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Time and language – critical remarks on diagnosis and training methods of temporal-order judgment

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Review

Abstract. A lively discussion concerning the causal relation between auditory temporal processing and phoneme identification has evolved over the last decades. Subjects with language impairments not only show deficits in the identification of stop-consonant vowel syllables, but also have problems detecting the temporal order of acoustic stimuli. Recently published studies claim that an improvement in phoneme discrimination can be achieved through the training of temporal-processing abilities. Critical assessment of these studies often reveals the following weaknesses: first, the diagnostic and training methods vary between studies, which makes comparisons difficult. Second, usually only mean differences between groups or before/after treatment are presented. The success in diagnosis and training of individuals or subgroups is not documented. Third, only few diagnostic measures employed have been tested for reliability. Furthermore, the tests have not been designed according to modern psychometric methods. Fourth, several training modules are used in parallel. The effects of temporal-processing training cannot be isolated. Possible approaches for detecting the possible causal relation between the time and the language domain are discussed.

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TEMPORAL PROCESSING AND PHONEME IDENTIFICATION

Over the last decades studies have shown that children with specific language-learning impairments, children and adults with dyslexia, and patients with brain injuries in the left cerebral hemisphere with aphasic syndromes have difficulties identifying the correct order of rapidly presented, non-verbal stimuli (Farmer and Klein 1995, Steinbüchel et al. 1999, Swisher and Hirsh 1972, Tallal and Piercy 1973). This association of disturbed temporal-processing abilities and impaired language competence is being discussed on the phonemic level. The ability to discriminate certain stop-consonant-vowel syllables is theoretically based on the temporal analysis of rapidly occurring components in the speech signal (Bishop 1997, Fitch et al. 1997, Steinbüchel et al. 1996, Summerfield 1982). Elements in speech sounds, such as formant transitions (short sound waveforms that change frequency across a time interval of ca. 40 ms in consonant-vowel syllables, such as /pa/, /ta/ and /ka/, or /ba/ and /da/), or the voice-onset time (the time between the burst and the onset of laryngeal pulsing that determines voiced and unvoiced consonants, such as /da/ and /ta/ or /ga/ and /ka/), form temporal cues that have to be adequately processed if the consonants in speech are to be perceived accurately. Subjects with language impairments – children with language-development disorders or patients suffering from aphasia following brain injury – can have problems discriminating stop-consonants and often show increased temporal-order thresholds. This has led to the hypothesis of a general temporal-processing deficit in the auditory system. It is assumed that this deficit is an underlying cause of language impairment on the phonemic level (Steinbüchel and Pöppel 1993). In principle, it seems promising to assess basic temporal-processing mechanisms in the brain as underlying constraints in cognition. Such an approach would not only augment our understanding of cognitive functioning, but would also lead to new therapeutic tools in clinical neuropsychology (Wittmann 1999).

Diagnostic findings of an association between language and the auditory temporal domain have been collected over the last 40 years. Up to a few years ago researchers were still puzzled about how to apply this knowledge from basic research to strategies for clinical interventions (Wolff 1993). Only recently training procedures in temporal processing have been developed to improve the ability of temporal resolution for acoustic stimuli in subjects with language impairments. Studies have been published showing an improvement in phoneme identification by lowering temporal-order thresholds through feedback training in children with language-learning impairments (Merzenich et al. 1996) and in patients with brain injuries and aphasia (Steinbüchel 1995). In these computer-based training procedures, the temporal order of two successively-presented stimuli has to be identified at decreasing inter-stimulus intervals. The inter-stimulus interval is lowered when the sequence of stimuli can reliably be identified. In this way thresholds for the detection of temporal order can be significantly decreased. Considering the difficulties in perceiving rapidly-occurring elements in the speech signal, other software modules designed especially for children with language-learning impairments train syllable discrimination by manipulating the saliency of the acoustic waveform of speech. The formant transitions are modified by varying the duration and the amplitude of the signal. With extended and enhanced formant transitions, children seem to be able to identify syllables more easily (Rey et al. 2002, Tallal and Piercy 1975, for an electrophysiological study see Bradlow et al. 1999). The aim of the training is to gradually decrease the duration and the amplitude to values of regularly-spoken language (Habib et al. 2002, Tallal et al. 1996).

There are indications that temporal-processing deficits already can be detected in early infancy and are predictive of later language outcome (Benasich et al. 2002). In a prospective longitudinal study, children between 6 and 9 months of age with a family history of specific language impairment were less accurate in temporal discrimination of successive complex tones than control children. In a conditioned head-turn procedure, children had to discriminate which came first, the high or the low tone, presented at fundamental frequencies of 300 Hz and 100 Hz, respectively (for an accurate description of methodology, see Benasich 2002). At age 3, temporal-processing skills predicted a substantial amount of variance of comprehension in standardized language tests. Valid diagnostic tools would certainly help to identify children with a high risk for language disorder at an early stage. Moreover, an intervention with an adequate training method could start at early stages of language development. To sum up, diagnostic tools and training devices that detect temporal-processing deficits and – more importantly – improve performance could play an important role as complementary methods in language therapy for specific language-development disorders in children and in patients with neurological injuries and aphasia.

POSSIBLE CONCEPTUAL AND METHODOLOGICAL FLAWS

Theoretical criticism

In the reports of diagnosed temporal-processing deficits in language-impaired subjects and of the claimed success of training devices, conflicting positions about the validity of the theoretical concept, as well as contrasting empirical findings, can be found in the literature. Theoretical criticism of the approach concentrates on two main points (e.g., Mody et al. 1997, Rosen 1999, Studdert-Kennedy and Mody 1995).

First, the repeatedly reported correlations between non-verbal temporal tasks and language skills could depend on a general cognitive capacity, such as intelligence, attention or other common factors and need not imply a causal relationship. There are indications that intelligence correlates slightly with children's performance in a temporal-order task (Landauer 1998) and that order-threshold differences between children with dyslexia and controls fail to reach significance when the covariate intelligence is controlled for (Berwanger, unpublished results). Most studies that report temporal-processing differences between dyslexic subjects and controls just show that mean intelligence scores do not differ between the groups (e.g., Laasonen et al. 2002), or cognitive skills are even not controlled for (Nittrouer 1999, Reed 1989, Rey et al. 2002). More subtle analyses of possible cognitive factors that could influence both temporal processing and language skills, should, therefore, be applied.

Second, the difficulty in differentiating stop-consonant vowel syllables may be caused by an inability to identify similar short stimuli and not by problems in detecting the temporal order of spectral features. Accordingly, language-impaired subjects confuse stop consonants because of their spectral similarity as speech stimuli and not because of an underlying general auditory deficit in perception of rapidly-changing acoustic events. Brevity of similar speech stimuli – and not the transitional character of acoustic features in consonants – is seen as the critical variable causing problems for language-impaired subjects (Studdert-Kennedy and Mody 1995).

Variations in methodologies

Reading the literature on the debate, it is remarkable that there is no common method that is being applied for diagnosing temporal-processing abilities. Based on findings showing that patients with brain injuries in the left cerebral hemisphere and aphasia are impaired in the perception of temporal order, i.e., they perform with increased order thresholds in the auditory and visual domain (Efron 1963, Swisher and Hirsh 1972), the hypothesis of a central temporal-processing mechanism located in the left cortical hemisphere that is also involved in phoneme discrimination has been proposed (Pöppel 1997). Complementary to the findings in patients with aphasia, adults with dyslexia seem to be impaired in cross-modal (audiotactile, visuotactile, audiovisual) temporal-order detection (Laasonen et al. 2002). To sum up, methods for the detection of a general temporal-processing deficit (independent of sensory modality) have been applied that showed differences between language-impaired groups and controls.

In an elaborate review, however, Farmer and Klein (1995) came to the conclusion that there is evidence of an auditory-processing deficit in dyslexia, but identified conflicting evidence of such a deficit in the visual domain. Regarding the deficits in phoneme discrimination in language-impaired subjects, the hypothesis of an auditory-processing deficit has been formulated. Therefore, researchers have mainly focused on temporal processing of the auditory system. In addition to the hypothesis of a auditory deficit in temporal-order identification a more broadened interpretation of auditory temporal-processing impairments exists that includes auditory backward-masking effects as a cause of phoneme discrimination disabilities in children with specific language impairments (Wright et al. 1997, for further non-linguistic auditory tasks associated with language disorders see Wright et al. 2000).

In the last few years, temporal processing in the sense of perception of sequential sounds has been used in temporal-order judgment tasks using nonverbal stimuli and employing verbal stimuli.

TEMPORAL ORDER OF NONVERBAL STIMULI

Two stimulation modes can be applied for the presentation of two consecutively-presented sounds. In an intra-hemispheric condition, a sound is presented to both ears followed by a second, different sound with a certain inter-stimulus interval. The task of the subject is to recognize the temporal order of the two sounds that differ in their physical properties, like frequencies. In a different intra-hemispheric condition, the temporal onset of two longer sounds that temporally overlap to a great extent has to be indicated. In an inter-hemispheric condition, one sound is presented to the left ear, and a second sound is presented to the right ear. Usually the two stimuli have identical physical properties (e.g., click sounds). Here, the subject has to tell whether the click in the left or in the right ear came first. In adults, order-thresholds for these different stimulation conditions converge roughly to values between 20 and 60 ms (Hirsh 1959, Kanabus et al. 2002, Lotze et al. 1999, Mills and Rollman 1980). In the intra-hemispheric condition with two tones that overlap for a considerable duration, the threshold for the correct detection of the temporal onset lies in this time range (Pastore and Farrington 1996). This perceptual threshold of around 30 ms has been discussed as the acoustic basis for the voicing boundary defined by the voice-onset time (VOT) in stop consonants of approximately the same time range (Steinbüchel et al. 1999). Voiced consonant vowels, like /da/ and /ga/ have a VOT of less than 30 ms. The respective unvoiced consonant vowels /ta/ and /ka/ have a VOT of longer than 30 ms. Specific temporal-response properties of the auditory cortex reflecting the phonetic parameters seem to serve as neural cues for the perception of voicing contrasts (Simos et al. 1998, Steinschneider et al. 1995). This could reflect the neuronal link between auditory temporal processing and specific phoneme processing.

In the diagnosis of temporal-processing disorders, the employed methods are characterized by different stimulus durations. In the inter-hemispheric condition, patients with aphasia (Steinbüchel et al. 1999) and children with language disorders (Barth et al. 2000) were diagnosed with a system using clicks of 1 ms duration (Mates et al. 2001). In the condition most frequently used for children with language-learning impairments, the intra-hemispheric condition, tones (sinusoids or with broad–band spectrum) have a duration of 75 ms (Nittrouer 1999, Tallal and Piercy 1973). Besides the fundamental differences in stimulus presentation (intra- vs. inter-hemispheric) and stimulus quality (clicks vs. tones), the temporal characteristics of the two task conditions are quite disparate. With a stimulus duration of 1 ms in the inter-hemispheric condition, an inter-stimulus interval (ISI) (the interval from the offset of the first click to the onset of the second click), of e.g., 30 ms means a stimulus-onset asynchrony (SOA) of 31 ms (the interval from onset of the first click to the onset of the next click). With a stimulus duration of 75 ms in the intra-hemispheric condition, however, an ISI of 30 ms would mean a SOA of 105 ms.

With respect to the aforementioned order threshold of 20 to 40 ms, reported SOA thresholds of ca. 85 ms for two consecutively presented stimuli with durations of 75 ms in normal children are quite high (Merzenich et al. 1996). Children may require longer intervals for temporal-order judgment in the cited intra-hemispheric task than adults, who perform with SOAs of 20 to 40 ms in different intra-hemispheric conditions (Kanabus et al. 2002, Pastore and Farrington 1996). This is the case in the inter-hemispheric condition, where normal children perform with higher order-thresholds than adults. The threshold values steadily decrease from the age of 5 (with thresholds around 100 ms) to the age of 11, when thresholds are comparable to those of adults (Berwanger et al. 2003).

TEMPORAL ORDER OF VERBAL STIMULI

Basically, the idea of measuring temporal-order judgment employing verbal stimuli follows the same rationale as the intra-hemispheric stimulation method with non-verbal stimuli. Two different syllables are presented in succession, and the subject has to indicate the temporal order. Typically, two consonant-vowel syllables, like /ba/ and /da/ (critical in the time domain), and two steady-state vowels, like /ε/ and /æ/ (not critical in the time domain), all with a duration of 250 ms, are presented to the subject. Detection of temporal orer in language-impaired subjects is disturbed for two consonant-vowel syllables, but not for two steady-state vowels (Reed 1989, Tallal and Newcombe 1978, Tallal and Piercy 1974). From these results and the findings of deficits in temporal-ordering of non-speech material, the authors conclude that impaired temporal-processing mechanisms are the cause for the problems in adequately processing consonant-vowel syllables. The "conceptual muddle" in the interpretation of these results as criticized by Studdert-Kennedy and Mody (1995) comes into play as Tallal and co-workers explain their findings as related to the brief duration of formant transitions (Tallal and Piercy 1974), mechanisms involved in auditory masking (Tallal and Stark 1980) and difficulties in processing rapidly-changing sensory input (Tallal et al. 1996).

Regarding the temporal-order judgment of stimuli with durations of 250 ms and with ISIs ranging between 8 and 305 ms, the SOAs presented to the subjects vary between 258 and 555 ms. This time range differs greatly from the discussed temporal-order threshold (or difference limen of the stimulus-onset asynchrony) of around 30 ms (Pastore and Farrington 1996, Pöppel 1997), even when one takes into account that children might have higher thresholds. This leads to another serious problem in the understanding of the results: If children in general have less temporal acuity in the auditory processing of non-speech sounds than adults, how can they detect the temporal characteristics of the formant transitions and the voice-onset time? As normal children have no problem in discriminating stop consonants, how does the framework of the auditory-processing hypothesis explain their elevated order thresholds? This actually is a serious – but seldom – addressed question that could refute the temporal-processing hypothesis.

In any case, children with language-learning impairments have no problems detecting the temporal order of non-verbal sounds with 250 ms duration (Tallal and Piercy 1973). The problems are detected with stimulus durations of 75 ms. However, if the detection of temporal order of 250 ms stimuli is generally not impaired, one cannot speak of a valid temporal-order task in the sequencing of consonant vowels with 250-ms duration to assess possible group differences, as has been done by several authors following Tallal's work (Mody et al. 1997, Reed 1989). Then the problem in detecting the order of consonant vowels is not a problem of temporal ordering, but must lie somewhere else, e.g., in the abilities to discriminate phonemes. If a subject cannot discriminate easily between two consonants, then he or she naturally also cannot tell the temporal order of the two. Interestingly, children have to be trained extensively in the identification of the individual syllable prior to the temporal-judgment task. This may indicate that the results of this type of temporal-order task are based on an identification problem. The temporal-processing hypothesis is related to phoneme identification or to phoneme discrimination between contrasting consonant vowels, and not to temporal-order identification of two consecutively presented consonant-vowel syllables. Application of this second method of temporal-order judgment of verbal stimuli does not increase our knowledge of temporal-processing mechanisms in language comprehension.

Group statistics

Empirically, contrasting results support or refute the hypothesis of a temporal-processing deficit, either showing group differences between subjects with language impairments and controls or showing that the two groups do not differ. For example, Nittrouer (1999) tested 110 children aged 8 to 10 years from a regular school. 17 children were rated as subjects with poor reading scores and compared to 93 children rated as normal readers. In the crucial temporal-order task (with sinusoidal tones of 75-ms duration), the poor readers did not differ statistically from the normal readers. In Reed's (1989) study with a temporal-order judgment task (with tones comprising complex waveforms of 75-ms duration), 23 children with reading disabilities differed significantly from age- and sex-matched controls (Reed 1989), corroborating the findings of Tallal's work testing 9 children with language-learning impairments and 12 controls (Tallal and Piercy 1973).

In the above-cited (and most other) studies, only mean values between groups have been reported and statistically analyzed. In most articles, no information is presented on how many of the children actually were diagnosed with a temporal-processing deficit, and at the same time, had problems in phoneme discrimination. As can be assumed for any heterogeneous group of subjects with a certain diagnosis, subgroups can be defined with special characteristics. Regarding developmental dyslexics, not every subject will be diagnosed with an impairment in temporal-order judgment (for a thorough discussion of this topic, see Farmer and Klein 1995). The group mean will reach the significance level depending on the size of the subgroup of dyslexic subjects with temporal-processing deficits. In Nittrouer's (1999) study, which detected no group differences between reading-impaired subjects and controls, the number of errors in temporal ordering was descriptively higher for children with poor reading abilities than for controls. The P value of 0.052 for overall group differences was very nearly significant; other important significance levels were not reported. Depending on the selection criteria (inclusion/exclusion criteria) and chance, the number of children with temporal-processing impairments – the special subgroup – will vary from study to study, leading to contradictory results. Accordingly, future studies should identify the possible subgroup of children that actually has temporal-processing deficits and avoid the sole presentation of mean values. It will be a challenge to find out the approximate number of children that really have a deficit in temporal processing. Bishop et al. (1999) concluded in their study, in which they thoroughly controlled for the reliability and magnitude of temporal-processing deficits in a sample of language-impaired subjects, that – if at all – only a small number of children might have an auditory deficit leading to language problems.

A further effect of subgroup characteristics is often neglected, but is still relevant when collecting normative data. Gender differences in performance have been described for a number of sensorimotor tasks, including temporal-order judgment. In a group of healthy adults, as well as in brain-damaged subjects with left- or right-hemispheric injuries (with and without aphasia) men consistently performed with significantly lower order thresholds than women (Wittmann and Szelag 2003).

Reliability of measure

It is an established fact in experimental testing, that different methods of measurement of a psychometric function lead to different thresholds. Modern adaptive procedures are often employed in psychometric testing in which stimulus values (e.g., inter-stimulus intervals) are selected during a session on the basis of the subject's responses in previous trials. Many parameters of a psychometric function have to be considered, such as the threshold, the slope, the guessing, and the lapsing rate (Strasburger 2001). These new adaptive methods have been developed to increase the efficiency and reliability of the measurement (Leek 2001). The slope of the function, for example, provides information about the reliability of the threshold estimate. These algorithms, however, have hardly entered the field of clinical neuropsychology. In most assessments of temporal processing the method of constant stimulation with pre-defined inter-stimulus intervals is employed. In such cases even a threshold value can be taken as a measure of performance. Only the overall number of errors is considered for further evaluation.

Especially in children with language-learning impairments and in patients with brain injuries and aphasia, measures of efficiency and reliability would form important criteria for assessing a possible causal relationship with language processing ruling out other interfering factors, such as sustained attention and alertness. Unfortunately, "modern" assessment techniques are rarely incorporated in the diagnoses of the discussed functions (for an exception, see Cacace et al. 2000). Moreover, the question of the reliability of the methods employed is not addressed. Stable values as measured in re-test reliability studies should be investigated for every method used. For example, a sufficient re-test reliability in normal children was only achieved for children aged 10 years or above with the inter-hemispheric stimulation method. Correlations of children aged 5 to 7 years were only weak. Children between 8 and 9 years of age performed with moderate correlations (Berwanger et al. 2003). To avoid false positive and false negative decisions when selecting subjects assumed to have temporal-processing impairments, reliable measures have to be employed – especially when individuals are to be identified for training.

The discussion of the reliability of measurement could solve the aforementioned serious problem of the discrepancy in the performance of normal children who generally seem to perform with less temporal acuity in temporal-order tasks, but have no difficulties discriminating stop consonants. An argument in favor of the temporal-processing hypothesis would be that the children, in principal, could perform with the same thresholds as adults, but need more test sessions before they reach the same performance level. Children demonstrate mean lower thresholds in a second measurement session (Berwanger et al. 2004). They might need longer to adapt to the rather artificial situation of repeatedly telling the temporal order of sounds. Some children may need more test sessions to be able to focus their attention on the relevant cues for an adequate response.

Training effects

The development of training devices for auditory processing has mainly focused on children with language-learning impairments. The success of the clinical intervention program "Fast ForWord" designed by Tallal and colleagues has unquestionably been documented (http://www.scientificlearning.com). Their impressive success, however, cannot be interpreted easily. A whole battery of training devices is administered to improve children's phonological skills. Training with extended durations in the speech signal, with amplifications of the transitional elements, and of temporal-order judgment are components of the software-based intervention (Merzenich et al. 1996, Tallal et al. 1996). In similar studies, only training with extended and amplified components of the critical speech signal led to improvements in a number of phonological tasks (Habib et al. 2002). In a clinical setting, all training devices that may improve language function must, of course, be combined to receive an optimal training outcome. More scientifically-based studies that carefully control for the size of training effects of separate training modules should still be undertaken. If one strictly followed the temporal-processing hypothesis, only non-verbal stimuli would be used to test group differences in diagnostic settings and for training effects. Only through sophisticated argumentation can one interpret the effects of training with modified speech as consistent with the general auditory-processing hypothesis. In the training with modified speech, children with phonological-processing difficulties were extensively exposed to verbal stimuli. A purely non-linguistically oriented training in temporal-order judgment of click pairs led to an improvement in phoneme discrimination in the only one training study with aphasic patients (Steinbüchel 1995). Not a single study has yet shown that a purely non-verbal auditory training device can improve phoneme-discrimination abilities in children with specific language impairments.

CONCLUSIONS

Regarding diagnostic and training tools of temporal-processing skills, there still exist a big gap between the results of neuropsychological research in university-based labs and the employment of these methods in schools, speech therapeutic practices or rehabilitation clinics, despite the efforts of companies marketing hardware or software systems. In this article we stressed some selected critical points that deserve further consideration.

First, valid and reliable methods for the measurement of temporal-order judgment have to be developed. Question has to be solved concerning intra- or inter-hemispheric stimulation, stimulus duration, and employment of non-verbal or verbal stimuli. Most studies are concerned with the question of finding valid instruments that predict phonological competence. Hardly any reliability studies can be found that show how stable values are over two or more sessions.

Second, more emphasis has to be placed on subgroups and individual cases. Most studies report only mean values between groups. After diagnosing a subject with language impairments with valid and reliable methods of temporal-order judgment, standardized criteria have to be applied to decide whether an individual has a temporal-processing deficit that should be trained with valid devices or not.

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