixS4-xx
		T2 x S1	12 = 1T x 1S x 4E x 3W	12	12	2	IFixT2-FixS1-xx
		T2 x S2	12 = 1T x 1S x 4E x 3W	12	12	2	IFixT2-FixS2-xx
		T2 x S4	12 = 1T x 1S x 4E x 3W	12	12	2	IFixT2-FixS4-xx
Totals		6			72	12	
Fixed	Varied	T1 x {S1,S2,S4}	36 = 1T x 3S x 4E x 3W	36	24	2	IFixT1-VarS-A(B)-
		T2 x {S1,S2,S4}	36 = 1T x 3S x 4E x 3W	36	24	2	IFixT2-VarS-A(B)-
Totals		2			48	4	
Varied	Fixed	{T1,T2} x S1	24 = 2T x 1S x 4E x 3W	24	16	2	IVarT-FixS1-A(B)-
		{T1,T2} x S2	24 = 2T x 1S x 4E x 3W	24	16	2	IVarT-FixS2-A(B)-
		{T1,T2} x S4	24 = 2T x 1S x 4E x 3W	24	16	2	IVarT-FixS4-A(B)-
Totals		3			48	6	
Varied	Varied	{T1,T2} x {S1,S2,S4}	72 = 2T x 3S x 4E x 3W	72	48	4	IVarT-VarS-A(B)-
Totals		1			48	4	
Identification Total		12			216	26	

DISCRIMINATION-NEW

Talker	Sentence	Runs		1st-interval	2nd-interval	Product /2*	No. of Stimuli/ Waves to be used	No. of Trials to be presented in **each session**	No. of Minutes	IDN Filename(s)
				No. of possible waveforms						
Fixed	Fixed	T1 x S1	*same*	12 = 1T x 1S x 4E x 3W	2 = 1T x 1S x 1E x 2W	12	12	12	2	DFixT1-FixS1-A(B)-xxxx
			diff	12 = 1T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	54	12			
		T1 x S2	*same*	12 = 1T x 1S x 4E x 3W	2 = 1T x 1S x 1E x 2W	12	12	12	2	DFixT1-FixS2-A(B)-xxxx
			diff	12 = 1T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	54	12			
		T1 x S4	*same*	12 = 1T x 1S x 4E x 3W	2 = 1T x 1S x 1E x 2W	12	12	12	2	DFixT1-FixS4-A(B)-xxxx
			diff	12 = 1T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	54	12			
(force token to be different in each interval		T2 x S1	*same*	12 = 1T x 1S x 4E x 3W	2 = 1T x 1S x 1E x 2W	12	12	12	2	DFixT2-FixS1-A(B)-xxxx
			diff	12 = 1T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	54	12			
		T2 x S2	*same*	12 = 1T x 1S x 4E x 3W	2 = 1T x 1S x 1E x 2W	12	12	12	2	DFixT2-FixS2-A(B)-xxxx
			diff	12 = 1T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	54	12			
		T2 x S4	*same*	12 = 1T x 1S x 4E x 3W	2 = 1T x 1S x 1E x 2W	12	12	12	2	DFixT2-FixS4-A(B)-xxxx
			diff	12 = 1T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	54	12			
Totals		6						72	12	
Fixed	Varied	T1 x {S1,S2,S4}	*same*	36 = 1T x 3S x 4E x 3W	6 = 1T x 2S x 1E x 3W	108	36	36	4	DFixT1-VarS-A(B)-xxxx
			diff	36 = 1T x 3S x 4E x 3W	18 = 1T x 2S x 3E x 3W	324	36			
(force token & script to be different in each interval)		T2 x {S1,S2,S4}	*same*	36 = 1T x 3S x 4E x 3W	6 = 1T x 2S x 1E x 3W	108	36	36	4	DFixT2-VarS-A(B)-xxxx
			diff	36 = 1T x 3S x 4E x 3W	18 = 1T x 2S x 3E x 3W	324	36			
Totals		2						72	8	
Varied	Fixed	{T1,T2} x S1	*same*	24 = 2T x 1S x 4E x 3W	3 = 1T x 1S x 1E x 3W	36	24	24	3	DVarT-FixS1-A(B)-xxxx
(force token & talker to be different in each interval)			*diff*	24 = 2T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	108	24			
		{T1,T2} x S2	*same*	24 = 2T x 1S x 4E x 3W	3 = 1T x 1S x 1E x 3W	36	24	24	3	DVarT-FixS2-A(B)-xxxx

		diff	24 = 2T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	108	24			
	{T1,T2} x S4	*same*	24 = 2T x 1S x 4E x 3W	3 = 1T x 1S x 1E x 3W	36	24	24	3	DVarT-FixS4-A(B)-xxxx
		diff	24 = 2T x 1S x 4E x 3W	9 = 1T x 1S x 3E x 3W	108	24			
Totals	3						72	9	
Varied Varied *(force token, talker & script to be different in each interval)*	{T1,T2} x {S1,S2,S4}	*same*	72 = 2T x 3S x 4E x 3W	6 = 1T x 2S x 1E x 3W	216	48	48	6	DVarT-VarS-A(B)-xxxx
		diff	72 = 2T x 3S x 4E x 3W	18 = 1T x 2S x 3E x 3W	648	48			
Totals	1						48	6	
Discrimination Total	12						264	35	

T1 = talker 1	S1 = sentence 1	W = waveform tokens	* divide by 2, b/c order is not important
T2 = talker 2	S2 = sentence 2	E = emotions	
	S4 = sentence 4		

Table 1: Study Design by Identification and Discrimination.

Subject	Age (yrs)	Device	Duration of Deafness[1] (yrs)	Ear implanted	Experience with CI Device (yrs)	CI Strategy	Hearing Aid in other ear?
CIA1	72	Cochlear Nucleus 24 Contour	progressive	R	2.5	ACE	Y
CIA2	46	Cochlear Nucleus 24	5	L	4	ACE	N
CIA3	45	Cochlear ESPrit 3G	~12 [2]	L	2.5 [2]	ACE	N
CIA4	67	ABC Auria BTE	3	R	2.5	HiRes S	Y
CIA5	34	ABC Clarion Body Processor	~15	R	3	CIS	N
CIA6	75	Cochlear Nucleus 24	~1	R	5	ACE	N
CIA7	56	ABC Clarion II BTE	6	R	3.5	HiRes P	N
CIA8	74	Cochlear Nucleus 24	8	R	2	ACE	Y
CIA9	62	Cochlear Nucleus 24 Contour	1	R	3.5	ACE	Y
CIA10	56	Cochlear Nucleus 24	2	R	5.5	ACE	Y
CIA11	36	ABC Clarion II BTE	progressive	R	3.5	CIS	Y

[1]Duration of Deafness is a subjective assessment, given by the subjects, based on when they felt their hearing loss had become severe-to-profound. The period of time from acquiring this level of hearing loss until their CI surgery is listed in the Table.

[2]This subject wore a CI device for 5 years but had it explanted 13 years ago for medical reasons. Duration of deafness is based on the number of years with severe-to-profound hearing loss prior to the first CI surgery (2) and on the number of years without any CI device prior to the second CI surgery (10). Experience with CI device, for this subject, represents experience with the current CI device.

Table 2: Subject Demographics

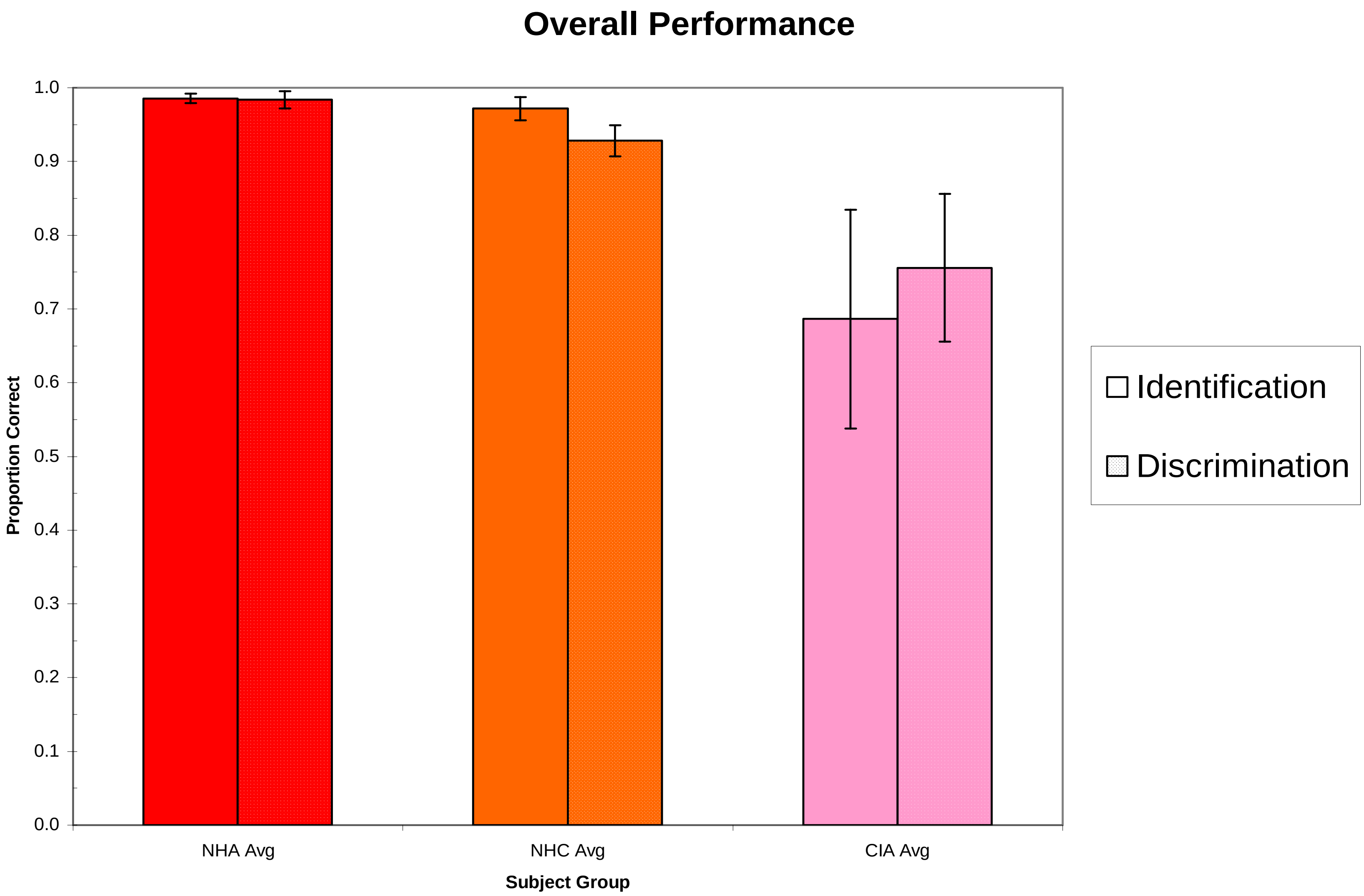

Figure 1: An overview of the overall performance for all subject groups on identification and discrimination tasks.

Subj ID	**Age (Yr, Mo)**	**Identification Possible**	**Identification Score**	**Discrimination Possible**	**Discrimination Score**
NHA1	29	707/720	0.982	1036/1056	0.981
NHA2	24	429/432	0.993	526/528	0.996
NHA3	55	424/432	0.982	514/528	0.974
NHA Avg			0.986		0.984
stdev			0.007		0.012
NHC1	12,4	418/432	0.968	504/528	0.955
NHC2	9,6	424/432	0.982	483/528	0.915
NHC3	6,0	426/432	0.986	479/528	0.907
NHC4	6,11	411/432	0.951	494/528	0.936
NHC Avg			0.972		0.928
stdev			0.016		0.021
CIA1	72	275/432	0.637	372/528	0.515
CIA2	46	359/432	0.831	443/528	0.839
CIA3	45	326/432	0.755	409/528	0.775
CIA4	67	210/432	0.486	387/528	0.733
CIA5	34	401/432	0.928	469/528	0.888
CIA6	75	176/432	0.407	352/528	0.667
CIA7	56	284/432	0.657	382/528	0.724
CIA8	74	304/432	0.704	409/528	0.775
CIA9	62	299/432	0.692	427/528	0.809
CIA10	56	282/432	0.653	402/528	0.761
CIA11	36	345/432	0.799	437/528	0.828
CIA Avg			0.686		0.756
stdev			0.148		0.100

Table 3: Raw Data for the Identification and Discrimination tasks for all subjects.

	Identification				Discrimination		
Subj ID	**T1**	**T2**	**Var-T**		**T1**	**T2**	**Var-T**
NHA1	1.000	0.963	0.981	NHA1	0.993	0.986	0.971
NHA2	0.992	0.992	0.995	NHA2	1.000	0.993	0.996
NHA3	0.983	0.967	0.990	NHA3	1.000	0.986	0.979
Avg NHA	0.992	0.974	0.989		0.998	0.988	0.982
Stdev	0.008	0.016	0.007		0.004	0.004	0.013
	T1	**T2**	**Var-T**		**T1**	**T2**	**Var-T**
NHC1	0.950	0.967	0.979	NHC1	1.000	0.993	0.996
NHC2	0.983	0.975	0.995	NHC2	0.965	0.951	0.863
NHC3	0.992	0.967	0.995	NHC3	0.903	0.979	0.867
NHC4	0.992	0.925	0.964	NHC4	0.979	0.979	0.883
Avg NHC	0.979	0.958	0.983		0.962	0.976	0.902
Stdev	0.020	0.023	0.015		0.042	0.018	0.063
	T1	**T2**	**Var-T**		**T1**	**T2**	**Var-T**
CIA5	0.908	0.983	0.927	CIA5	0.924	0.924	0.846
CIA2	0.858	0.800	0.833	CIA2	0.896	0.910	0.763
CIA11	0.808	0.733	0.854	CIA11	0.854	0.875	0.783
CIA3	0.808	0.775	0.729	CIA3	0.813	0.847	0.708
CIA8	0.842	0.600	0.703	CIA8	0.806	0.806	0.738
CIA9	0.825	0.675	0.693	CIA9	0.875	0.875	0.729
CIA7	0.725	0.642	0.646	CIA7	0.778	0.757	0.671
CIA10	0.758	0.558	0.667	CIA10	0.847	0.819	0.675
CIA1	0.650	0.600	0.672	CIA1	0.743	0.764	0.646
CIA4	0.625	0.317	0.526	CIA4	0.799	0.778	0.667
CIA6	0.517	0.358	0.391	CIA6	0.743	0.681	0.613
Avg	0.757	0.640	0.695		0.825	0.821	0.712
CI Stdev	0.117	0.191	0.150		0.060	0.074	0.068

Table 4: Raw Data for the Talker Effects for Identification and Discrimination for all subjects.

	Identification					Discrimination			
Subj ID	**S1**	**S2**	**S4**	**Var-S**		**S1**	**S2**	**S4**	**Var-S**
NHA1	0.979	0.979	0.972	0.990	NHA1	0.995	0.964	0.995	0.978
NHA2	1.000	0.975	1.000	0.995	NHA2	1.000	1.000	1.000	0.992
NHA3	0.938	0.988	0.975	1.000	NHA3	0.969	0.990	0.990	0.963
Avg NHA	0.972	0.981	0.982	0.995		0.988	0.985	0.995	0.978
Stdev	0.032	0.007	0.015	0.005		0.017	0.019	0.005	0.015
	S1	**S2**	**S4**	**Var-S**		**S1**	**S2**	**S4**	**Var-S**
NHC1	0.938	1.000	0.975	0.964	NHC1	0.958	0.979	0.938	0.950
NHC2	1.000	0.963	0.988	0.979	NHC2	0.927	0.927	0.969	0.883
NHC3	0.975	0.975	1.000	0.990	NHC3	0.938	0.875	0.958	0.888
NHC4	0.950	0.950	0.988	0.958	NHC4	0.906	0.948	0.990	0.921
Avg NHC	0.966	0.972	0.988	0.973		0.932	0.932	0.964	0.911
Stdev	0.028	0.021	0.010	0.014		0.022	0.044	0.022	0.031
	S1	**S2**	**S4**	**Var-S**		**S1**	**S2**	**S4**	**Var-S**
CIA5	0.938	0.975	0.938	0.922	CIA5	0.927	0.938	0.896	0.850
CIA2	0.738	0.888	0.925	0.807	CIA2	0.802	0.875	0.896	0.821
CIA11	0.838	0.813	0.813	0.792	CIA11	0.854	0.813	0.917	0.788
CIA3	0.850	0.725	0.788	0.734	CIA3	0.781	0.750	0.885	0.738
CIA8	0.625	0.663	0.813	0.729	CIA8	0.771	0.771	0.906	0.725
CIA9	0.775	0.625	0.775	0.672	CIA9	0.700	0.825	0.917	0.771
CIA7	0.688	0.600	0.813	0.700	CIA7	0.708	0.760	0.865	0.658
CIA10	0.700	0.513	0.700	0.693	CIA10	0.740	0.844	0.844	0.704
CIA1	0.675	0.513	0.738	0.651	CIA1	0.708	0.667	0.802	0.679
CIA4	0.500	0.425	0.638	0.464	CIA4	0.677	0.729	0.906	0.688
CIA6	0.475	0.350	0.488	0.391	CIA6	0.698	0.646	0.833	0.596
Avg	0.709	0.645	0.766	0.687		0.761	0.783	0.879	0.729
CI Stdev	0.142	0.194	0.127	0.150		0.077	0.087	0.038	0.075

Table 5: Raw Data for Sentence Effects for Identification and Discrimination for all subjects.

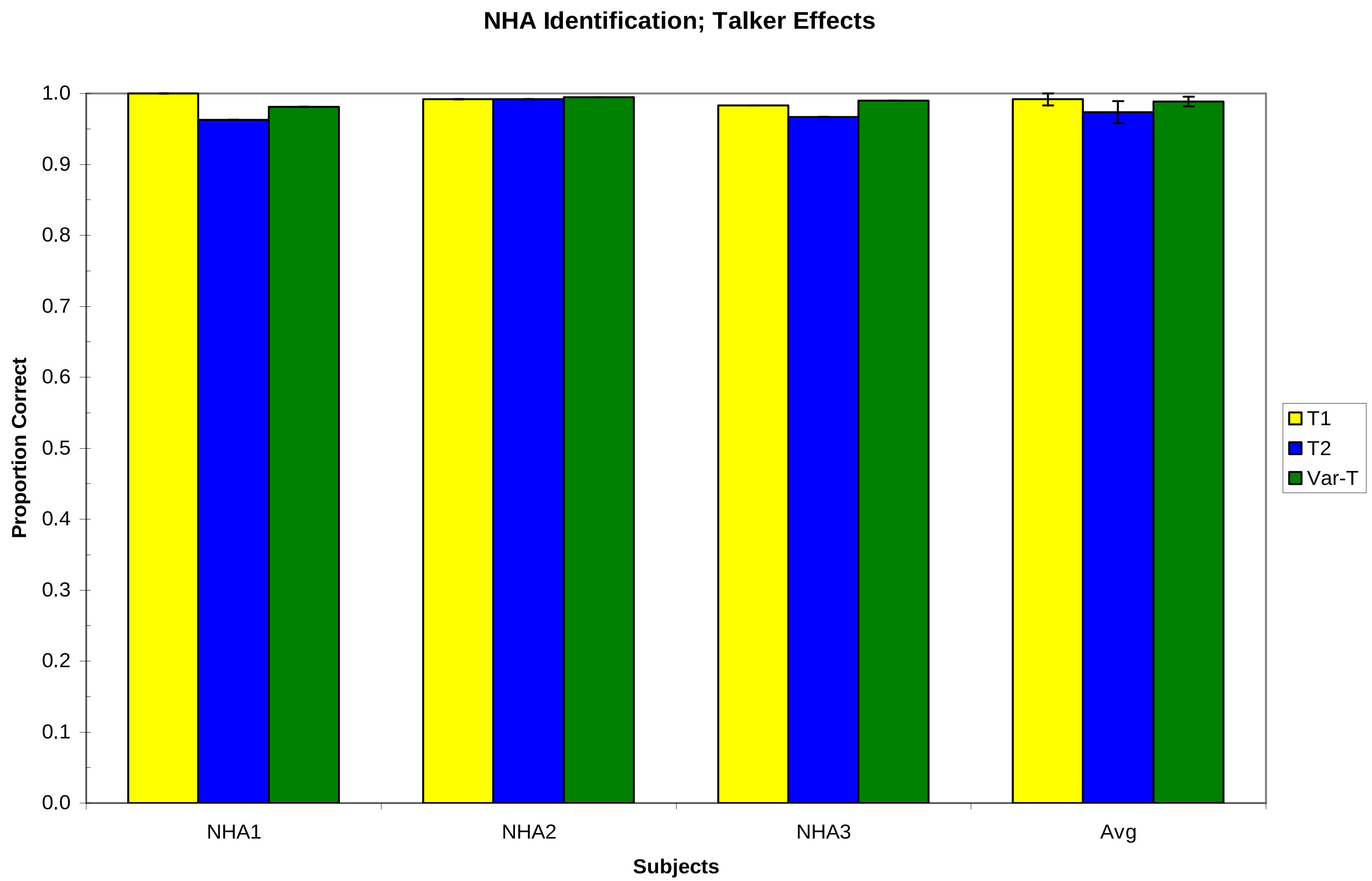

Figure 2: NHA Talker Effects on the Identification Task.

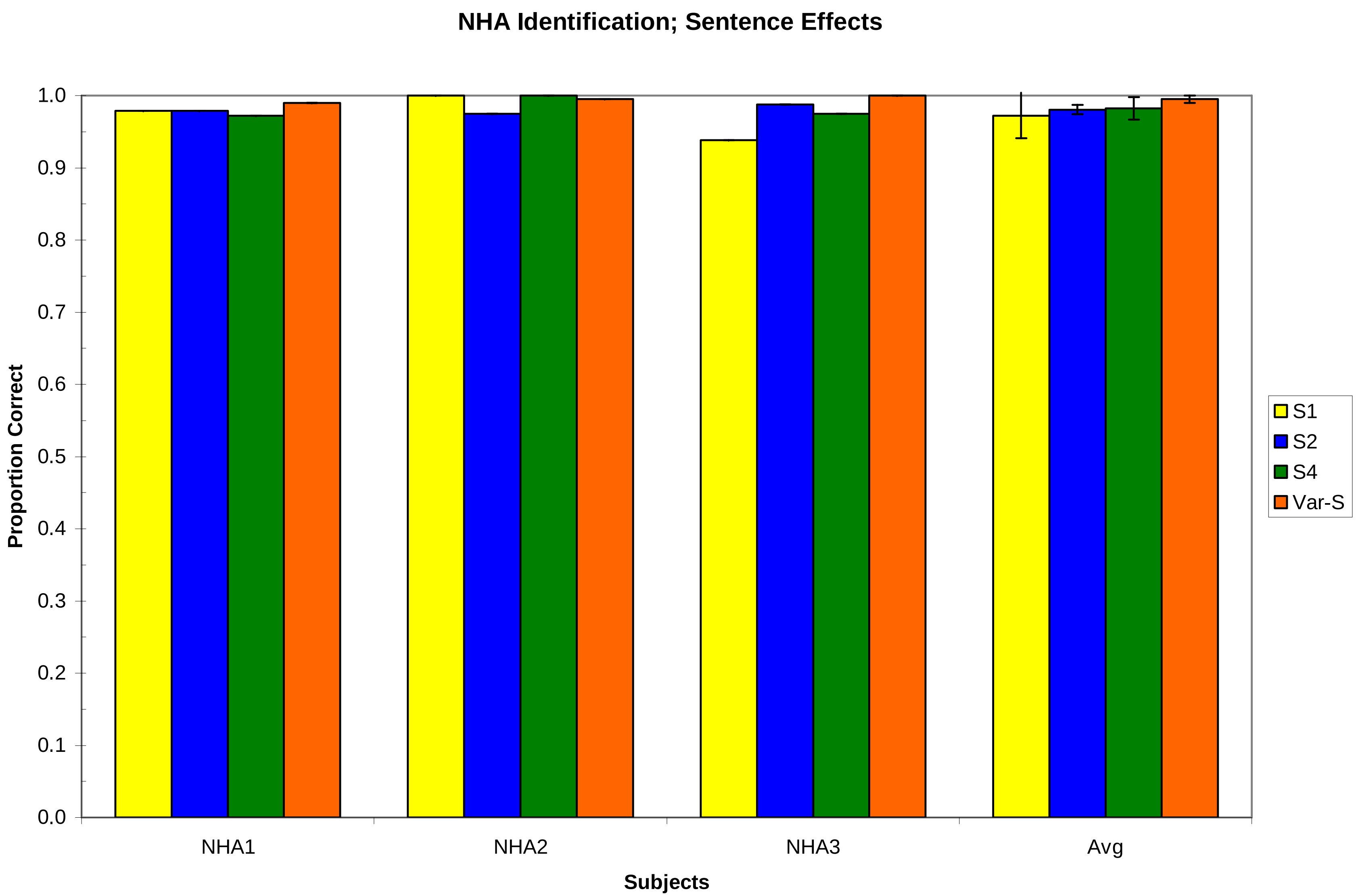

Figure 3: NHA Sentence Effects on the Identification Task.

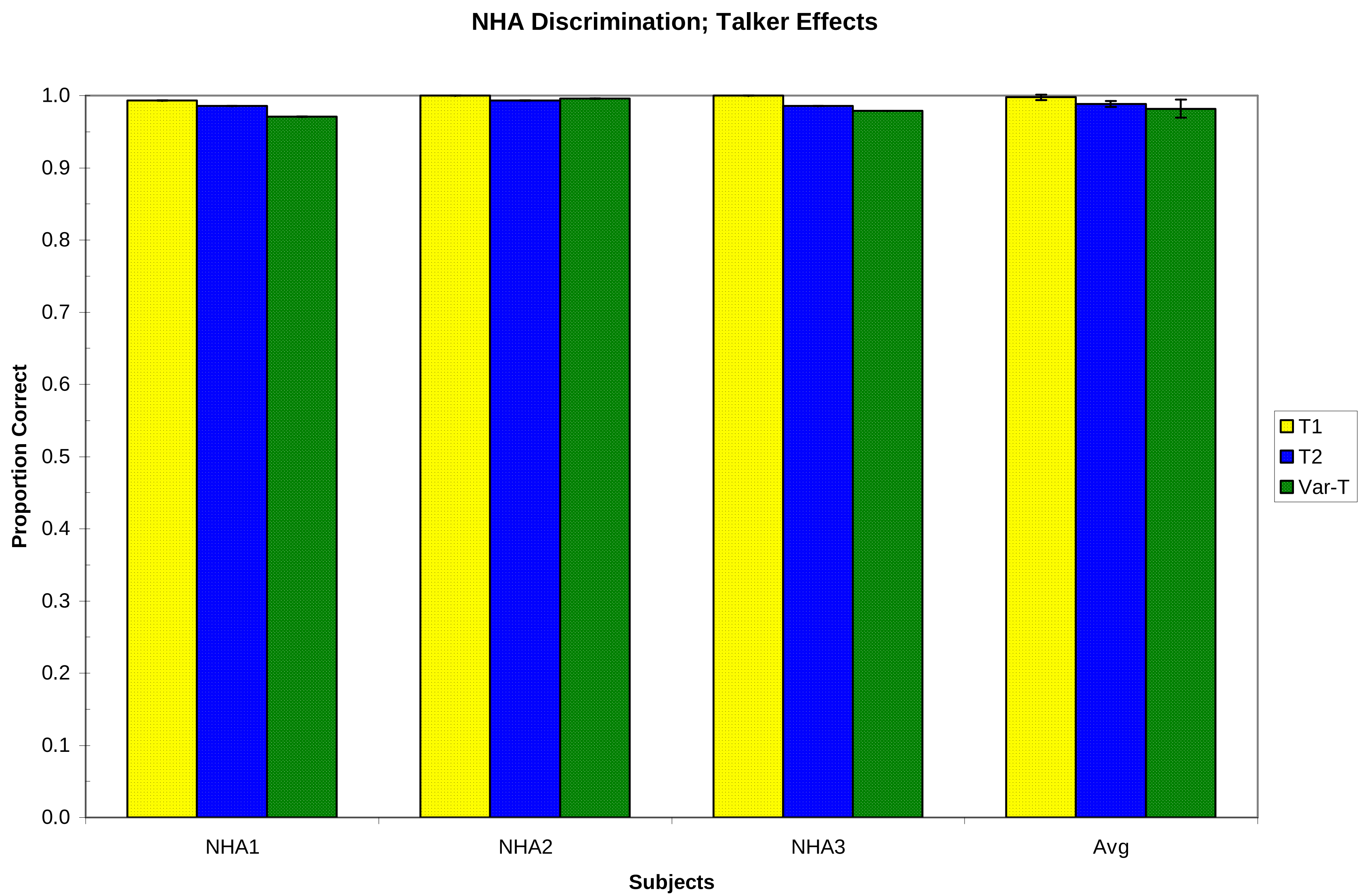

Figure 4: NHA Talker Effects on the Discrimination Task.

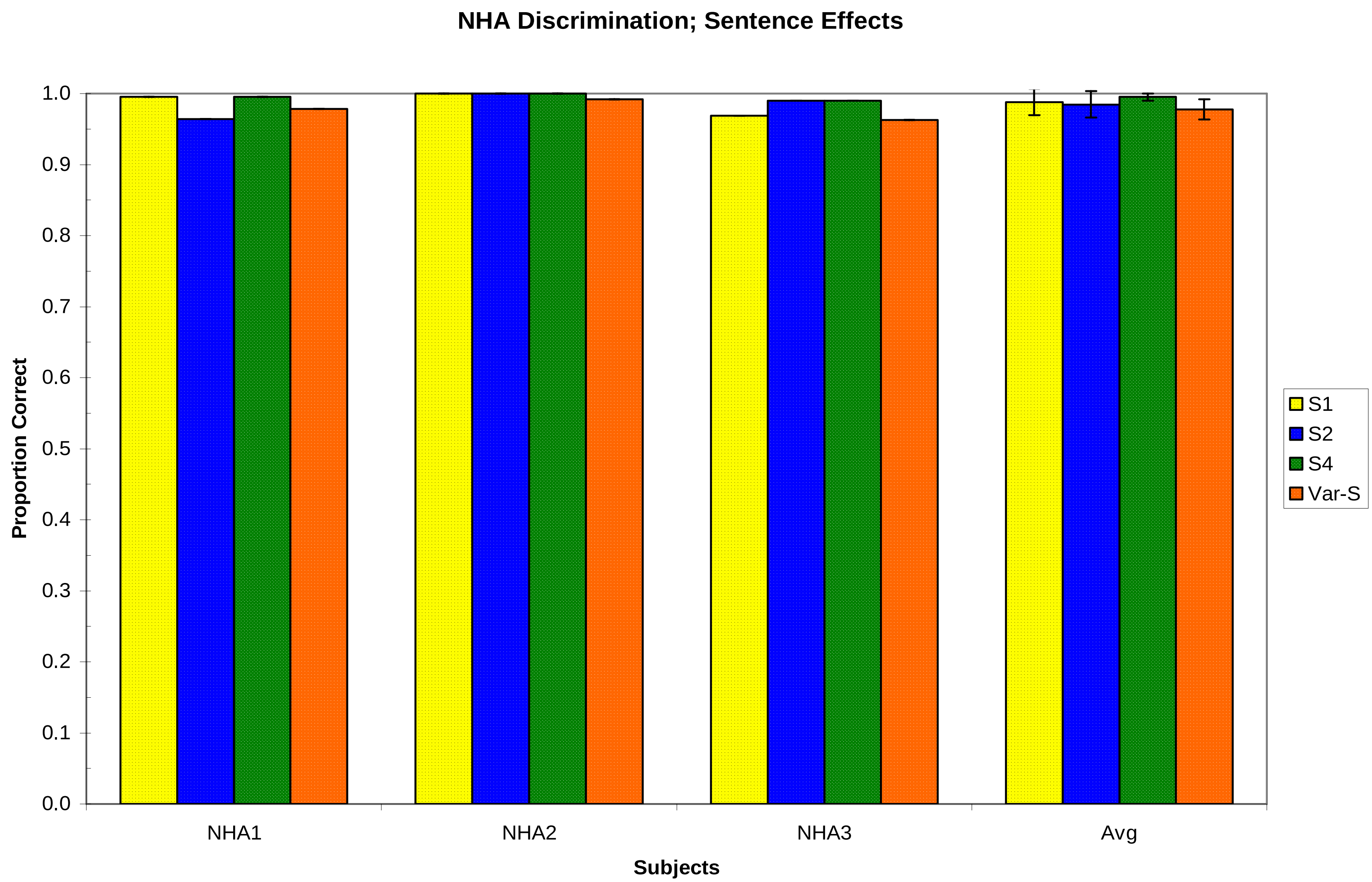

Figure 5: NHA Sentence Effects on the Discrimination Task.

Anova: Two-Factor Without Replication
Identification Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
NHA1	3	2.9443	0.981433	0.000342
NHA2	3	2.9782	0.992733	3.2E-06
NHA3	3	2.94	0.98	0.000144
T1	3	2.975	0.991667	6.97E-05
T2	3	2.9214	0.9738	0.000244
Var-T	3	2.9661	0.9887	4.68E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.000292	2	0.000146	1.361758	0.353938	6.944272
Columns	0.00055	2	0.000275	2.566125	0.191851	6.944272
Error	0.000429	4	0.000107			
Total	0.001271	8				

Table 6: ANOVA Results for NHA Talker Effects on the Identification Task.

Anova: Two-Factor Without Replication
Discrimination Data

SUMMARY	Count	Sum	Average	Variance
NHA1	3	2.95	0.983333	0.00013
NHA2	3	2.989	0.996333	1.2E-05
NHA3	3	2.9653	0.988433	0.000112
T1	3	2.9931	0.9977	1.59E-05
T2	3	2.9653	0.988433	1.63E-05
Var-T	3	2.9459	0.981967	0.000163

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.000257	2	0.000129	3.85725	0.116593	6.944272
Columns	0.000375	2	0.000188	5.622496	0.068844	6.944272
Error	0.000133	4	3.34E-05			
Total	0.000766	8				

Table 7: ANOVA Results for NHA Talker Effects on the Discrimination Task.

Anova: Two-Factor Without Replication
Identification Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
NHA1	4	3.92	0.98	5.53E-05
NHA2	4	3.97	0.9925	0.000142
NHA3	4	3.901	0.97525	0.000721
S1	3	2.917	0.972333	0.000994
S2	3	2.942	0.980667	4.43E-05
S4	3	2.947	0.982333	0.000236
Var-S	3	2.985	0.995	0.000025

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.000635	2	0.000318	0.969802	0.431576	10.92477
Columns	0.000789	3	0.000263	0.803037	0.536168	9.779538
Error	0.001965	6	0.000327			
Total	0.003389	11				

Table 8: ANOVA Results for NHA Sentence Effects on the Identification Task.

Anova: Two-Factor Without Replication
Discrimination Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
NHA1	4	3.932	0.983	0.000225
NHA2	4	3.992	0.998	0.000016
NHA3	4	3.912	0.978	0.000198
S1	3	2.964	0.988	0.000277
S2	3	2.954	0.984667	0.000345
S4	3	2.985	0.995	0.000025
Var-S	3	2.933	0.977667	0.00021

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.000867	2	0.000433	3.063629	0.121106	10.92477
Columns	0.000467	3	0.000156	1.101335	0.418661	9.779538
Error	0.000849	6	0.000141			
Total	0.002183	11				

Table 9: ANOVA Results for NHA Sentence Effects on the Discrimination Task.

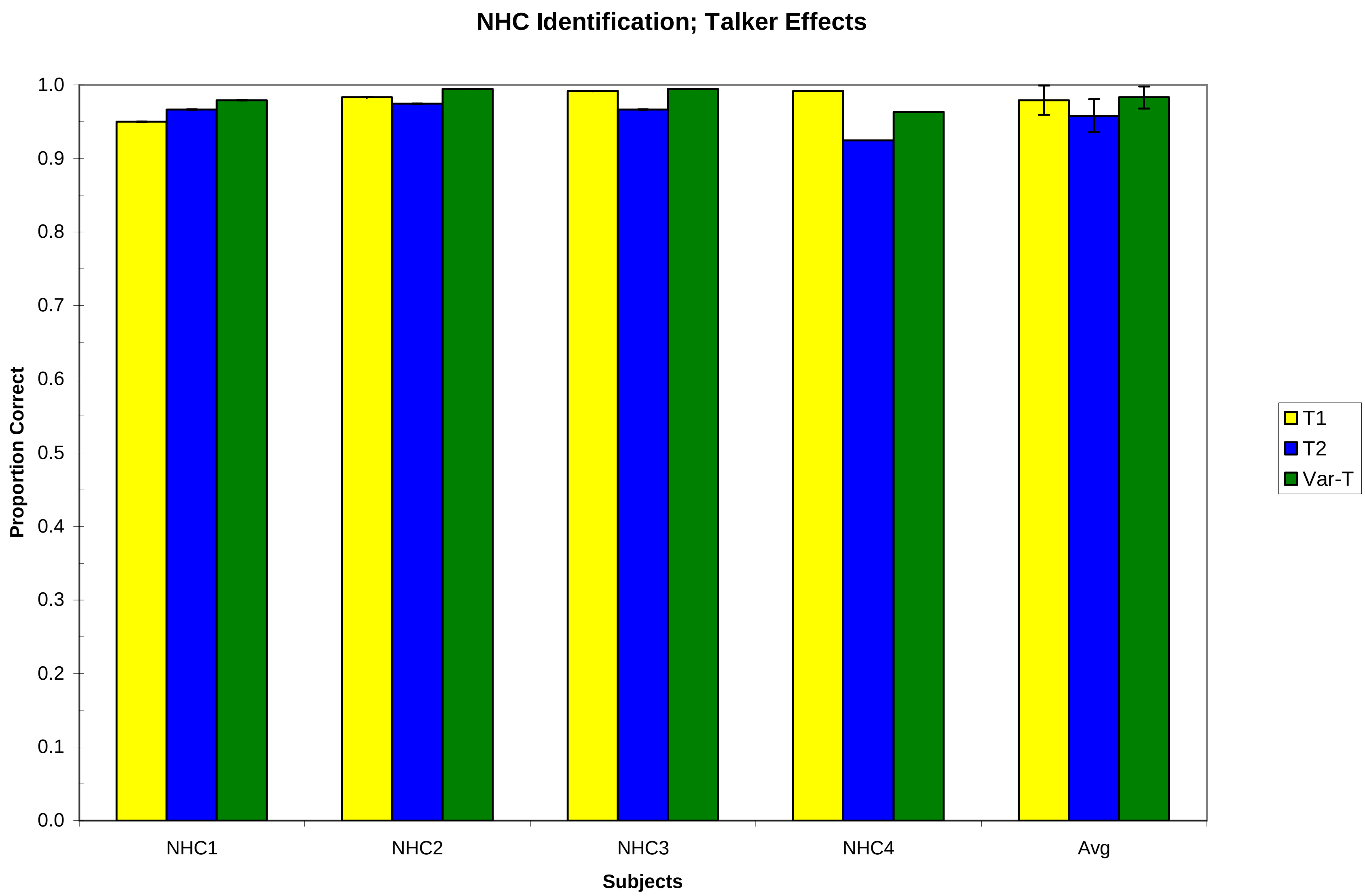

Figure 6: NHC Talker Effects on the Identification Task.

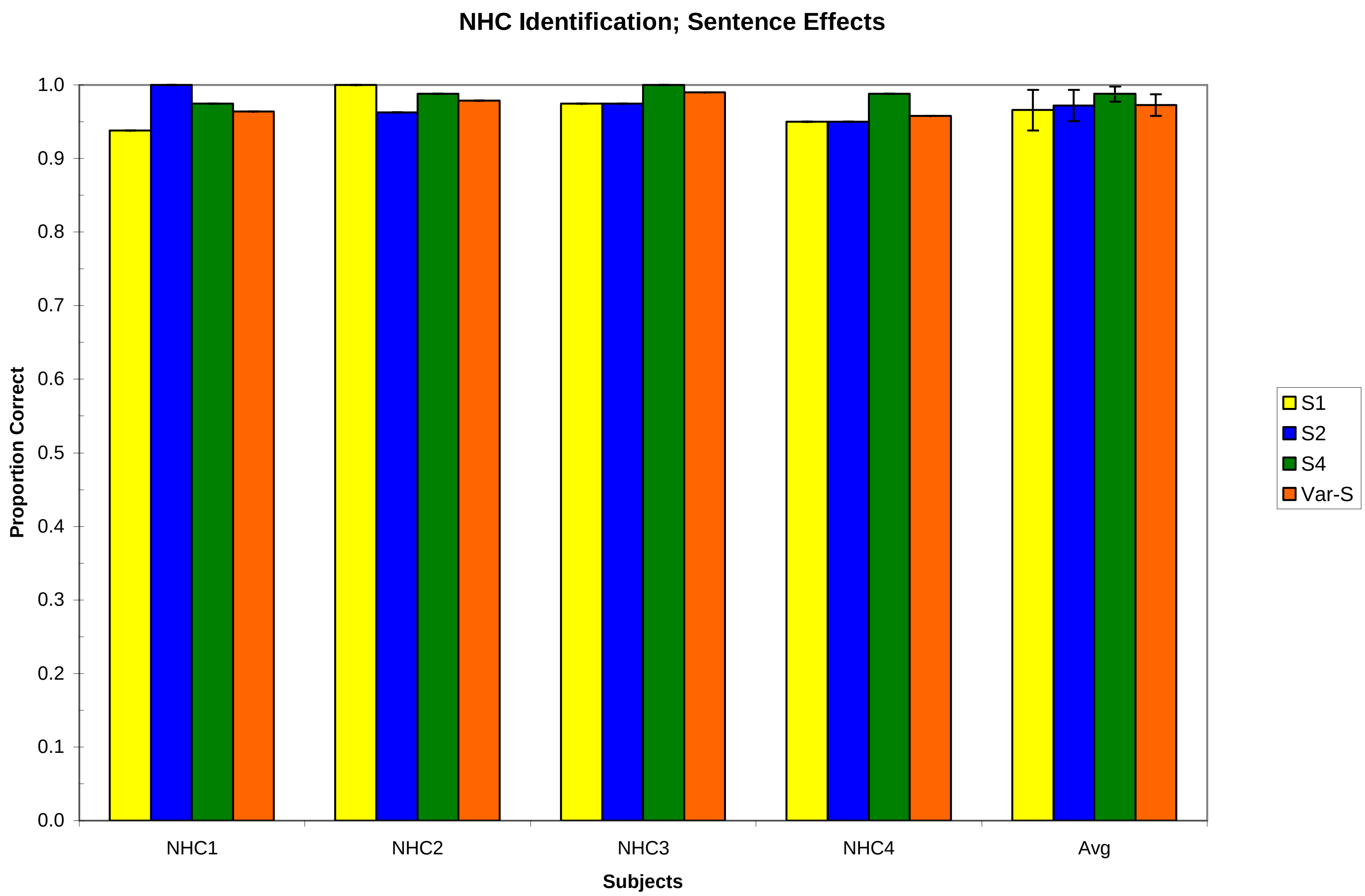

Figure 7: NHC Sentence Effects on the Identification Task.

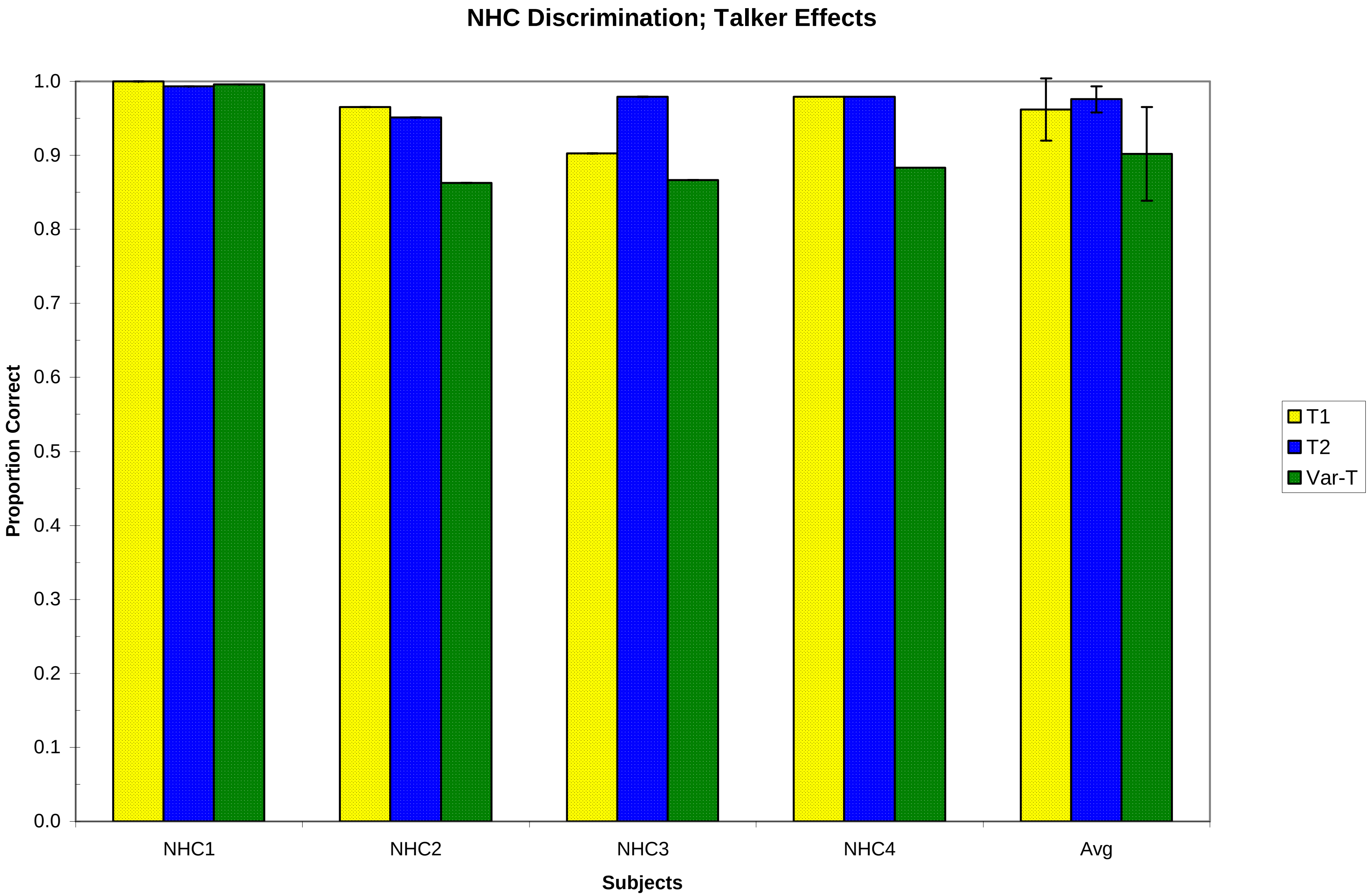

Figure 8: NHC Talker Effects on the Discrimination Task.

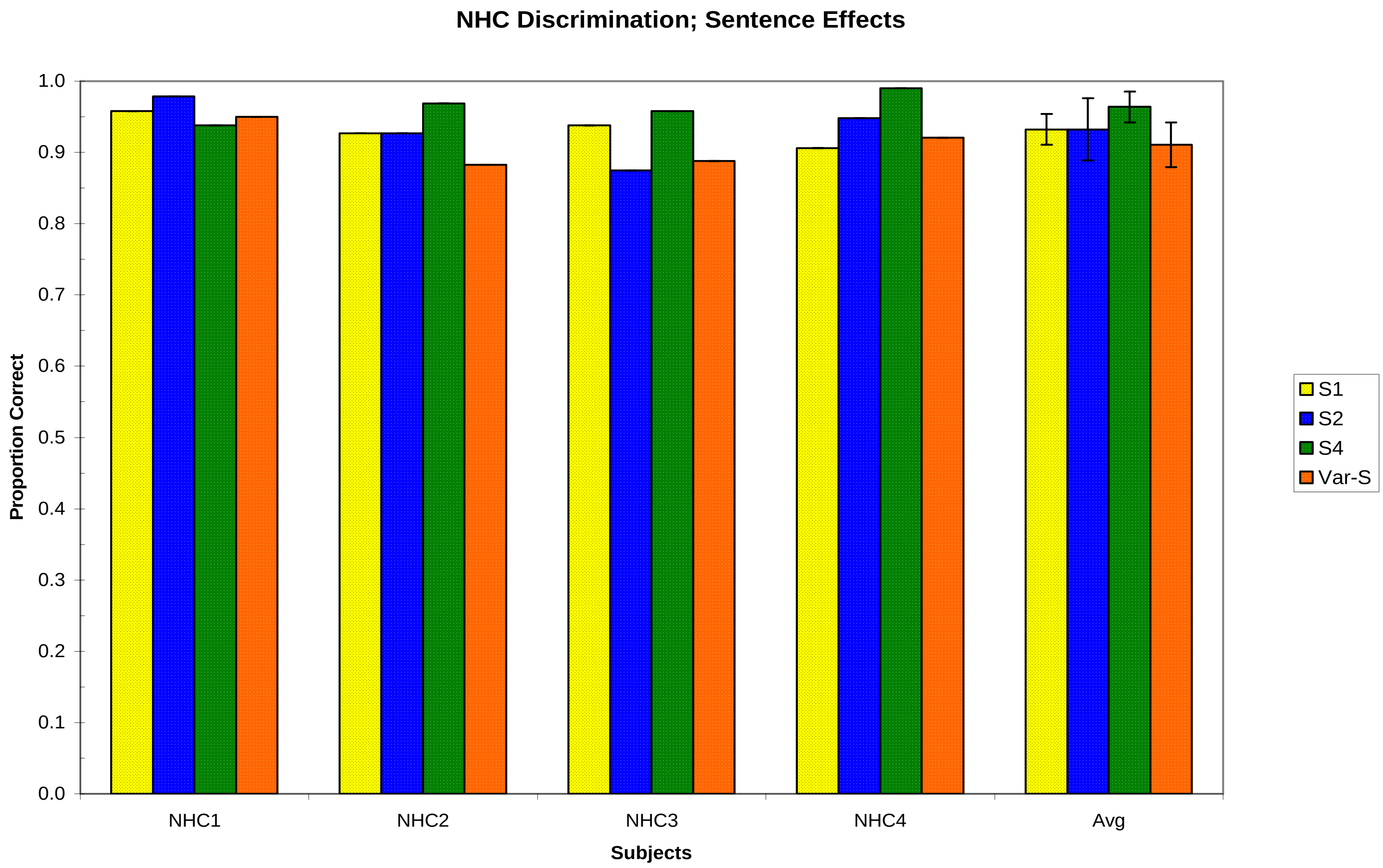

Figure 9: NHC Sentence Effects on the Discrimination Task.

Anova: Two-Factor Without Replication
Identification Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
NHC1	3	2.8959	0.9653	0.000215
NHC2	3	2.9531	0.984367	9.89E-05
NHC3	3	2.9532	0.9844	0.000237
NHC4	3	2.8802	0.960067	0.001121
T1	4	3.9167	0.979175	0.000394
T2	4	3.8334	0.95835	0.00051
Var-T	4	3.9323	0.983075	0.000224

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.001454	3	0.000485	1.506299	0.305736	4.757063
Columns	0.001414	2	0.000707	2.197076	0.192348	5.143253
Error	0.00193	6	0.000322			
Total	0.004798	11				

Table 10: ANOVA Results for NHC Talker Effects on the Identification Task.

Anova: Two-Factor Without Replication
Discrimination Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
NHC1	3	2.989	0.996333	1.18E-05
NHC2	3	2.7792	0.9264	0.003111
NHC3	3	2.7487	0.916233	0.003299
NHC4	3	2.8417	0.947233	0.003066
T1	4	3.8473	0.961825	0.001752
T2	4	3.903	0.97575	0.000307
Var-T	4	3.6083	0.902075	0.003985

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.011412	3	0.003804	3.3969	0.094487	4.757063
Columns	0.012256	2	0.006128	5.472215	0.044399	5.143253
Error	0.006719	6	0.00112			
Total	0.030387	11				

Table 11: ANOVA Results for NHC Talker Effects on the Discrimination Task.

Anova: Two-Factor Without Replication
Identification Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
NHC1	4	3.877	0.96925	0.000661
NHC2	4	3.93	0.9825	0.000243
NHC3	4	3.94	0.985	0.00015
NHC4	4	3.846	0.9615	0.000326
S1	4	3.863	0.96575	0.000759
S2	4	3.888	0.972	0.000453
S4	4	3.951	0.98775	0.000104
Var-S	4	3.891	0.97275	0.00021

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.001483	3	0.000494	1.437633	0.295201	6.991917
Columns	0.001046	3	0.000349	1.01357	0.430916	6.991917
Error	0.003095	9	0.000344			
Total	0.005624	15				

Table 12: ANOVA Results for NHC Sentence Effects on the Identification Task.

Anova: Two-Factor Without Replication
Discrimination Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
NHC1	4	3.825	0.95625	0.000298
NHC2	4	3.706	0.9265	0.001233
NHC3	4	3.659	0.91475	0.001569
NHC4	4	3.765	0.94125	0.001358
S1	4	3.729	0.93225	0.000471
S2	4	3.729	0.93225	0.001913
S4	4	3.855	0.96375	0.000471
Var-S	4	3.642	0.9105	0.000978

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.00389	3	0.001297	1.534175	0.271605	6.991917
Columns	0.005766	3	0.001922	2.274013	0.148897	6.991917
Error	0.007607	9	0.000845			
Total	0.017263	15				

Table 13: ANOVA Results for NHC Sentence Effects on the Discrimination Task.

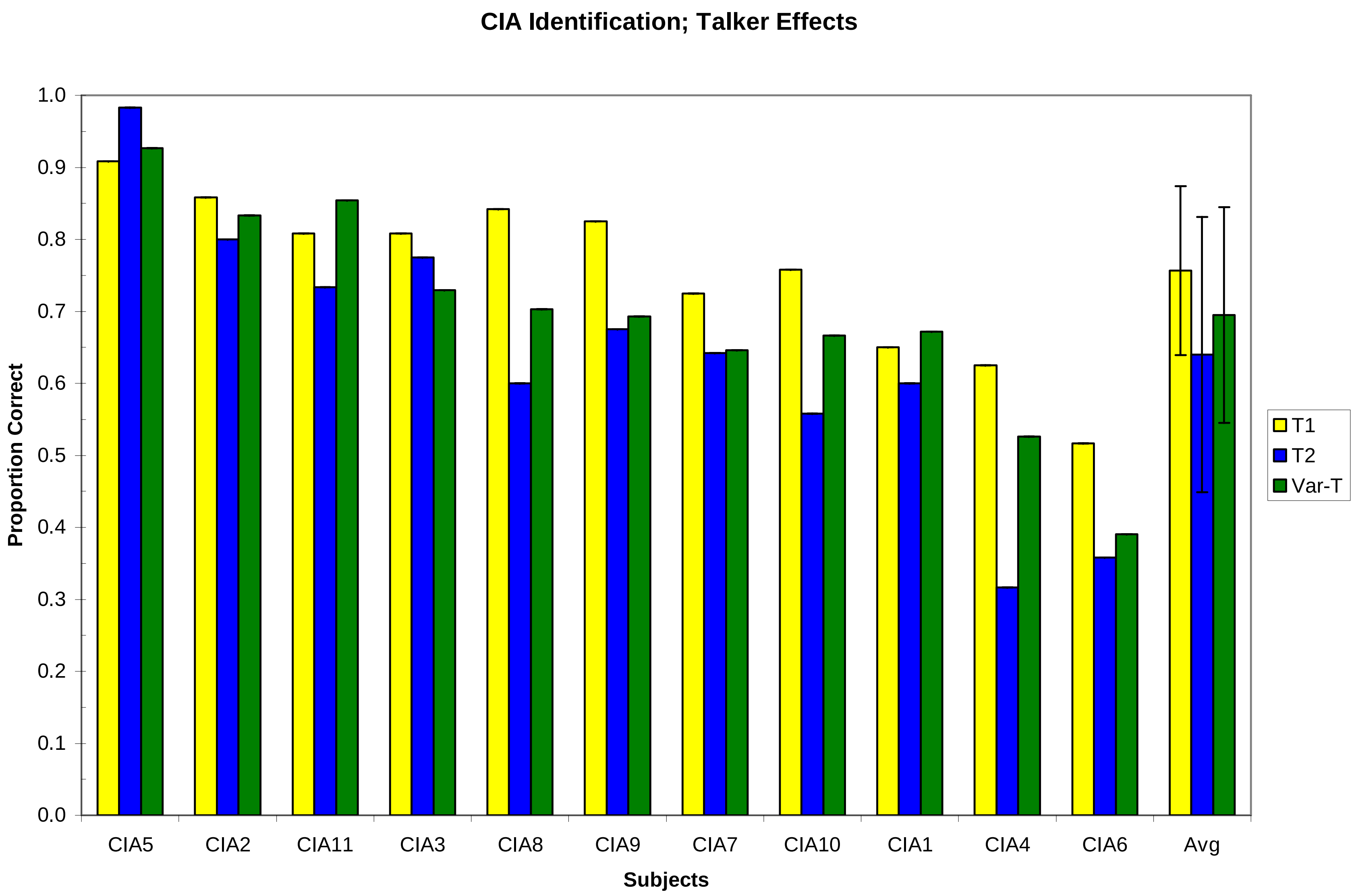

Figure 10: CIA Talker Effects on the Identification Task.

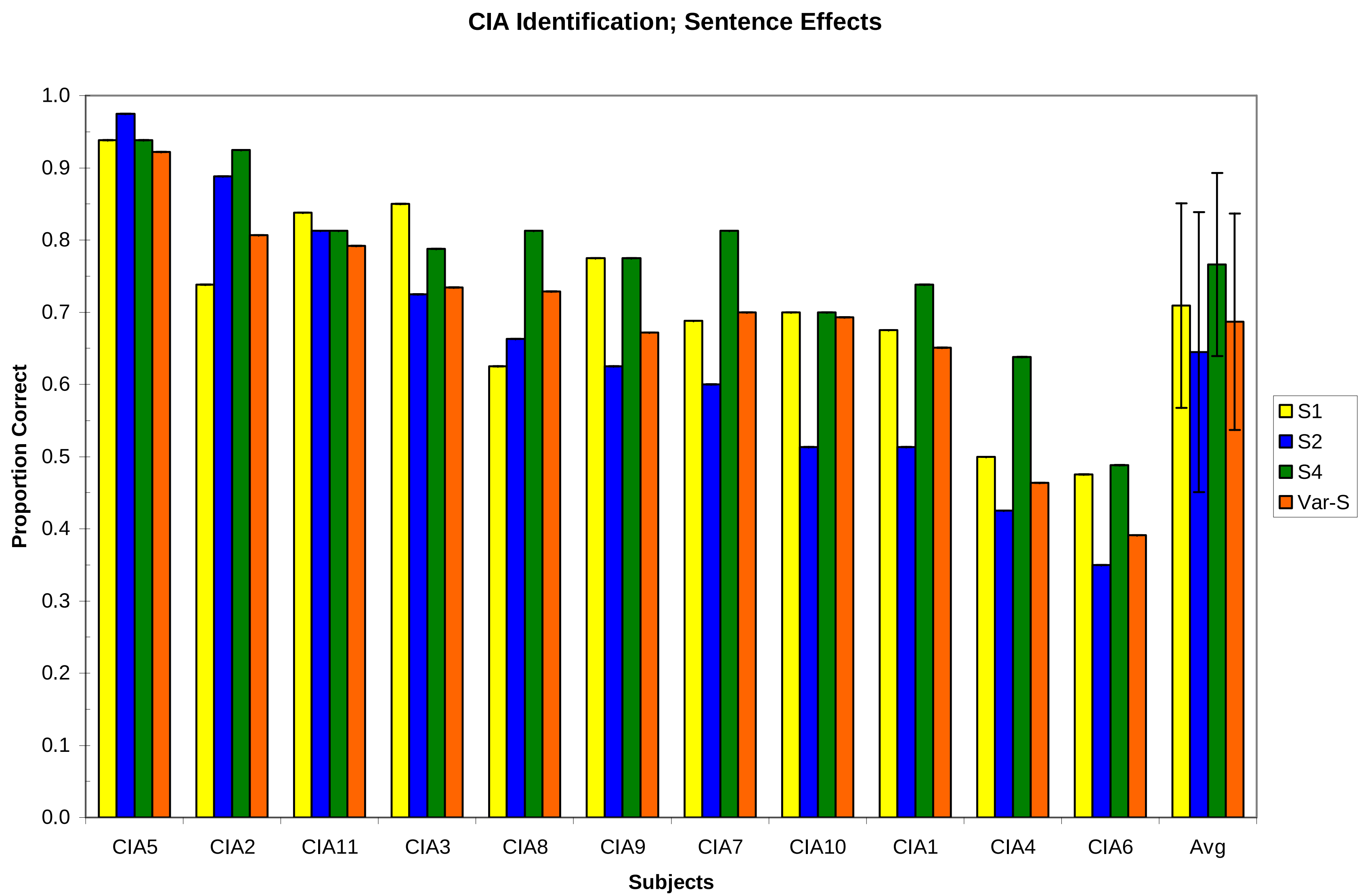

Figure 11: CIA Sentence Effects on the Identification Task.

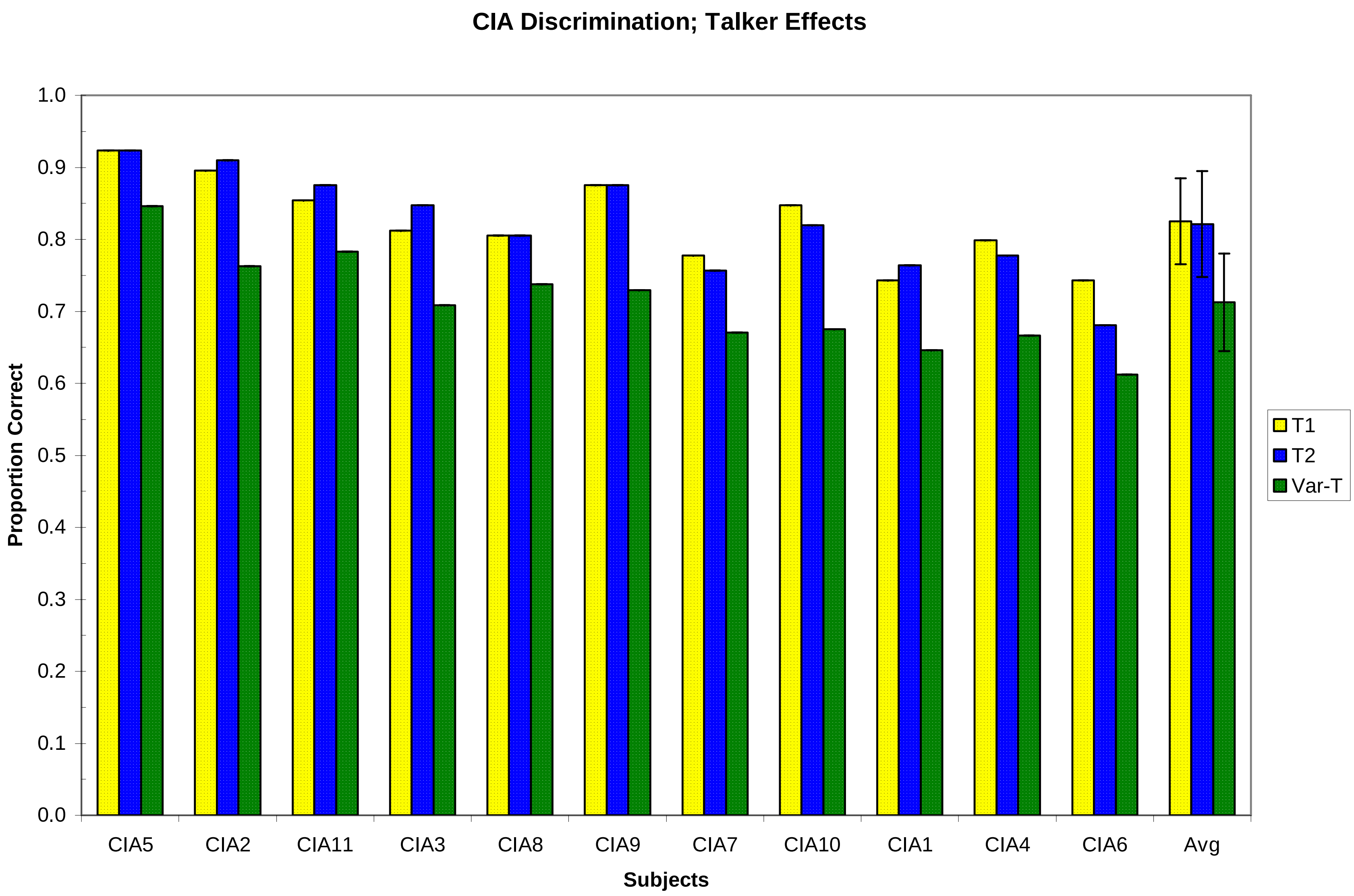

Figure 12: CIA Talker Effects on the Discrimination Task.

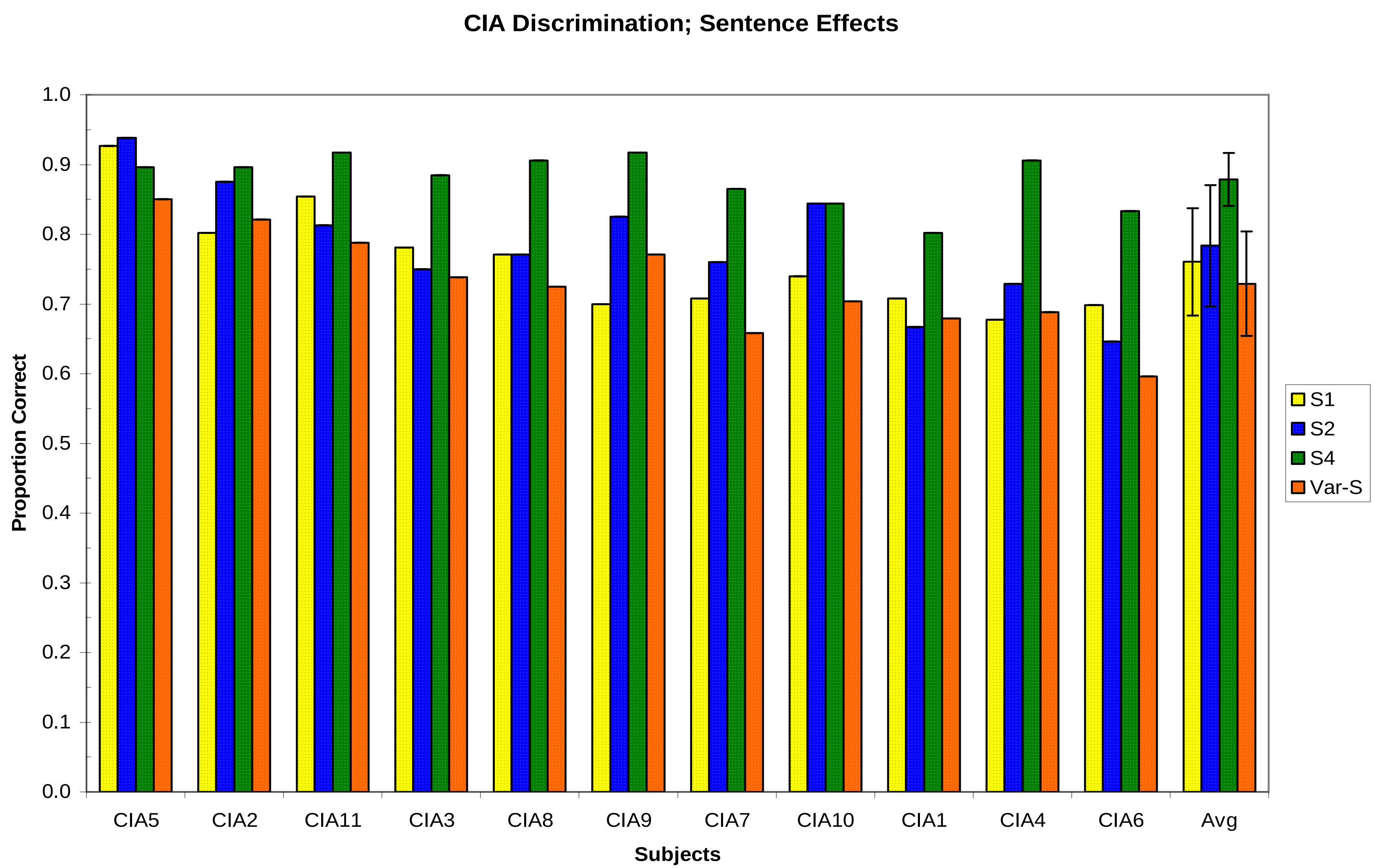

Figure 13: CIA Sentence Effects on the Discrimination Task.

Anova: Two-Factor Without Replication
Identification Data

SUMMARY	Count	Sum	Average	Variance
CIA5	3	2.8187	0.939567	0.001523
CIA2	3	2.4916	0.830533	0.000855
CIA11	3	2.3958	0.7986	0.003725
CIA3	3	2.3125	0.770833	0.001577
CIA8	3	2.1448	0.714933	0.01471
CIA9	3	2.1927	0.7309	0.006719
CIA7	3	2.0125	0.670833	0.002205
CIA10	3	1.9833	0.6611	0.010024
CIA1	3	1.9219	0.640633	0.001358
CIA4	3	1.4677	0.489233	0.024776
CIA6	3	1.2656	0.421867	0.007006
T1	11	8.3249	0.756809	0.013786
T2	11	7.0416	0.640145	0.036537
Var-T	11	7.6406	0.6946	0.022456

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.65379	10	0.065379	17.67285	8.01E-08	2.347878
Columns	0.074967	2	0.037484	10.13236	0.000914	3.492828
Error	0.073988	20	0.003699			
Total	0.802746	32				

Table 14: ANOVA Results for CIA Talker Effects on the Identification Task.

Anova: Two-Factor Without Replication
Discrimination Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
CIA5	3	2.693	0.897667	0.002018
CIA2	3	2.5681	0.856033	0.006609
CIA11	3	2.5125	0.8375	0.002311
CIA3	3	2.368	0.789333	0.005226
CIA8	3	2.3487	0.7829	0.001546
CIA9	3	2.4792	0.8264	0.007086
CIA7	3	2.2055	0.735167	0.003217
CIA10	3	2.3416	0.780533	0.008546
CIA1	3	2.1528	0.7176	0.003975
CIA4	3	2.2431	0.7477	0.005029
CIA6	3	2.0362	0.678733	0.004267
T1	11	9.0766	0.825145	0.003547
T2	11	9.0347	0.821336	0.00541
Var-T	11	7.8374	0.712491	0.004589

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.125831	10	0.012583	26.13416	2.53E-09	3.368186
Columns	0.090027	2	0.045014	93.49012	7.1E-11	5.848932
Error	0.00963	20	0.000481			
Total	0.225488	32				

Table 15: ANOVA Results for CIA Talker Effects on the Discrimination Task.

Anova: Two-Factor Without Replication
Identification Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
CIA5	4	3.773	0.94325	0.000505
CIA2	4	3.358	0.8395	0.007007
CIA11	4	3.256	0.814	0.000354
CIA3	4	3.097	0.77425	0.003324
CIA8	4	2.83	0.7075	0.006793
CIA9	4	2.847	0.71175	0.005702
CIA7	4	2.801	0.70025	0.007638
CIA10	4	2.606	0.6515	0.008536
CIA1	4	2.577	0.64425	0.009002
CIA4	4	2.027	0.50675	0.008594
CIA6	4	1.704	0.426	0.004415
S1	11	7.802	0.709273	0.020133
S2	11	7.09	0.644545	0.037559
S4	11	8.429	0.766273	0.016086
Var-S	11	7.555	0.686818	0.022369

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.860733	10	0.086073	25.63041	5.17E-12	2.979094
Columns	0.084866	3	0.028289	8.423633	0.000328	4.50974
Error	0.100748	30	0.003358			
Total	1.046347	43				

Table 16: ANOVA Results for CIA Sentence Effects on the Identification Task.

Anova: Two-Factor Without Replication
Discrimination Data

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
CIA5	4	3.611	0.90275	0.001553
CIA2	4	3.394	0.8485	0.001959
CIA11	4	3.372	0.843	0.003174
CIA3	4	3.154	0.7885	0.004467
CIA8	4	3.173	0.79325	0.00612
CIA9	4	3.213	0.80325	0.008371
CIA7	4	2.991	0.74775	0.007844
CIA10	4	3.132	0.783	0.005177
CIA1	4	2.856	0.714	0.003738
CIA4	4	3	0.75	0.011317
CIA6	4	2.773	0.69325	0.010414
S1	11	8.366	0.760545	0.005919
S2	11	8.618	0.783455	0.007577
S4	11	9.667	0.878818	0.001443
Var-S	11	8.018	0.728909	0.005598

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.150623	10	0.015062	8.253475	3E-06	2.979094
Columns	0.137655	3	0.045885	25.14291	2.49E-08	4.50974
Error	0.054749	30	0.001825			
Total	0.343027	43				

Table 17: ANOVA Results for CIA Sentence Effects on the Discrimination Task.

CIA 1

	Angry	Scared	Happy	Sad
Angry	92	5	4	7
Scared	21	53	32	2
Happy	12	51	44	1
Sad	4	4	10	90

CIA 2

	Angry	Scared	Happy	Sad
Angry	95	11	2	0
Scared	7	70	27	4
Happy	1	3	104	0
Sad	1	17	0	90

CIA 3

	Angry	Scared	Happy	Sad
Angry	93	4	0	11
Scared	3	75	27	3
Happy	1	33	73	1
Sad	5	13	1	89

CIA 4

	Angry	Scared	Happy	Sad
Angry	78	3	25	2
Scared	9	44	53	2
Happy	7	71	29	1
Sad	7	1	37	63

CIA 5

	Angry	Scared	Happy	Sad
Angry	104	4	0	0
Scared	13	93	2	0
Happy	1	1	106	0
Sad	1	5	0	102

CIA 6

	Angry	Scared	Happy	Sad
Angry	79	10	19	0
Scared	17	25	62	4
Happy	45	21	40	2
Sad	6	18	48	36

CIA 7

	Angry	Scared	Happy	Sad
Angry	82	17	8	1
Scared	4	58	37	9
Happy	4	44	60	0
Sad	3	14	3	88

CIA 8

	Angry	Scared	Happy	Sad
Angry	89	5	14	0
Scared	2	60	38	8
Happy	4	23	80	1
Sad	0	9	20	79

CIA 9

	Angry	Scared	Happy	Sad
Angry	105	2	1	0
Scared	11	66	28	3
Happy	0	50	57	1
Sad	10	4	19	75

CIA 10

	Angry	Scared	Happy	Sad
Angry	96	6	6	0
Scared	11	34	63	0
Happy	0	36	72	0
Sad	8	6	10	84

CIA 11

	Angry	Scared	Happy	Sad
Angry	103	2	1	2
Scared	9	59	38	2
Happy	0	15	92	1
Sad	7	2	4	95

Table 18: CIA Identification Confusion Matrices by Subject.

CI Adults

Master Totals	Angry	Scared	Happy	Sad
Angry	1188	0	0	0
Scared	0	1188	0	0
Happy	0	0	1188	0
Sad	0	0	0	1188

Combined ID Totals

Total	Angry	Scared	Happy	Sad
Angry	1016	69	80	23
Scared	107	637	407	37
Happy	75	348	757	8
Sad	52	93	152	891

Percentages

Total %	Angry	Scared	Happy	Sad	
Angry	86	6	7	2	
Scared	9	54	34	3	
Happy	6	29	64	1	
Sad	4	8	13	75	
					69

Table 19: CIA Identification Confusion Matrix with Combined Subject Data from Table 18.

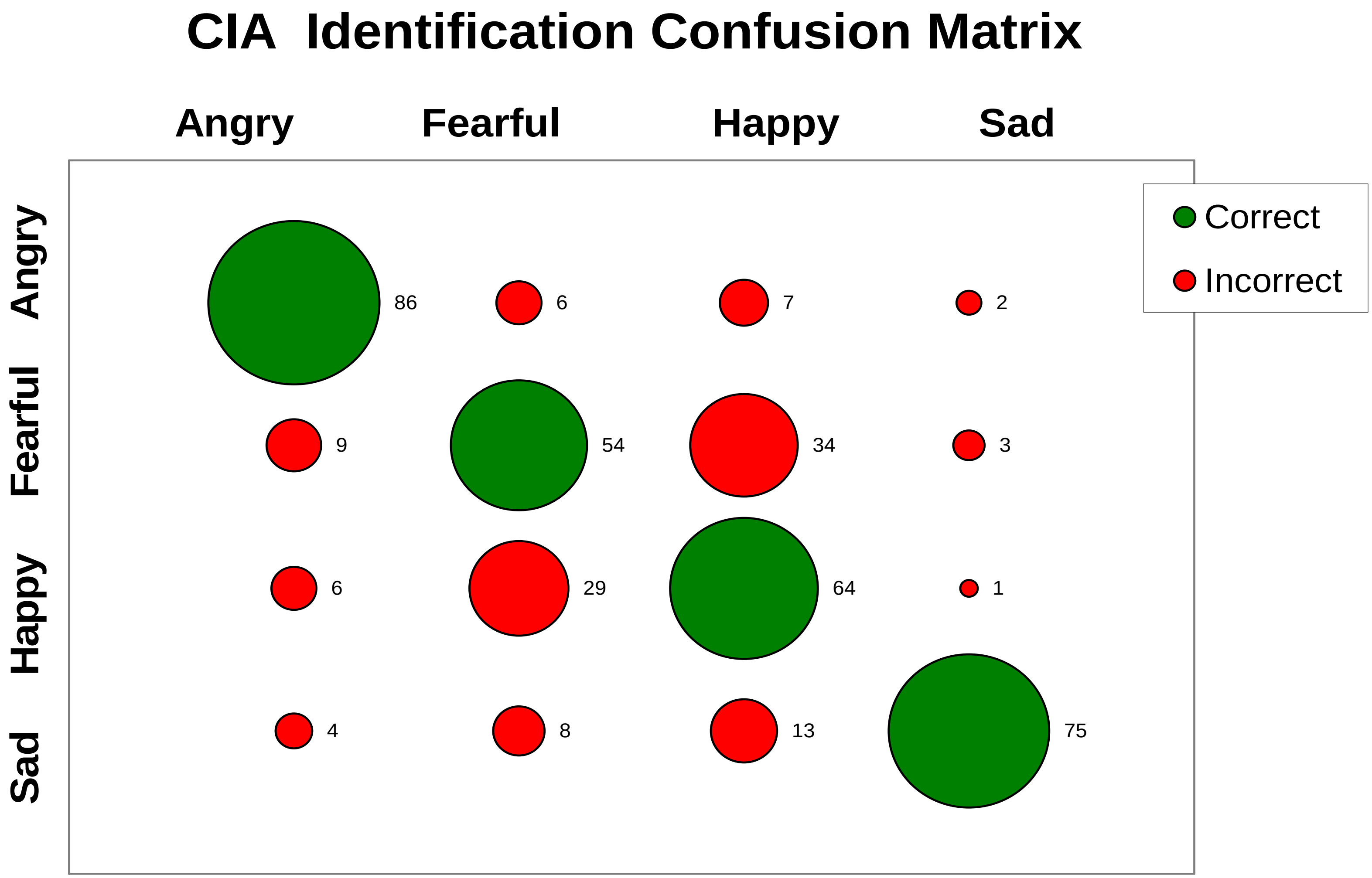

Figure 14: CIA Identification Confusion Matrix Bubble Plot.

CI
Adults

Type 1	Same	Different
Same	581	145
Different	0	0

Type 1	Same	Different
Same	80%	20%
Different	0	0

Type 2	Same	Different
Same	518	208
Different	0	0

Type 2	Same	Different
Same	71%	29%
Different	0	0

Type 3	Same	Different
Same	574	152
Different	0	0

Type 3	Same	Different
Same	79%	21%
Different	0	0

Type 4	Same	Different
Same	511	215
Different	0	0

Type 4	Same	Different
Same	70%	30%
Different	0	0

Type 5	Same	Different
Same	0	0
Different	101	383

Type 5	Same	Different
Same	0	0
Different	21%	79%

Type 6	Same	Different
Same	0	0
Different	70	414

Type 6	Same	Different
Same	0	0
Different	14%	86%

Type 7	Same	Different
Same	0	0
Different	45	439

Type 7	Same	Different
Same	0	0
Different	9%	91%

Type 8	Same	Different
Same	0	0
Different	242	242

Type 8	Same	Different
Same	0	0
Different	50%	50%

Type 9	Same	Different
Same	0	0
Different	91	393

Type 9	Same	Different
Same	0	0
Different	19%	81%

Type 10	Same	Different
Same	0	0
Different	49	435

Type 10	Same	Different
Same	0	0
Different	10%	90%

Table 20: CIA Discrimination Data sorted by Type.

Stim\Resp		SAME TRIALS											
		Type 1			Type 2			Type 3			Type 4		
		Angry v. Angry			Fearful v. Fearful			Happy v. Happy			Sad v. Sad		
		Same	Diff	%	Same	Diff	%	Same	Diff	%	Same	Diff	%
CIA1	Same	51	15	77	42	24	64	32	34	48	45	21	68
	Diff	0	0		0	0		0	0		0	0	
CIA2		49	17	74	53	13	80	62	4	94	55	11	83
		0	0		0	0		0	0		0	0	
CIA3		58	8	88	41	25	62	45	21	68	43	23	65
		0	0		0	0		0	0		0	0	
CIA4		43	23	65	48	18	73	52	14	79	42	24	64
		0	0		0	0		0	0		0	0	
CIA5		61	5	92	51	15	77	60	6	91	55	11	83
		0	0		0	0		0	0		0	0	
CIA6		47	19	71	51	15	77	53	13	80	38	28	58
		0	0		0	0		0	0		0	0	
CIA7		54	12	82	38	28	58	47	19	71	48	18	73
		0	0		0	0		0	0		0	0	
CIA8		51	15	77	55	11	83	53	13	80	39	27	59
		0	0		0	0		0	0		0	0	
CIA9		59	7	89	43	23	65	56	10	85	43	23	65
		0	0		0	0		0	0		0	0	
CIA10		48	18	73	53	13	80	62	4	94	49	17	74
		0	0		0	0		0	0		0	0	
CIA11		60	6	91	43	23	65	52	14	79	54	12	82
		0	0		0	0		0	0		0	0	
Totals		581	145		518	208		574	152		511	215	
		0	0		0	0		0	0		0	0	
Avg				80			71			79			70
Stdev				9.1			8.9			13.2			9.4

Table 21: CIA Discrimination Data in the “Same” Condition by Subject.

DIFFERENT TRIALS

	Type 5 Angry v Fearful			Type 6 Angry v. Happy			Type 7 Angry v. Sad			Type 8 Fearful v. Happy			Type 9 Fearful v. Sad			Type 10 Happy v. Sad		
	Same	Diff	%	Same	Diff	%	Same	Diff	%	Same	Diff	%	Same	Diff	%	Same	Diff	%
Same	0	0		0	0		0	0		0	0		0	0		0	0	
Diff	15	29	66	6	38	86	5	39	89	25	19	43	6	38	86	5	39	89
	0	0		0	0		0	0		0	0		0	0		0	0	
	13	31	70	0	44	100	2	42	95	16	28	64	8	36	82	0	44	100
	0	0		0	0		0	0		0	0		0	0		0	0	
	5	39	89	4	40	91	8	36	82	19	25	57	4	40	91	2	42	95
	0	0		0	0		0	0		0	0		0	0		0	0	
	11	33	75	8	36	82	4	40	91	21	23	52	13	31	70	5	39	89
	0	0		0	0		0	0		0	0		0	0		0	0	
	6	38	86	3	41	93	1	43	98	10	34	77	1	43	98	1	43	98
	0	0		0	0		0	0		0	0		0	0		0	0	
	15	29	66	21	23	52	7	37	84	26	18	41	18	26	59	14	30	68
	0	0		0	0		0	0		0	0		0	0		0	0	
	15	29	66	10	34	77	5	39	89	19	25	57	15	29	66	5	39	89
	0	0		0	0		0	0		0	0		0	0		0	0	
	7	37	84	5	39	89	2	42	95	29	15	34	8	36	82	2	42	95
	0	0		0	0		0	0		0	0		0	0		0	0	
	5	39	89	3	41	93	2	42	95	18	26	59	6	38	86	4	40	91
	0	0		0	0		0	0		0	0		0	0		0	0	
	6	38	86	8	36	82	6	38	86	39	5	11	6	38	86	9	35	80
	0	0		0	0		0	0		0	0		0	0		0	0	
	3	41	93	2	42	95	3	41	93	20	24	55	6	38	86	2	42	95
	0	0		0	0		0	0		0	0		0	0		0	0	
	101	383		70	414		45	439		242	242		91	393		49	435	
			78			85			90			50			81			89
			10.0			13.2			5.4			18.2			11.9			9.5

Table 21 Continued: CIA Discrimination Data in the “Different” Condition by Subject.

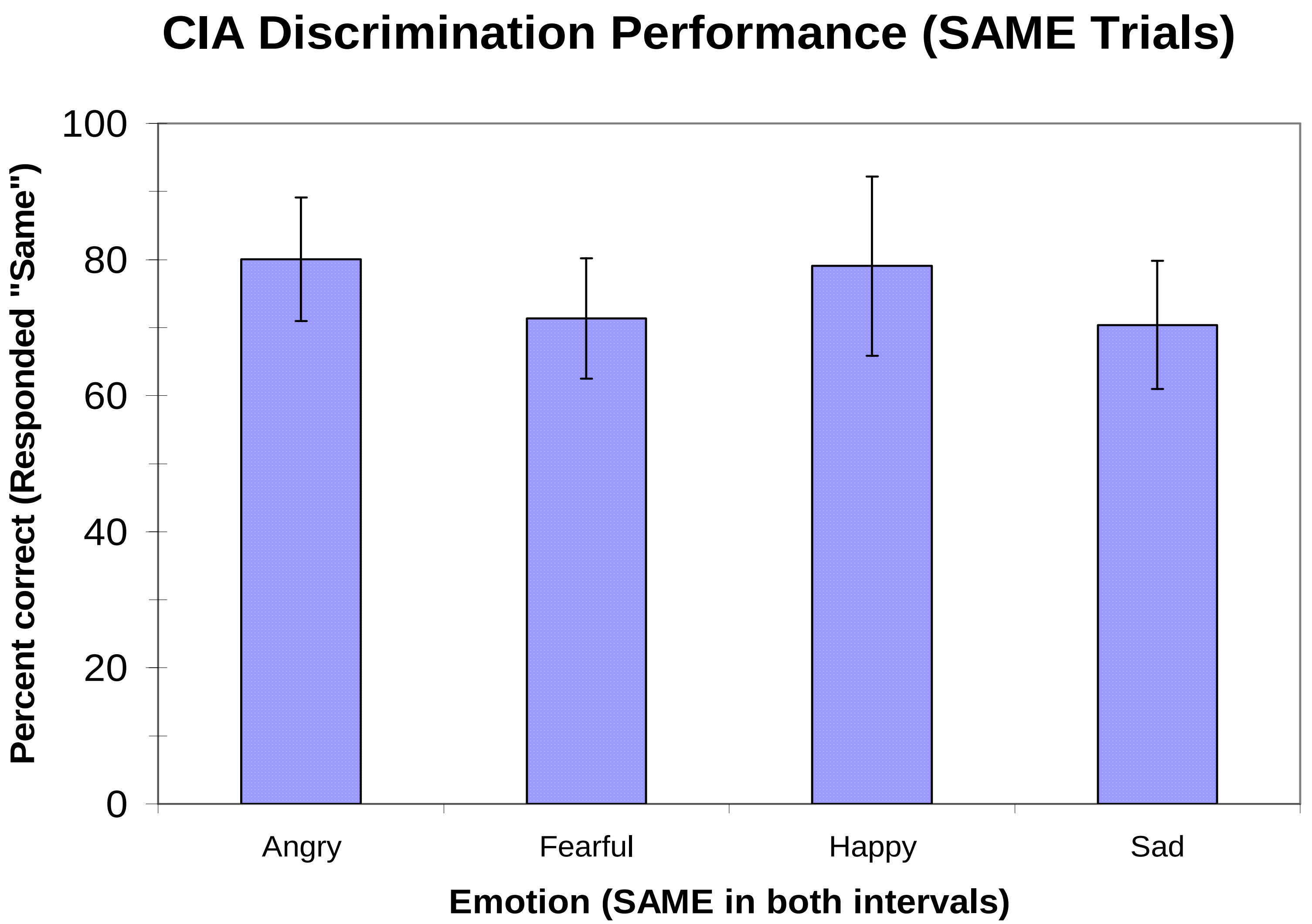

Figure 15: CIA Discrimination Matrix when the emotions were the same in both intervals.

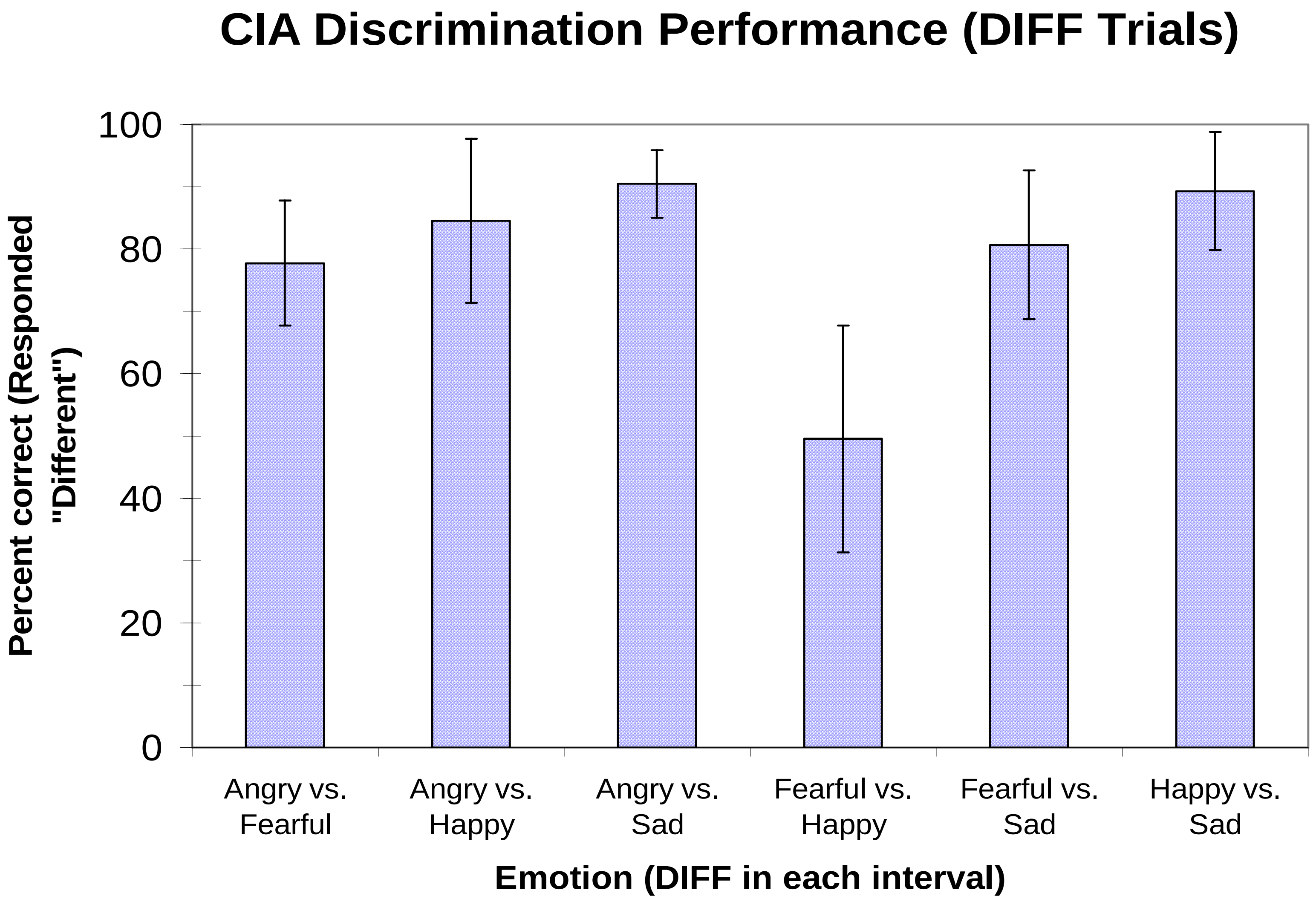

Figure 16: CIA Discrimination Matrix when the emotions were different in each trial.

Ordered by Subject ID #

Subj ID	Age (Yr, Mo)	Identification Possible	Identification Score	Discrimination Possible	Discrimination Score
NHA1	29	707/720	0.982	1036/1056	0.981
NHA2	24	429/432	0.993	526/528	0.996
NHA3	55	424/432	0.982	514/528	0.974
NHC1	12,4	418/432	0.968	504/528	0.955
NHC2	9,6	424/432	0.982	483/528	0.915
NHC3	6,0	426/432	0.986	479/528	0.907
NHC4	6,11	411/432	0.951	494/528	0.936
CIA1	72	275/432	0.637	372/528	0.515
CIA2	46	359/432	0.831	443/528	0.839
CIA3	45	326/432	0.755	409/528	0.775
CIA4	67	210/432	0.486	387/528	0.733
CIA5	34	401/432	0.928	469/528	0.888
CIA6	75	176/432	0.407	352/528	0.667
CIA7	56	284/432	0.657	382/528	0.724
CIA8	74	304/432	0.704	409/528	0.775
CIA9	62	299/432	0.692	427/528	0.809
CIA10	56	282/432	0.653	402/528	0.761
CIA11	36	345/432	0.799	437/528	0.828

Ordered by Age within Subject Group

	Age	Ident	Discrim
		NHA	**NHA**
NHA2	24	0.993	0.996
NHA1	29	0.982	0.981
NHA3	55	0.982	0.974
		NHC	**NHC**
NHC3	6	0.986	0.907
NHC4	6.92	0.951	0.936
NHC2	9.5	0.982	0.915
NHC1	12.3	0.968	0.955
		CIA	**CIA**
CIA5	34	0.928	0.888
CIA11	36	0.799	0.828
CIA3	45	0.755	0.775
CIA2	46	0.831	0.839
CIA7	56	0.657	0.724
CIA10	56	0.653	0.761
CIA9	62	0.692	0.809
CIA4	67	0.486	0.733
CIA1	72	0.637	0.515
CIA8	74	0.704	0.775
CIA6	75	0.407	0.667
		-0.81	-0.71

Table 22: Subject Data sorted by Age for the Identification and Discrimination Tasks.

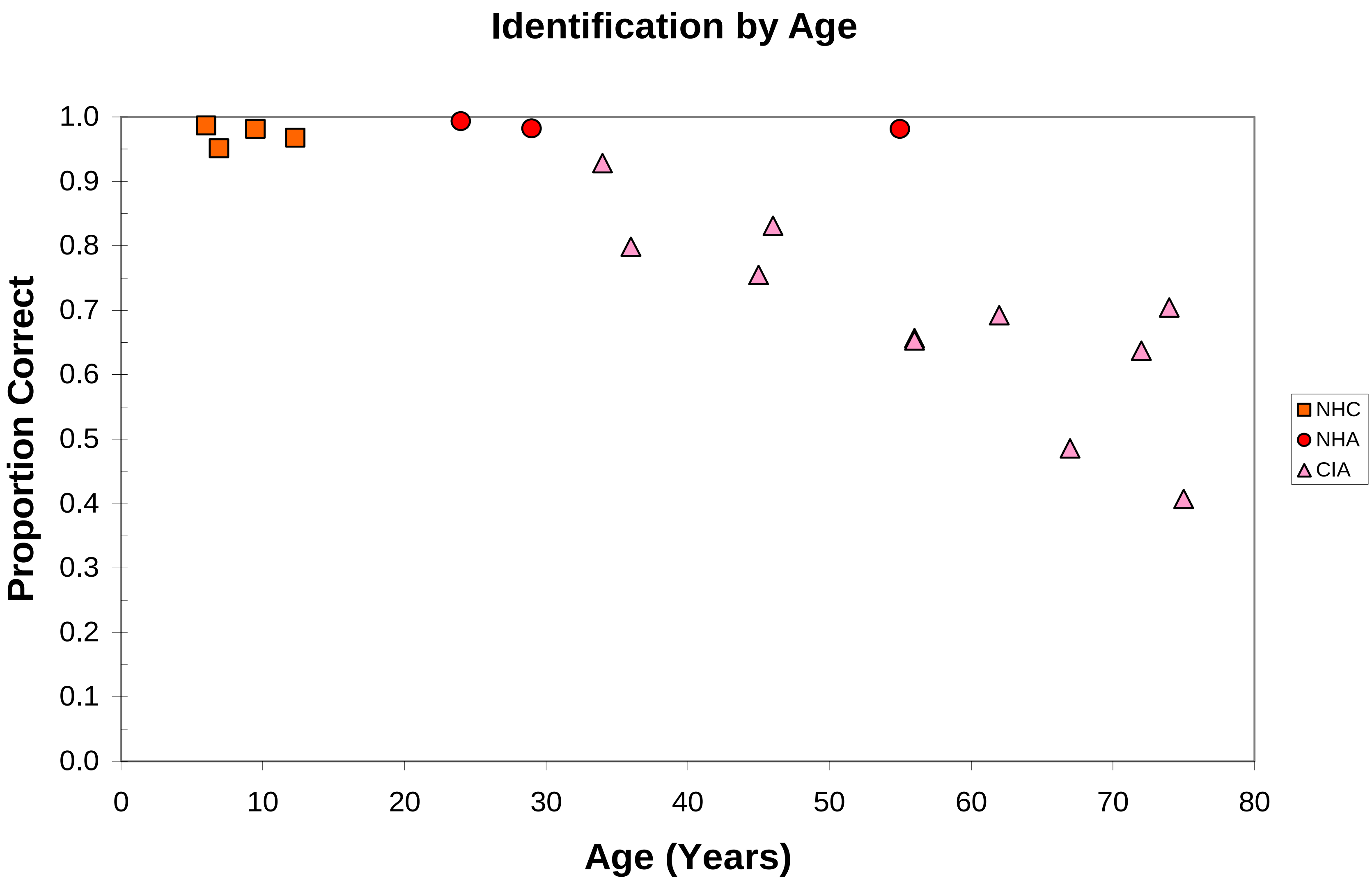

Figure 17: Identification Task Performance sorted by Age.

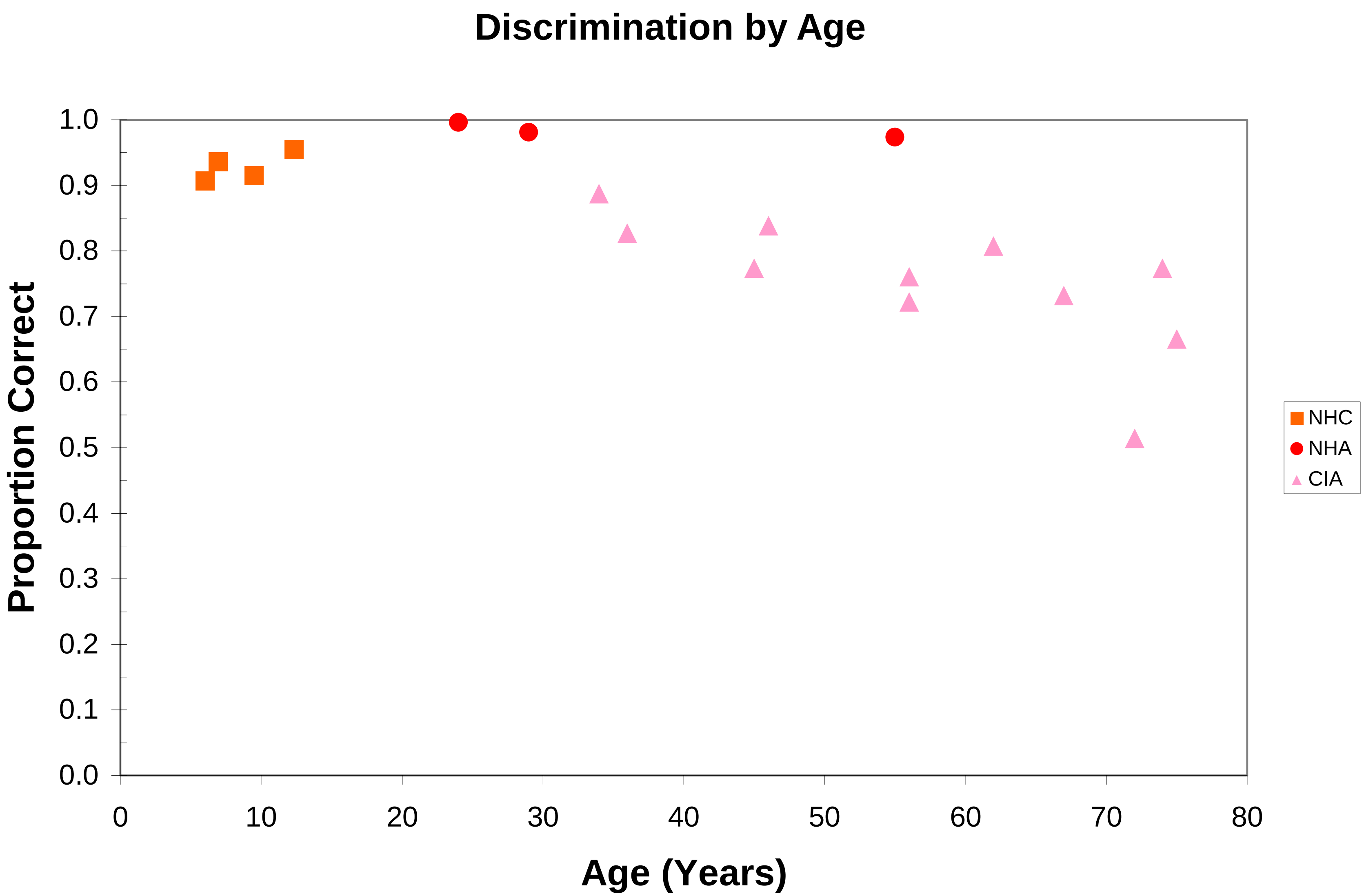

Figure 18: Discrimination Task Performance sorted by Age.

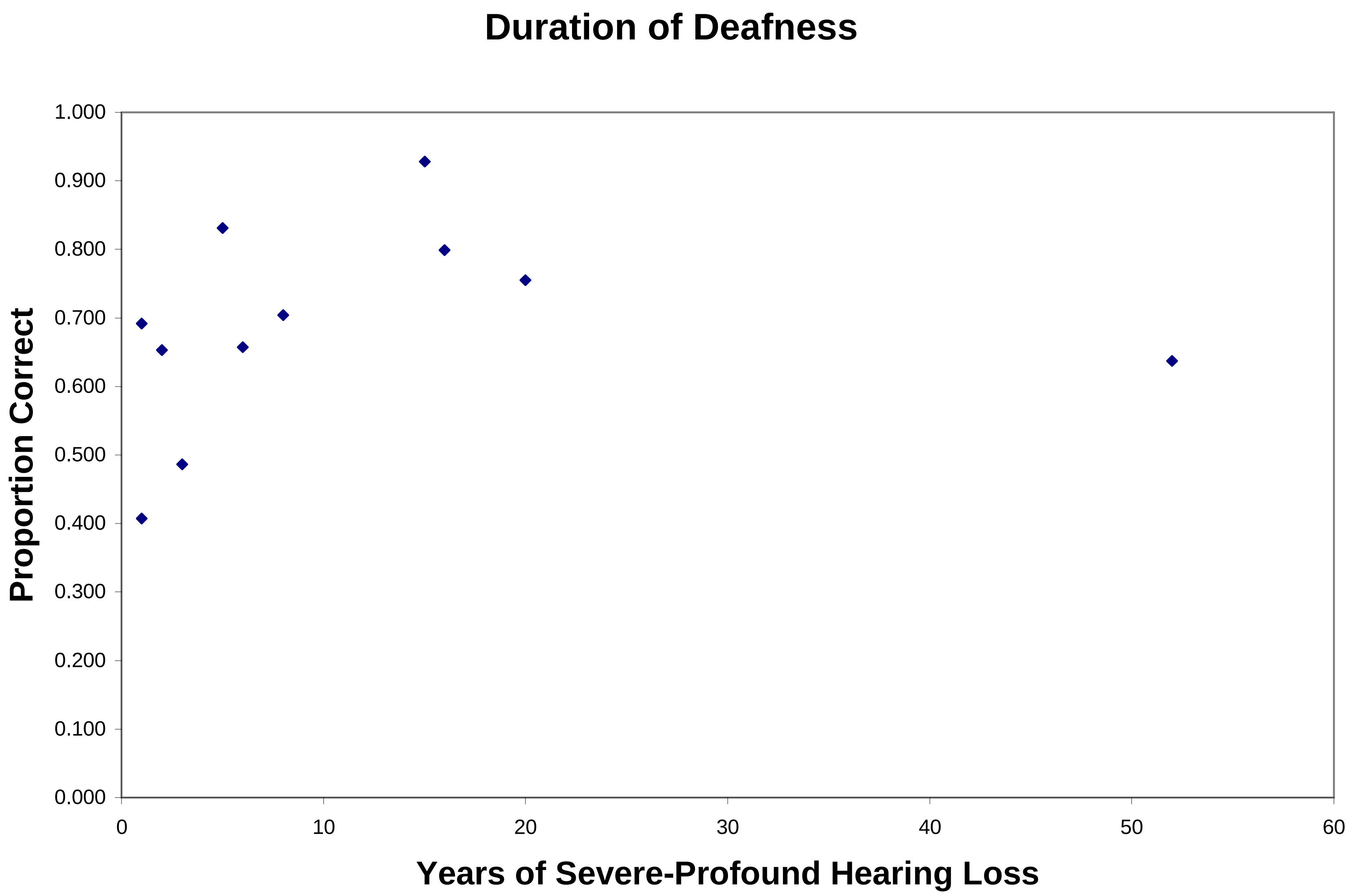

Figure 19: Duration of Deafness plotted against overall identification performance for the CIA group.

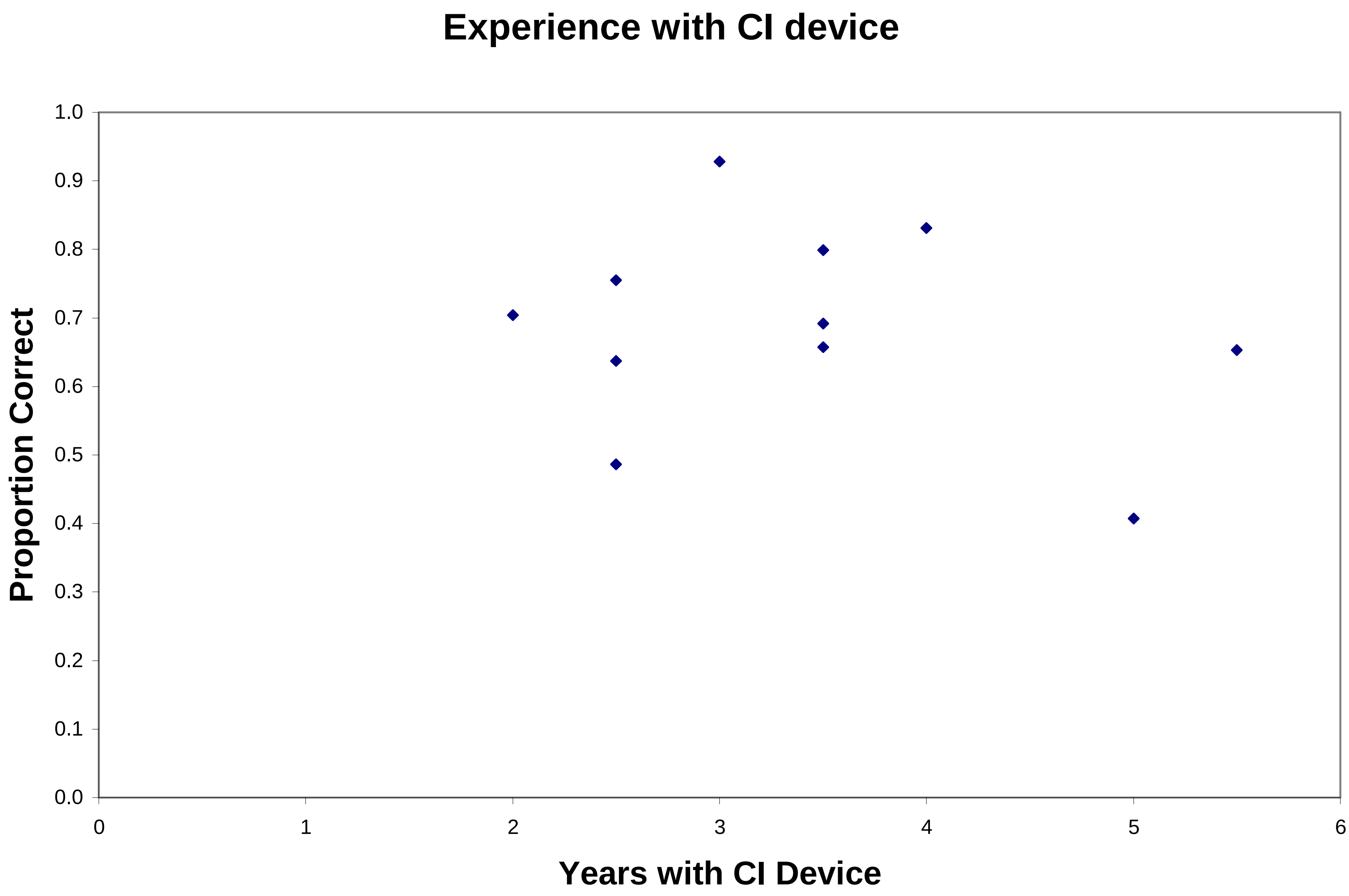

Figure 20: Experience with CI Device plotted against overall identification performance for the CIA group.