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Time reproduction of structured auditory events by deaf and hearing subjects.

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ABSTRACT

Congenital deafness affects different aspects of information processing and time perception. In deafness the accuracy of duration judgments seems to be linked to differences in the use of conventional time units, applied strategy as well as cognitive processes such as attention or working memory (Kowalska & Szelag, 2006). The present experiment investigated the effect of different event structures on duration reproduction in deaf and normal hearing subjects. The accuracy and variability of performances were calculated respectively by means of the absolute error score and coefficient of variation of time reproductions. Results showed a global underestimation of durations for all subjects; moreover all subjects performed more accurate reproductions for regular than for irregular patterns. No differences in reproduction accuracy between deaf and normal hearing subjects were found, even if reproductions in the deaf subjects showed a greater variability. Accuracy of time reproductions was improved when subject used a single strategy rather than more. Results confirm previous findings about the underestimation of time for deaf and normally hearing subjects, while a more predictable temporal structure of patterns seems to improve accuracy of time reproductions. Deafness affects time reproductions, even if, by means of the interdependence of sensorial systems (see Tharpe, Ashmead, & Rothpletz, 2002) auditory deficits seem to be compensated by other systems. A different strategy seems to be used by normal and deaf subjects probably due to differences in attention deployment and entrainment.

INTRODUCTION

Different models and experimental researches tried to determine the factors influencing time evaluation. Research shows that we can synchronize ourselves to environmental changes by means of implicit (automatic) or explicit (controlled) time-monitoring mechanisms (Michon, 1990). Models highlight the role of an internal clock (Treisman, 1963) or timer (Berlyne, 1966), and predict a positive linear relationship between the degree of attention devoted to time and the accuracy of time judgment (Thomas and Weaver, 1975). Other models are derived from the hypothesis proposed by Ornstein (1969) and consider memory coding as the main determinant of accuracy in time evaluation. Zakay (1990) explained these two approaches in the frame of a more general distinction between retrospective time evaluation (performed by retrieving information from memory in order to reconstruct the time interval) and prospective time evaluation (obtained by directing attention towards relevant temporal information and by processing it in real time). This distinction suggests that the two approaches should pertain to two different situations in everyday life. Previous studies confirmed that estimations are longer and less accurate under retrospective conditions (Bueno, 1994). Many factors should be considered in order to draw a comprehensive model of psychological time, and two main research areas focus on the role of top-down and bottom-up processes. The first research area indicates the constitutional factors that seem to have an influence on time evaluation. These studies highlight the following factors which appear to have an influence on time evaluation: stress and arousal (Delay & Mathey, 1985; Zelkind, 1973; Falk & Bindra, 1954); age (Green, 1975; Tuckman, 1965; Wallach & Green, 1961); personality (Melges, 1982; Orme, 1969); psychiatric disorders (Melges, 1989; Stein, 1977); effects of drugs on consciousness (Fischer, 1966; Frankenhauser, 1959; Goldstone, Broadman, & Lhamon, 1958); hypnosis (Cooper & Erickson, 1959; Zimbardo, Marshall, White, & Maslach, 1973); meditation (Deikman,1963) and sensorial deprivation (Banks & Cappon, 1962; Murphey, Hampton, & Myers, 1962; Reed & Kenna, 1964).

The second research area examines the temporal coding mechanism and the characteristic of the events, underlying: the role of sensorial modality (Glenberg & Swanson, 1986; Goldstone & Goldfarb, 1964); the stimulus familiarity (Avant & Lyman, 1975; Devane, 1974); the structural coherence of events (Boltz, 1989, 1991a; Jones & Boltz, 1989); the number of the interval's events (Ornstein, 1969; Schiffman & Bobko, 1974); the number of changes during the estimation (Block, 1974, 1978; Poynter & Homa, 1983); the time estimation task (Brown, 1985; Brown & West, 1990; Hicks, Miller, & Kinsbourne, 1976) and the context effects on time evaluation (Block, 1989). Sometimes results from these two research areas are conflicting, perhaps due to the differences in experiment settings; but nonetheless factors like attention, expectation, and temporal characteristics of events are always considered central for the comprehension of time estimation processes, that operate within specific time estimation limits (London, 2002).

The model of dynamic attention proposed by Jones (1987) could be considered in the middle position between these two research areas. According to Jones (1987) real world events are not organized arbitrarily, temporal and non-temporal cues of events continuously supply information about their temporal course, and the accuracy time judgment depends mainly on the perceived discrepancy between the actual and the expected duration of an event. By "event" we refer here to an object or activity in the environment, which unfolds for a period of time (e.g., a single note in a melody), and has an onset: the period between two successive onsets is defined "Inter Onset Interval" (IOI), and more events can be part of more complex temporal structure. During the perception of a temporal structure, we could percept the flow of some events as a "group" (e.g. by Gestalt rules), and for a more complex structure we could perceive the "rhythm". According to Fraisse (1984) the rhythm derives from the interplay between the "structure of successions", that depends on the tendency to gather elements that are closer in time (between 200ms and 2sec.), and the "structure of accents", that depends on changes in temporal and non-temporal characteristics. Top-down processes may often impose this structure of accents, by which stimuli can assume a regular form and be more predictable, but rhythmic organization emerges mainly from durations and accents that are driven by bottom-up processes. Temporal markers (accents) correspond to changes in non-temporal information and their importance depends on the number of simultaneous changes. Jones (1987) distinguishes between the "horizontal" and "vertical" component of the rhythmic organization. In the first case, the process is described as an "associative chain" (Lashley, 1951): every element of the sequence represents the triggering stimulus for the following element, and associative chunking produces the "grouping" of events. As for vertical component of the rhythmic organization Jones intends the hierarchical organization of events (Martin, 1972), in which elements at one level are nested in a group of element at a higher level, in such a way that the group defined at one level represents the term of reference for the elements of the inferior level. The distribution of markers defines the relationships among intervals at different levels, and internal time intervals of events may be hierarchically nested. The predictability of a duration increases when the structural coherence of events is high.

Natural events possess a high degree of structural coherence and tend to elicit an automatic mode of attending. But sometimes events require a controlled mode of attending and an active segmentation of the flow of stimulation, by means of counting and grouping strategies. The different levels of structural coherence of events produce different degrees of expectation on their time course, and time evaluations should therefore be affected by the confirmation/violation of such an expectation. Experimental results confirmed the role of temporal structure showing that an interval that ends before the expected time is underestimated, while in the case duration lasts longer than the expected end is overestimated, and this effect increases as the structural coherence increases as well. This hypothesis was verified by means of a retrospective paradigm, and according to Boltz (1995) the structural organization determines the way the events are codified and recovered from memory: for events with low structural coherence the processing of temporal information requires additional sources, separate and independent processing mechanisms. Boltz (1992) found that the duration of regular events is remembered better than the duration of irregular ones that tends to be overestimated; while Macar (1996) reports that casual sequences of stimuli were more underestimated than regular sequences. In summary, these studies show that structural coherence improves accuracy in time estimation, but one should consider both the factors that determine the structure of the events. Several models have been proposed in order to explain how hierarchical structure is processed and recognized: some models are based on the assumption that the processing of a temporal sequence happen in a sequential way (Parncutt, 1994), and the recognition takes place by testing on-line specific hypotheses about the basic time-unit and by reconstructing the higher levels of organization as soon as the structure of the lower level is identified. Other models explain the recognition of a temporal sequence by selecting the interpretation that better describes the temporal structure among all the possible ones (Povel and Essens, 1985). Finally, other models interpret the structure recognition as a synchronization process occurring in the interaction between the cognitive system and the environment (Mc Auley, 1994; Large and Kolen, 1994): an array of reciprocally connected oscillators may reproduce in real time the hierarchical organization of a sequence, without any explicit definition of segmentation rules, or identification of a basic time-unit (Large and Jones, 1999).

A previous study assessed prospective time evaluation accuracy for structured auditory events, with an event-counting task as a secondary task (Di Matteo, 2002): results confirm that event structure affects time reproduction, and reveal that while periodic cues globally enhance accuracy in time reproduction, serial structure only indirectly affects time reproduction. In the light of these findings, the aim of our experiment is to evaluate the effects of processing of the horizontal and vertical component that determine the structural coherence of a temporal structure.

Researchers often use visual or auditory stimuli in their experimental setting on temporal judgment: according to the modality-appropriateness hypothesis (Welch, 1999; Welch & Warren, 1980), perception gives precedence to the ''best'' sensory modality for the task at hand: vision for spatial judgments and audition for temporal judgments (Bertelson & Aschersleben, 1998; Kitagawa & Ichihara, 2002; Kitajima & Yamashita, 1999; Recanzone, 2003; Repp & Penel, 2002; Wada, Kitagawa, & Noguchi, 2003). A recent study shows that when the senses deliver conflicting information, the perceptual system automatically abstracts temporal structure from its visual form and represents this structure using an auditory code, resulting in the experience of ''hearing visual rhythms.'' (Guttman, Gilroy, Blake, 2005). Previous studies reports that the allocation of attention for visual stimuli is more prominent for deaf than hearing subjects, in order to orient themselves and receive signals (Harris, 1992; Swisher, 1993), and behavioral and neuro-imaging studies (ERP) confirm cortical evidences for visual specialization in deaf subjects (Neville & Lawson, 1987).

In the light of these remarks, the aim of our study is also to investigate time judgment by auditory and haptic modality with hearing and deaf people, in order to control the deficit impact on time reproductions.

EXPERIMENT

A. Methods

Subjects performed a dual task paradigm: the time reproduction of stimuli as the main task, and a counting task of sequence events.

1) Participants. Seventy-three subjects aged between 20 and 30 years participated at the experiment (mean= 24.75; s.d.= 3.89). The group was composed by 37 normally hearing people (18 men e 19 women, mean= 24.16, s.d. = 2.43), and 36 deaf subjects: 20 congenitally deaf (13 men and 7 women) and 16 hypoacusic deaf (9 men and 7 women). Participants' music education was assessed by means of a simple interview: no one of them had a music listening and/or playing experience that might give them an advantage in the performance. All deaf subjects knew the Italian Sign Language.

2) *Material.* Subjects reproduced the duration of 48 auditory equitone patterns, already used for a previous study (Di Matteo, 2002). Patterns differed in the periodic and serial temporal structure and have been constructed by composer Fabio Cifariello Ciardi according to Tonal and Non-Tonal composition (Nardo D., Londei A., Pantano P., Olivetti M., Lenzi G., 2004). Stimuli were used in previous studies (Di Matteo, 2002) but for our aim we have extracted the rhythmic structure from musical fragments, by removing completely the melody from notes, and using a "conga" timbre for each event (the sound was chosen in order to obtain a clear perception of single events, even when IOI was short, and each event duration was 120ms). Mean duration of patterns was 7.44s (from 6 to 8.5s, s.d. = 1.26s), and the mean number of events within each patterns was 22.25 (from 17 to 27 events, s.d. = 5.14). In periodic structures, the period between accents in non-adjacent events was constant for regular patterns and variable for irregular ones. Regarding serial structure, continuous or discontinuous patterns were composed following multiplicative or additive relationship between adjacent events. This segmentation criterion results in four-pattern type: regular (continuous / discontinuous), irregular (continuous / discontinuous), with 12 patterns for each category: two patterns for each category were used for the training session, and remaining 10 patterns for the trial session.

3) *Procedure.* After a training session consisting of eight practice trials, each subject completed four blocks of ten experimental trials: subjects were asked to reproduce the whole duration of patterns and count the number of events in each pattern. The patterns were presented in a random order across blocks, under the constraint that at least two stimuli of each type were included in each block. The computer monitored all stimuli and responses (using a MAX-MSP program) and a keyboard was used as a response console. All participants perceived the stimuli by ear and haptically too, by placing their hands on the speakers that produce vibrations every time a single event was played from the computer. The timbre of events was "conga" sound, so it was possible to distinguish between accented and non accented events also using only haptic perception, because the volume of accented events was 75% more than unaccented ones and this produced a more evident vibration. The instructions required participants to listen to an auditory pattern and then to reproduce its overall duration by pressing a button in order to mark the start and the end of an equal time interval, as with a stopwatch. Every pattern could be activated by pressing a button in the keyboard, and after 3 seconds the stimulus was played from the computer: this interval was necessary to allow people to move the hand to the box, in order to "feel" patterns haptically. The program did not accept reproductions lower than 1000ms (this was to avoid accidental "clicks"), and the temporal resolution of the computer timer that recorded time reproductions was 5ms. A visual cue (a 32x4 cm bar on the computer screen) controlled by the reproductions' start/stop action was inserted to give a visual representation of the time course of time reproductions: this bar was filled with a yellow colour at a constant speed from the left to the right side, the maximum time for filling the box was 20sec. Either participant and experimenter didn't receive any feedback of performances during the test. Strategies used by participants were assessed by means of a simple interview, and we ask also the time the counting task was assessed: subjects could count the events: a) during the listening of pattern or b) after the listening of pattern or c) both during than after the listening. The entire experimental session lasted around 50 minutes.

4) Design. The experimental design was a 2x2x3 mixed factorial design, with two "within subjects" factors and one "between groups" factor. The within subject factors were the periodic structure (regular vs. irregular) and the serial structure (continuous vs. discontinuous) of the auditory events. The between factor was the hearing condition of participant (normal hearing / hypoacusic deaf / congenitally deaf), stimuli were a random factor. Time estimates were assessed by means of reproduction and the reproduced duration represented the dependent variable.

B. Results

Analyses were carried out for time reproductions and number of events. Other analyses were made by grouping data according to the quantity of strategies for time evaluation (single/multiple) and at the time when the counting task was made, in order to know more about the influence of attention during time evaluation. Separated analyses of Variance were carried out on the effective durations and on the number events of the pattern with stimulus type as a within factor: results did not show significant differences among the four classes of stimuli, and the durations and the number of tones were not significantly related to each other ($r=0.301$, $p>0.05$). The average of the reproduced durations, the absolute error scores (AES= |estimates duration - effective duration|/effective duration) and the coefficients of variation (COF= standard deviation/mean of the reproduced durations) were computed for each subject and each class of stimuli. While the raw reproduced duration supply information about the general trend of the performance, the AES and the COF provide information about the overall accuracy and variability respectively. The errors will be positive for overestimation and negative for underestimation.

1) *Hearing condition*. ANOVAs carried out on the mean of reproductions, with items as random factor showed that all subjects systematically underestimated the effective duration of the patterns (mean error= -1160.72s; s.d.= 1501.69s, Test t = -6.60435, d.f. =72, $p<0.000000$) and the events number of the patterns (mean error= -3.53082; s.d.= 4.722410, Test t = -6.38813, d.f. =72, $p<0.000000$), independently from the pattern structure. The AESs and COFs were compared by means of a factorial ANOVA, with a) subjects' hearing condition (hearing/deaf), b) the strategy in time estimation (single / multiple) and c) the actual time when the counting task was made (during the listening / after the listening / both conditions) as between factors. The two within factors were the periodic and serial structure of stimuli. Result show no

accuracy differences in time reproductions by hearing and deaf subjects (F1, 61=0.43684, p<0.51114), but a main effect of hearing condition in reproduction's variability (F1, 61=15.141, p<0.00025). Other analysis on the hearing condition as between factor (hearing / hypoacusic deaf / congenital deaf) showed analogous results, with no differences in reproduction accuracy (F2, 70=0.38740, p<0.68027) but a main effect of variability of performances (F2, 70=7.6907, p<0.00096), and congenital deaf subjects' reproductions more variable than those of the hearing subjects (Post Hoc Tukey Test p<0.000699, Fig. 1). This effect is observed also in other analysis carried out on errors in the counting task (F2, 70=3.5752, p<0.03323, Post Hoc Tukey Test p<0.042115).

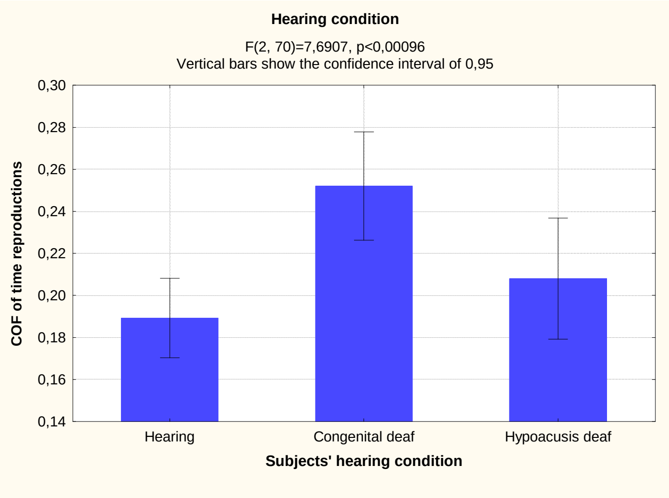

Figure 1. The bars show the degree of consistency in duration reproductions of structured events in hearing and deaf subjects. The coefficient of variation is obtained by calculating the standard deviation of the reproductions made by each participant for each class of events and by dividing this value for the corresponding mean.

2) *Estimation strategies and time when the counting task was made.* Factorial ANOVA on AESs e COFs of participant performances, with hearing conditions, estimation strategy, actual time when counting task was made as between factors, and patterns structure as within factor, showed a main effect of reproduction accuracy (F1, 61=8.1611, p<0.00584) and an interaction of hearing condition and estimation strategy (F1, 61=6.4844, p<0.01342, Fig. 2): reproductions of congenital deaf subjects were more variable those of hearing ones when used more strategies at the same time (Post Hoc Tukey Test, p<0.001911).

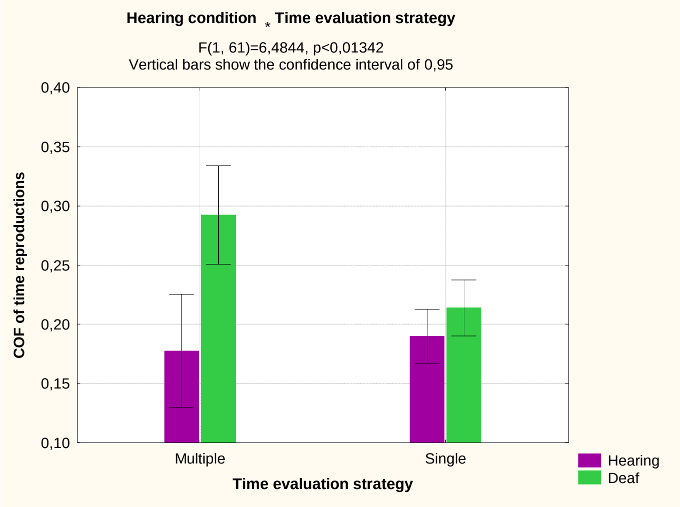

Figure 2. The bars show the degree of consistency in duration reproductions. Time reproductions by congenital deaf subject seem more variable when they used a multiple strategy.

Analysis showed a main effect the time when the counting task was made (F2, 61=7.1546, p<0.00162, Fig.3): when participants counted events at the same time they were listening to the pattern, the reproduction was less accurate than when they counted after having listened (Post Hoc Test Tukey p<0.011443) or in two phases (during and after listening to the pattern, Post Hoc Tukey Test p<0.032519).

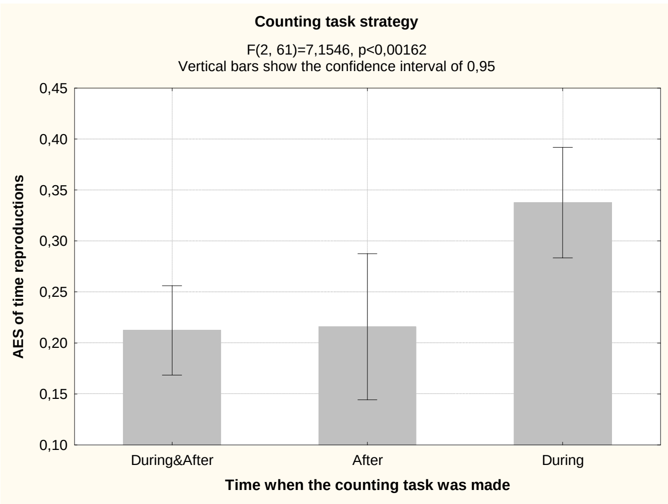

Figure 3. The bars show the absolute error score in time reproductions according to the time when the counting task was made by subjects.

COF factorial ANOVA on counting errors showed an interaction between the strategy of estimation and the time when counting task was made (F2, 61=3.9192, p<0.02504, Fig. 4): when the counting task is performed during listening, participant errors in events counting are less variable when they used a single strategy (Post Hoc Test Duncan, p<0.030754). When participant used a multiple strategy, the estimation was less variable if the counting task was performed twice (during and after the listening, Post Hoc Test Duncan, p<0.035390).

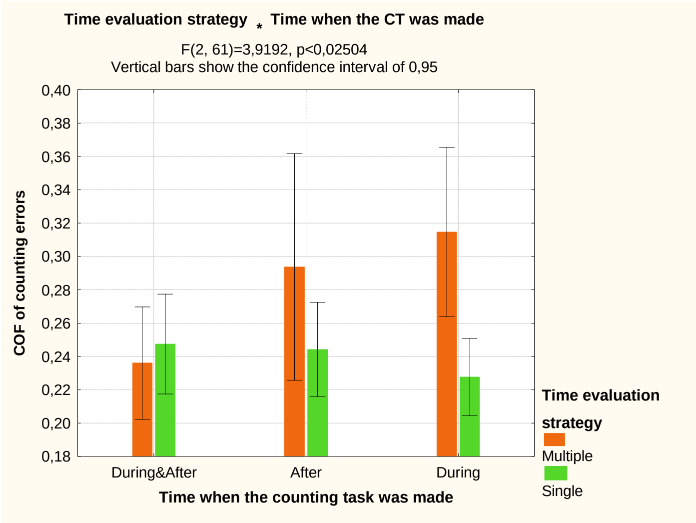

Figure 4. The degree of consistency in events counting errors: when people count twice (during and after the listening) the estimation are less variable.

3) *Pattern's temporal structure*. The factorial ANOVA performed on the reproductions AES revealed a main effect of the periodic structure (F1, 61=12.785, p<0.00069), showing that the accuracy of reproduction for regular patterns was better than for irregular ones (Fig. 5).

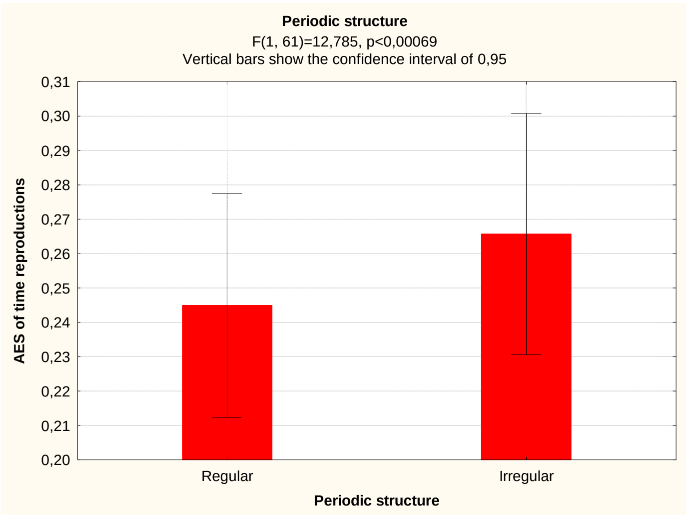

Figure 5. The bars show the absolute error score in judging the duration of the structured events according to their periodic structure.

The factorial ANOVA performed on the counting AES revealed a main effect of the serial structure (F1, 61=22.104, p<0.00002): results show that discontinuous patterns are reproduced more accurately with respect to continuous patterns (Fig. 6).

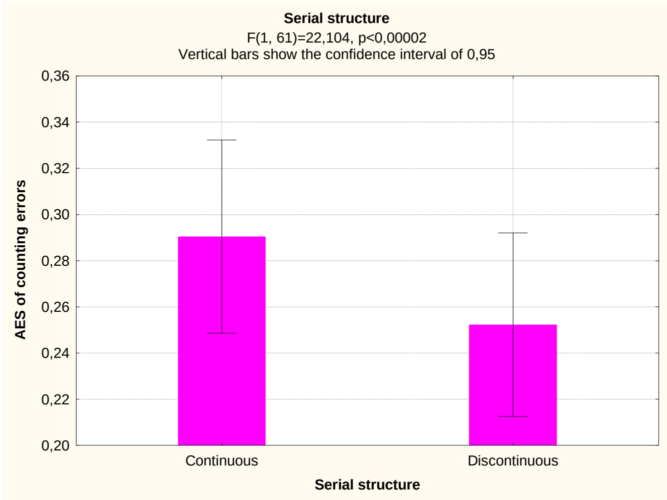

Figure 6. The panel summarizes the effects of serial structure of the auditory event on counting task accuracy.

The analysis revealed a significant interaction between periodic and serial structure (F1, 61=6.8892, p<0.01094, Fig. 7): participant estimations for continuous serial structure are more accurate when the periodic structure is regular than irregular (Post Hoc Test Tukey, p<0.00072), but estimations for irregular discontinuous patterns are more accurate than those of irregular continuous ones (Post Hoc Test Tukey, p<0.009095), and irregular discontinuous more accurate than irregular continuous (Post Hoc Test Tukey, p<0.000155).

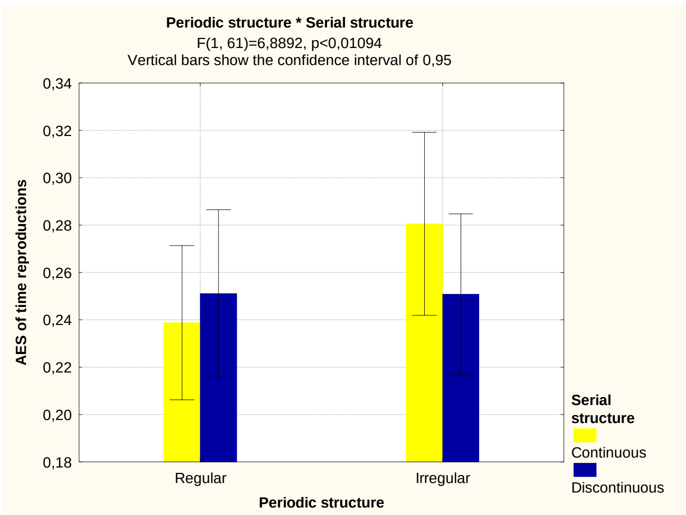

Figure 7. The bars show the accuracy in judging the duration of the structured events according to their periodic and serial structure.

DISCUSSION

Periodic and serial cues of stimuli globally affect time reproduction and estimation of pattern events. A general underestimation was observed in normal hearing and deaf subjects' reproduction. This effect confirm a previous study (Di Matteo, 2002) where under a prospective paradigm time estimations were carried out by evaluating time-intervals in real time.

Regarding the effect connected to the hearing condition of participant, in previous studies the region of accurate estimation was found significantly limited in deaf people, deaf subjects showed a time underestimation with visual stimuli (Kowalska e Szelag, 2004, 2006): in their experiment stimuli duration (around 6s) is similar to pattern duration of our experiment (mean = 7.44s). Our study seems to confirm the hypothesis that deafness is responsible for differences in time estimation and counting variability: the degree of consistency across subject in judging the duration of the structure events seems more variable in deaf subjects, but there is not significant effect in the accuracy of time reproductions between hearing and deaf subjects. This evidence seems to contradict the finding that time estimation should not have a specific physic foundation (Poynter, 1989), and indirectly supports hypotheses identifying auditory sensory modality as dominant in perception of the temporal features of stimuli (Welch, 1999; Welch & Warren, 1980). Anyway, recent studies showed that the deficit in a sensorial system has an effect even positive than negative, respectively by the compensation and the interdependence functions of the other systems (Tharpe, Ashmead, & Rothpletz, 2002).

The use of one or more strategies in judging the duration could have an effect on performance, and seem to confirm by the results: the employment of more strategies of the same time should decrease cognitive resources devoted to the temporal task. Results support the hypothesis of a linear positive relationship between the degree of attention devoted to temporal information and the accuracy of time evaluation (Thomas & Weaver, 1975; Macar, Grondin & Casini, 1994). The effect is more prominent for deaf subject's performances when they used multiple strategies, and this seem to induce the idea of a sophisticated and specific mechanism for hearing subjects temporal evaluations.

Underestimation effect that has been observed in the counting task was reported also by previous studies that examined directly the estimation of the number of either visual (Krueger, 1984) or auditory items (Robinson, 1992). This effect was mainly attributed to cognitive factors involved in interpreting or assigning a particular number to a percept, instead of perceptual or sensory factors (their subjects performed the estimation without counting). In our study participants were explicitly required to count in order to determine the number of events during and/or after the pattern listening. The significant positive linear relationship between the actual and the counted number of events suggests that subjects attended carefully to the secondary task, even if other influencing factors could have affected the underestimation (as impatience etc.). When the subject counts the items during the listening of stimuli, reproductions are less accurate than when the counting task is carried out after the listening (try to reconstruct the pattern) or in two phases (during and after the listening). Fetterman e Killen (1990) report data that are in line with our comments, by showing a shortening of time estimation performed while counting the number of items in the same interval. Maybe when the subject carry out the counting task during the listening there are less attention resources for temporal task, and this results in a less accurate estimation. Macar, Grondin & Casini (1994) indicate that the sharing of attention between temporal a non–temporal information reduces accuracy in a time reproduction task. Our results support also the two processors hypothesis (Kahneman, 1973), supposing that a time processor and a stimuli processor compete for the limited resources of the cognitive system.

The counting task is performed better when subject use more strategies to perform reproductions than when he use a single strategy. On the contrary, subjects that use more strategies perform better the task if count two time (during and after the listening) than when they are counting only after the listening.

Regarding the effects related to the structure of the auditory events, periodic structure has been revealed responsible for accuracy and variability of performances: even time reproductions than event counting are more accurate and less variable for regular patterns than irregular ones. Results confirm findings of a previous study with a dual task paradigm used to assess prospective time evaluation accuracy for structured auditory events (Di Matteo, 2002). Simple periodic regularity on timing accuracy has been repeatedly reported in literature with time reproduction tasks (Boltz, 1995; Macar, 1996) and rhythm reproduction tasks (Drake & Gerard, 1989). An unexpected interaction between periodic and serial structure was observed: time reproductions for continuous patterns are more accurate when the periodic structure is regular than irregular, but estimations for irregular discontinuous patterns are more accurate than those of irregular continuous ones, and irregular discontinuous more accurate than irregular continuous. Our data show that regular periodic structure should be responsible for accuracy when patterns are continuous in their serial structure, but seems that a discontinuous serial organization could enhance the time reproduction accuracy. Also the analysis of counting task errors revealed that the accuracy seems to be performed better when patterns are discontinuous than continuous in their serial structure. Analysis on counting errors has revealed similar results.

CONCLUSION

Our study supports the hypothesis according to which the periodic and serial structure of stimuli affects the accuracy of time reproductions. Differences in time reproductions seem to be connected to the deficit. It may be that variability of performances in deaf subjects shows a different deployment of attention, and the allocation of resources on visual system could therefore reduce the accuracy in time reproduction tasks.

Further investigation could clarify the role of tactual perception in hearing and deaf people.

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