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Age-Related Differences in Speed of Processing: Unconfounding Age and Experience

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This study was designed to explore age constraints on speed of processing on a lexical decision task. In order to unconfound age and experience, the participants were presented with two lexical decision tasks, one in German (the native language) and one in English (the second language), as well as a symbol matching task. Three groups of subjects were formed: (1) 16-year-olds who had received formal instruction in English for 5 years, (2) 16-year-olds who had received only 1 year of instruction in English, and (3) 14-year-olds who had received 3 years of instruction in English. Inclusion of these three groups permitted the study of the effects of language experience in the absence of the usual age–experience confound. When the lexical decision task involved German words and nonwords, the older children responded more quickly than the younger subjects. However,

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when the stimulus items were English words and non-words, this age-related progression was disrupted and response speed was related to experience with English as a second language. These results suggest that experience is an important factor to consider when trying to account for lexical access times. Implications for understanding age-related differences are discussed.

Age-related changes in information processing speed have been reported in a wide variety of tasks (Bisanz & Resnick, 1978; Chi, 1977; Kail, 1986; Keating & Bobbitt, 1978; Naus & Ornstein, 1977; Whitney, 1986), leading to the claim that age differences in the speed of cognitive processing are ubiquitous (Kail, 1986). In the current study, we examine two hypotheses concerning the nature of the linkage between age and speed of processing. From one perspective, age defines a narrow limit on the speed with which a child can process information, perhaps reflecting a central limiting processing mechanism that increases with age (Kail, 1986). In contrast, from a second perspective, age specifies a relatively wide bandwidth within which experience (with materials or task) exerts a rather large role in determining actual speed.

Most research on developmental differences in speed of processing is silent regarding the nature of the age constraint, largely because these studies are plagued by a natural confounding between age and familiarity with the stimulus materials. That is, simply by virtue of their age, older children have more experience than younger children with most types of stimuli. In an attempt to alleviate this age × experience confounding, Kail (1986) employed very simple tasks with which all children had little familiarity. Although this approach clearly eliminates the confounding, it does not yield information about the age constraint because the possible impact of experience is limited substantially by the very nature of the tasks utilized.

Within the present context, the most relevant study is one conducted by Roth (1983) in which there was an attempt to unconfound domain knowledge with age. Roth asked children and adults to make "same/different" judgments regarding chess boards that were presented simultaneously. Half of the subjects were considered "experts" at chess, and the others were "novices." Reaction time measures indicated that the usual adult superiority in speed of processing could be markedly reduced when children and adults possessed equivalent amounts of domain knowledge. However, even when age and domain experience were unconfounded, age differences in reaction times were still observed. Roth concluded that some part of the observed age effect was due to knowledge differences, but that age still imposed a considerable constraint.

Although Roth's results are compelling, Whitney (1986) cautions against conceptualizing speed of processing as a unitary variable that is consistent across tasks. For example, it is possible that patterns of reaction time obtained in a "same/different" judgment task might not hold for a lexical decision task in which subjects make judgments about whether a letter string forms a word or a nonword. To determine if generalization from a same/different task is possible, we examined the role that relative familiarity or experience with lexical items plays in determining age-related patterns of lexical decision times. The stimuli employed in this investigation were sampled from the subjects' native language, as well as another language that they were in the process of learning. By examining performance in a second language, it was possible to unconfound age and experience by finding some young children with more experience with the second language than older children.

The overall plan of this research was to examine three groups of subjects in terms of their lexical decision times in German, their native language, and English, their second language. The first group was composed of 16-year-olds (ninth graders) who had 5 years of instructional experience with English as a second language. The second group consisted of a sample of 16-year-olds (ninth graders) who had only 1 year of instruction in English. In contrast, the third group included 14-year-olds (seventh graders) with 3 years of instruction in English. The groups chosen permitted important contrasts between children of different ages and levels of familiarity with German and English.

In addition to providing information relevant to the age constraint on processing speed, this study also has implications for discussions of the relations between the representations of two languages. Specifically, a central issue in bilingualism research concerns whether the two languages are represented independently or interdependently (Chen & Leung, 1989; Gerard & Scarborough, 1989; Mägiste, 1984). The independence model asserts that processing in one language occurs in a manner that is orthogonal to the second language, whereas the interdependence model assumes that the two languages are interrelated and that there would be processing interference between them. As Gerard and Scarborough (1989, p. 305) state: "There are data to support both of these hypotheses."

Given that we varied experience with both German and English it is possible to assess whether there are differential effects of proficiency in one language on the other. Because we have samples of 16-year-olds with differing amounts of experience with a second language, we can assess whether degree of second language experience affects first language performance; that is, we can compare 16-year-olds with 5 years of experience with English with those with 1 year of experience. However, when we explore the impact of variations in experience in a native language on second language performance, we have an age $\times$ experience confound.

On the basis of research on bilingualism, we hypothesized that two different patterns of performance on the lexical decision task with German words were possible. First, based on the assumption that the two languages are represented independently of each other, the normal age-related progression in performance would be predicted. Thus, from this perspective it would be expected that 16-year-olds would produce faster lexical decision times than 14-year-olds, although the overall similarity in age of these two samples might result in minimal differences in speed. Of course, experience with English would not be expected to influence the reaction times with German words and nonwords. Second, based on the assumption of interference between the two languages, increases in the total amount of experience in a specific second language would be predicted to lead to a slowing in performance in the first language. Thus, 16-year-olds with 5 years of experience with English would be slower on the German stimuli than their peers with less experience with a specific foreign language.

There were also a number of alternative predictions regarding the children's performance on the lexical decision task with English materials. A first prediction was that age-related differences in processing speed would be due solely to developmental or maturational factors. From this perspective, there is a general increase in processing speed from childhood to adulthood, and experience is thought to contribute little to performance. Accordingly, to the extent that all of the English words employed in the study are known by all subjects, patterns of performance with these materials would be predicted to mirror those of the German words.

In contrast, a second prediction derives from the hypothesis that age-related differences in processing speed are primarily due to variables that are generally correlated with age, with specific familiarity with materials exerting a secondary influence. Consistent with this view, research on bilingualism has suggested that students' facility with a first language is related to their acquisition of a second language (Hakuta, 1986). In the current context, it might be expected that the 16-year-olds' greater familiarity with German would lead to their overall superiority to the 14-year-olds in terms of performance with English materials. However, it would also be predicted that the 16-year-olds with 5 years experience would be faster than those with only one year of experience.

A third prediction emerges from the hypothesis that age-related differences in lexical processing speed are primarily due to experience with the lexical stimuli. In support of this hypothesis, Gardner, Rothkopf, Lapan, and Lafferty (1987) found that direct experience with lexical items is a better predictor of lexical decision times in adults than the normative frequency with which an item is represented in the vocabulary. This hypothesis leads to a prediction of reaction time patterns that are dependent on experience, not age. Thus, 16-year-olds with 5 years of experience would be expected to be fastest, 14-year-olds with 3 years of experience would come next, and 16-year-olds with only one year of experience would be slowest.

METHOD

Subjects

The sample was chosen on the basis of the children's age and experience with English as a foreign language. All subjects were native speakers of German who had just completed either the seventh or ninth grades of local public gymnasia (secondary schools) in middle class neighborhoods of Munich, Germany. In addition, prior to their participation in the experiment, the children had received either 1, 3, or 5 years of formal instruction in English in school. However, because training in one foreign language typically begins in the fifth grade, with exposure to at least one additional foreign language taking place in the seventh grade, it was possible to sample subjects so that their experience with English was not perfectly correlated with age and grade in school. In all, three groups of 20 children were established: 16-year-olds (ninth graders) with 5 years of instruction in English (Group 16-5), mean age = 16 years; 1 month (range = 15 years; 0 months to 17 years; 5 months); 16-year-olds (ninth graders) with 1 year of instruction in English (Group 16-1), mean age = 15 years; 11 months (range = 15 years; 3 months to 17 years; 1 month), and 14-year-olds (seventh graders) with 3 years of instruction in English (Group 14-3), mean age = 14 years; 0 months (range = 13 years; 1 month to 14 years; 3 months). For groups 14-3 and 16-5, English was the first foreign language formally studied, whereas for Group 16-1, it was the second (following 4 years of French), and in some cases the third (following 2 years of Latin and 2 years of French) language studied.

A possible implication of not having random assignment of subjects to groups is that the two groups of sixteen year olds differed in non-random ways. Students who elected to take French or French and Latin prior to taking English might have different learning capabilities (or speed of processing) than those electing to start foreign language instruction with English. Given this possibility, it is important to point out that the decision regarding which program to enter was made prior to entry into the fifth grade by parents and before any formal assessment of foreign language ability. Thus, there is no reason, a priori, to expect ability differences between these two groups of students.

Tasks and Materials

The children were presented with two versions of a lexical decision task, one with English materials and one with German materials, and a symbol-matching task (see Posner, 1978). In the two lexical decision tasks, the subjects were asked to make decisions about whether each of a set of letter strings represented a word or a non-word. The reaction time to make each lexical decision was recorded. In the symbol-matching task, chosen to control for basic response speed, the subjects were asked to determine if two letters were the same or different in terms of their physical (i.e., upper-versus lowercase) characteristics. The intervals of time required to make the physical matches were recorded.

All subjects were asked to make word-nonword decisions about each of 138 German stimulus items and 138 English stimulus items. These two judgment tasks were separated by participation in the symbol matching task. In the lexical decision tasks, the stimulus materials were composed of two groups of 69 words and 69 nonwords, one set in German and the second in English. All of the words were nouns or words used primarily as nouns. The English words were selected from a first-year, fifth-grade English textbook used in the public schools of Munich, and were known to all of the participants in the experiment. Each of these words was translated into German from the English set of words. The selection of English materials was constrained such that the words, as well as their German equivalents, were between four and six letters in length and no longer than two syllables. In each set, each word was also converted to a nonword by changing one or two letters such that vowels replaced vowels and consonants replaced consonants. All of the resulting nonwords were pronounceable and followed the rules of orthography in their respective language. In the symbol matching task, the stimuli were composed of letters that shared the same name ("A" and "a"), but differed in case.

Procedure

Each subject was tested individually, seated in front of an IBM personal computer. Instructions were presented in German by a native speaker. For the lexical decision task, the subject was asked to indicate words by depressing the"J" ("ja" [yes]) and nonwords by depressing the "N" ("nein" [no]) key. These keys were also used to indicate physical matches (e.g., "A" and "A") and nonmatches (e.g., "A" and "a"). Subjects used their right hands for responding and responded using their middle finger for the "J" and their pointer finger for the "N". Their fingers were resting on each key throughout the experiment. For both tasks, the stimuli were centered on the computer monitor and were removed when a response was made or 3000 ms had elapsed.

For one half of the children, the German version of the lexical decision task was presented first, whereas for the other half, the English version was given initially. On each of the lexical decision tasks, words and nonwords were intermixed randomly according to unique random orders of presentation that were generated for each individual subject. Each of the 138 stimulus items was presented once. The symbol-matching task was inserted between the two lexical decision tasks. On the symbol-matching task, the four pairs of stimuli resulting from all combinations of "A" and "a" were each presented 10 times. The sequencing of the resulting 40 trials was determined by individual random orders that were generated for each subject. However, a programming error resulted in the loss of the data from the first trial of the symbol matching task, and thus only 39 trials were available for each subject.

RESULTS

To explore differences in the accessibility of information as a function of age and experience with the stimulus materials, major emphasis was placed on the children's performance on the two lexical decision tasks. Of particular interest was the pattern of reaction times required for the correct identification of words in the two languages, although the number of errors (e.g., responding "ja" to nonwords and "nein" to words) was also of relevance. However, before the data from the lexical decision tasks could be explored, it was necessary to examine differences in general response speed, as assessed by performance on the symbol matching task.

Symbol Matching Task

The children's performance on the symbol matching task was extremely accurate. Indeed, the mean number of errors made for the 14-3, 16-1, and 16-5 subjects was .15, .30, and .30, respectively, across the series of 39 trials, $F(2, 57) = .57$, $p > .05$. With this high level of accuracy, the pattern of reaction times could be examined directly, after outlier times were removed. These outlier values were eliminated by removing reaction times that were greater than three standard deviations above and below each individual's mean reaction time. After removing these reaction times, which were assumed to represent momentary lapses in attention, each child's median reaction time was calculated. The resulting means of these medians were 826.65, 893.18, and 882.05 ms for the 14-3, 16-1, and 16-5 subjects, respectively, $F(2, 57) = .42$, $p > .05$, indicating no significant difference in speed of response among the three participating groups.

Lexical Decision Tasks: Pattern of Errors

The mean percentage of errors are displayed in the bottom half of Table 1 indicated separately for German and English words and nonwords, as a function of number of years of instruction in English. As can be seen, the children were highly accurate in their judgments of words and non-words in German, and the performance of the three groups did not differ. In contrast, performance was less accurate with the English materials, and the pattern of errors was associated with the children's experience with in English. Also, across both languages,there were more errors made for words than nonwords (.06 and .04 respectively) but this difference was larger in English (.11 and .06) than in German (.02 and .01).

An analysis of variance carried out on these data, with Group as a between-subjects factor, and Language and Stimulus Type (words/nonwords) and within-subjects factors, confirmed these impressions, yielding significant main effects due to Group, $F(2, 57) = 16.6$, $p < .001$, Language, $F(1, 57) = 193.87$, $p < .001$, and Stimulus Type, $F(1, 57) = 11.88$, $p < .001$,and the Group × Language, $F(2, 57) = 24.30$, $p < .001$, and Language × Stimulus Type, $F(1, 57) = 7.08$, $p < .01$, interactions. Subsequent Newman-Keuls tests demonstrated that the groups did not differ with the German materials, but that with the English items, the 16-1 children differed significantly from the subjects in each of the two other groups. The Group × Stimulus Type interaction, $F(2, 57) = .08$, $p > .05$, and the three-way interaction, $F(2, 57) = .14$, $p > .05$, were not significant.

Lexical Decision Tasks: Corrected Response Times

In the analysis of the lexical decision performance, the average reaction time was computed for each child over the 69 words and the 69 nonwords in both German and English. Following this, outlier values that fell beyond (plus and minus) three standard deviations of each individual mean in each language were removed. Median response times for words and nonwords in German and in English were then calculated for each subject and corrected for response speed by subtracting his or her median reaction time on the symbol matching task. Our initial inclination was to use response time from the symbol matching task as a covariate for the lexical decision reaction times. However, the analysis of covariance requires that the regression lines between the covariate and dependent measure be parallel between groups, and this assumption was not met in the data. Consequently, we reverted to using the difference score method of analysis which is the suggested alternative to analysis of covariance (Kirk, 1982). Nonetheless, a similar pattern of results is obtained if the analysis of covariance procedure is employed or if the analysis is conducted on the uncorrected reaction times. The resulting means of the difference scores are also displayed in Table 1, in which the corrected response times are indicated separately for German and English words and nonwords, as a function of number of years of instruction in English.

Inspection of Table 1 indicates that response times were faster for words (313 ms) than for nonwords (726 ms). Also, as would be expected on the basis of the children's general familiarity with the two languages, decisions were faster with the German materials than with the English items (363 and 676 ms., respectively). In addition, the difference between reaction times for words and nonwords was greater for English (difference of 490 ms) than for German (335 ms). Most importantly, the three groups of subjects differed and the pattern of differences varied markedly across the two languages. Thus, the children's response times with the English stimuli varied as a function of experience with English, such that 16-5 group responded the quickest, the 14-3 group was in the middle, and the

TABLE 1
MEAN DIFFERENCE SCORES AND MEAN ERRORS (STANDARD DEVIATIONS) FOR GERMAN AND ENGLISH WORDS AND NONWORDS BY GROUP

	German		English	
Group	Word	Nonword	Word	Nonword
		Errors (%)		
16-5	.02	.01	.09	.04
	(.012)	(.015)	(.064)	(.043)
14-3	.02	.01	.07	.04
	(.018)	(.014)	(.036)	(.026)
16-1	.01	.01	.15	.11
	(.021)	(.011)	(.058)	(.119)
		Difference scores (ms)		
16-5	132	474	336	771
	(307)	(457)	(368)	(635)
14-3	319	660	377	746
	(272)	(409)	(201)	(501)
16-1	132	458	579	1245
	(143)	(408)	(451)	(1115)

16-1 group was the slowest. However, with the German stimuli, performance varied as a function of age, with the 16-5 and the 16-1 groups responding faster than the 14-3 group.

To examine these patterns, an analysis of variance was carried out on the difference scores, with Group as a between-subjects factor and Language and Stimulus Type (word/nonword) as within-subjects factors. This analysis resulted in significant effects due to Stimulus Type, $F(1, 57) = 71.97$, $p < .001$, and Language, $F(1, 57) = 16.05$, $p < .001$. In addition, the Stimulus Type × Language, $F(1, 57) = 4.96$, $p < .05$, and the Group × Language, $F(2, 57) = 4.20$, $p < .05$, interactions were also significant. Subsequent Scheffé tests demonstrated that with the German stimuli, both of the 16-year-old groups were significantly faster than the 14-year-old group (differences between means > 165 ms. were significant,$p < .05$). Also, with the English stimuli,the Scheffé tests indicated that the 16-1 group was significantly slower than the other two groups ($p < .05$), and the 14-3 and 16-5 groups did not significantly differ from each other ($p > .05$).

DISCUSSION

The results of this study are consistent with the view that age exerts a weak constraint on children's speed of processing in a lexical decision task. When age and experience were naturally confounded in the lexical decision task with German words, typical age-related differences in performance were found. Both of the 16-year-olds groups were significantly faster than the 14-year-old subjects. Thus, even with this relatively "old" sample of subjects, we replicated previous research findings showing age related differences in processing speed (Chi, 1977; Kail, 1986; Whitney, 1986). Moreover, when age and experience were unconfounded in the lexical decision task in English, experience had a stronger impact on performance than age. When English words were presented, we observed a relationship between reaction time and experience. Thus, the 16-year-olds with only 1 year of experience had the slowest reaction times, the 16-year-olds and 14-year-olds with 5 and 3 years of experience, respectively, had faster reaction times. Experience clearly seems to play an important role in determining the time required to make a lexical decision.

A possible alternative interpretation of these results were that our two 16-year-old groups were not really equivalent. Because we were not able to randomly assign subjects to groups, it is possible that the students who elected to one or more other languages prior to studying English are slower processors of linguistic information. Consequently, the difference we observed between the 16-5 and 16-1 groups were due to subject characteristics and not experience. There are two points that argue against this interpretation. First, the decision as to which course of language study to participate in occurred prior to fifth grade and, given the educational system in Germany, there does not appear to be any bias as to the type of child that enters either of the programs. Second, the two groups were not significantly different in their reaction times in their native language. If the two groups varied in terms of student characteristics, it would be expected that this difference would be observed in the German reaction times.

In addition to providing information concerning the role of experience in lexical access, the obtained data also have implications for debates concerning whether the two languages are represented separately or in an interrelated fashion. In particular, the performance of the 16-year-olds on the lexical decision task with German words permits the observation of whether increased proficiency in the second language interferes with performance in the first language. The results of this study showed clearly that there were no interference effects. Indeed, the mean reaction time with the German materials for subjects who had 5 years of experience in English was almost exactly the same as that of their peers who had only 1 year of instruction in English.

In general, the present paradigm appears to be an effective vehicle for unconfounding the typical age-experience relation. Although it would be worthwhile to extend this work with different combinations of first and second languages, our findings are clearly relevant for considerations of age-related changes in information processing and for discussions of lexical access in individuals who are developing bilingual competency.

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