Research on cognitive processes determining the mental capacity of aurally impaired children

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Abstract

The paper outlines the basic tenets of the information storage and processing theory, comparing it to other cognitive development theories. The authors present results of studies regarding the phenomenon of intelligence and applies them to characterize intellectual processes as they occur in children with significant or severe aural impairments. The presented research lasted for approximately one year and was based on a series of tests, applying the deductive and autocreative learning model as well as the assumption that assimilation of information may be described in probabilistic terms. Test results and conclusions enable the authors to formally assess that revalidation activities based upon information processing theories may significantly improve the effectiveness of teaching. The presented research proves also that aurally impaired children possess similar mental skills as their unimpaired counterparts.

1. Introduction

Studies of cognitive skills in aurally impaired children, conducted in line with Piaget's cognitive development theory, indicate across-the-board poorer results compared to children who are not hearing impaired [5]. The concept of a limited, nonspecific attention pool referred to as "mental energy" was first brought up in the seventies [2] but has developed little since then [8]. Cognitive development models evolved in tandem with information processing theories draw upon their predictions. As such, they relate to Piaget's original concepts, even though they may only be applicable to specific areas of development. This property also makes them easier to validate while enhancing their completeness and accuracy. In short, the presented model is based on two fundamental paradigms: the multi-store paradigm and the computer paradigm [7].

Experimental research in cognitive psychology and information theory usually views humans as users of a sign-based language, with limited capacity for information processing. Such studies tend to focus on the flow of information triggered by presenting a human subject with a specific task [6]. Cognition is decomposed into a number of basic processes which occur in a predetermined order. They include: recognizing, encoding, searching, sorting, categorizing, linking and coordinating various data items.

In the case of a hearing impaired child, obstruction is present at the initial (sensory) step. The defective aural receptor must be replaced with another means of data acquisition (such as optical perception). Subsequently data must be held in working memory long enough to ensure persistent encoding in the long-term memory store [1].

Given these assumptions, cognitive development should be based on accurate cognitive process schemas and focus on increasing the efficacy of control processes, both operative and verification-oriented [3]. On the grounds of modern information storage and processing theories the concept of intelligence – as well as the features of specific intellectual processes – can be divided into four aspects, each associated with a distinct processing layer [4]. The first of these deals with the performance of the nervous system itself, i.e. the rate and accuracy of neural signal transmission. The second comprises formal aspects of information processes commonly thought of as intellectual skills (characterized by quantities such as information processing rate, working memory capacity and reliability of long-term information storage). The third aspect focuses on processing strategies, i.e. the ability to select suitable intellectual tools and assemble them into mechanisms appropriate for the task at hand. Finally, the fourth aspect covers evaluation and control processes. The presented study of intellectual skills in hearing impaired children deals with the second of these four aspects.

The aim of our study is to provide a formal assessment of information processing skills in children with significant or severe aural impairment. The study subjects were students of a special primary school which emphasizes vocal communication throughout its curriculum. In the course of our research we focused on the rate of information processing, working memory capacity and information storage persistence in handicapped individuals [11].

2. Methods of assessing intellectual skills in aurally impaired children

The study, which lasted for approximately one year, concerned a group of 88 children with significant (23%) and severe (77%) prelingual hearing loss in both ears, aged 7-13. All subjects were fitted with hearing aids and attended a special primary school. The study involved a test which assessed intellectual skills by focusing on information storage and processing capabilities [9, 11]. The test was based on the deductive/autocreative learning model and, specifically, the assumption that assimilation of information (or lack thereof) may be expressed in probabilistic terms. The experimental procedure involved memorizing a series of n grouped stimuli where each group included a correct stimulus along with a number of incorrect stimuli. This enabled the authors to construct a relatively simple stochastic learning model centered upon the subject's ability to memorize one particular element from each set. In line with these assumptions, the learning process comprises three mutually independent events, each of which can be associated with a probability value:

- p – the likelihood of assimilating information on a given attempt;
- q – the likelihood of not assimilating information on a given attempt;
- c – the likelihood of information erasure on a given attempt.

According to probability calculus, if these basic events are indeed independent and their probabilities constant then the sum of p, q and c is always equal to 1. Information erasure may take on two forms: retroactive or proactive. Proactive erasure is commensurate to the lack of information assimilation on a given attempt. This stochastic learning process can be described by a function (f_i) which expresses the likelihood that information will not be assimilated on a given attempt. During the first attempt this probability is equal to q, while during the second attempt the corresponding value is q^2+qc, which may be denoted as $q(q+c)$. Applying mathematical induction yields $f_i=q(q+c)^{i-1}$ for the i-th attempt [9]. This formula describes a descending curve – thus, if q is interpreted (on the basis of empirical evaluation of the frequency of incorrect answers following the first memorization attempt) as an inverse of the working memory range, low values should be treated as indicative of rapid learning. q=0 indicates perfect memorization (success on the first attempt) while q=1 points to lack of learning. The (q+c) factor in the presented formula determines the rate at which the function asymptotically approaches 0. It can be interpreted as the error elimination rate and, consequently, as the rate of learning. We will hereafter refer to this coefficient as v: in formal terms v=(q+c). Much like in the case of q, low v indicates faster learning. The forgetfulness coefficient (c) is equal to v-q and carries a straightforward interpretation: the lower its value the better the outcome of the learning process. The presented formula also suggests that if the rate of learning is greater than the operating memory capacity, i.e. if v is lower than q, the forgetfulness coefficient becomes negative, losing its probabilistic meaning. This apparent violation of the classic multi-store memory model carriers an important empirical sense. The learning process depends on the subject being able to perform a specific task. While the task is being performed, the subject also assimilates information; however this is a latent phenomenon and therefore cannot be directly observed – it is only possible to determine whether the task itself has been successfully completed. Information may be assimilated even when the subject is not consciously aware of this fact: properly engineered experimental procedures or the subject's own mental faculties may cause such information to be subsequently recalled; a process sometimes referred to as "counter-forgetting" [10, 12]. This phenomenon occurs rather frequently, much like the erasure of previously assimilated information brought on by the large number of facts being forced into the limited operating memory during a prolonged learning session. Both phenomena have been subjected to further analysis in the course of our study.

As remarked above, our research included a custom test fulfilling each of the presented study criteria. The subjects were asked to memorize fifteen geometric shapes selected from a set of thirty. Figure 1 shows sample boards used in the test.

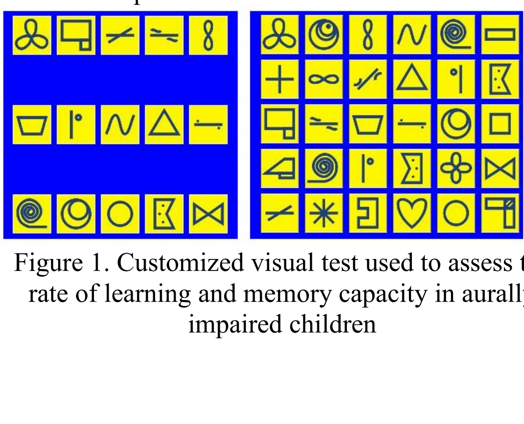

Figure 1. Customized visual test used to assess the rate of learning and memory capacity in aurally impaired children

The test scenario was supervised by the examiner and each round of the experiment proceeded in an identical fashion. During each round the subject was first shown a subset of fifteen shapes and then asked to identify the same shapes within the complete set of thirty. There were no time constraints and the examiner did not attempt to interfere with the memorization process. The test continued until the subject was able to succeed twice (i.e. identify all fifteen shapes without error).

3. Results of the assessment of mental capacity in aurally impaired children

In accordance with the presented stochastic learning model and following empirical estimates each of the parameters which contribute to the learning process can be quantified using a suitable formula [10, 11]. The likelihood of not memorizing a given piece of information during a single attempt (denoted q and interpreted as the inverse of the working memory range) is the relative frequency of erroneous responses following the first round of memorization. It can be calculated as $q=(b_1/n)$ where b_1 is the number of false negatives (i.e. the number of shapes which the child failed to identify despite their inclusion in the learning set). n is the desired number of correct responses which in this test equals 15 (all fifteen shapes correctly identified). The rate of learning is given as $v=1-(b_1/\Sigma b_i)$ where b_1 is the number of false negatives in the first round while Σb_i is the aggregate total of false negatives in the entire experiment. The index i is the number of attempts undertaken by the child until success (i.e. two fully correct responses) is achieved. The forgetfulness constant (c) is derived from the two coefficients mentioned above: $c=(v-q)$. In certain cases c may become negative, which indicates the counter-forgetting phenomenon. Test results, expressed in terms of actual values of q, v and c, are listed in Table 1 and Table 2.

Table 1. Average learning coefficients in aurally impaired children, by school grade (n=88)

	1st grade	2nd grade	3rd grade	4th grade	5th grade	6th grade
q_{avg}	0.41	0.51	0.51	0.35	0.54	0.47
v_{avg}	0.69	0.57	0.65	0.52	0.61	0.60
c_{avg}	0.28	0.05	0.14	0.17	0.07	0.13

As can be seen, v exhibited the smallest variance among all coefficients. The values of q (working memory capacity) were more widely distributed, and the values of c (memory persistence) even more so. This is a very important result, as similar studies related to the information processing theory, performed on a group of children without hearing impairments, reveal that while the average values of q and v remain relatively constant, c is highly variable. Examining aurally impaired children seems to confirm these results. In order to enable a more rigorous comparison we first need to determine the average values of q, v, and c in the control group of children without hearing loss. Accordingly, these values are given as $q_{avg}=0.5$ and $v_{avg}=0.6$, whereas c_{avg} oscillates around 0.15 [10, 11]. These baseline values are necessary to properly interpret the results listed in Table 2.

Table 2. Average learning coefficients in aurally impaired children, divided into two subgroups, grades 1-3, grades 4-6, as well as the entire study group grades 1-6 (n=88)

	Grades 1-3	Grades 4-6	Grades 1-6
q_{avg}	0.48	0.45	0.465
v_{avg}	0.64	0.58	0.61
c_{avg}	0.16	0.12	0.14

The average values of learning coefficients among children afflicted with hearing loss (n=88), when compared with control group results, indicate that the study subjects are no less capable of processing information. Their mental capacity remains within normal bounds, although their handicap does cause technical issues which need to be addressed by appropriate learning strategies. Of particular note are empirical results related to the c coefficient which characterizes the persistence of information storage. In the course of learning sessions this coefficient occasionally becomes negative and loses its probabilistic meaning. This occurs when the rate of learning (v) is greater than working memory capacity (q). Values of c obtained during the experiment are presented in Table 3 and Table 4.

Table 3. Populations of aurally impaired children in which the forgetfulness coefficient (c) becomes negative, by school grade (n=88)

	1st grade	2nd grade	3rd grade	4th grade	5th grade	6th grade
Total number of subjects	12	12	11	13	13	27
Subjects with c<0	0	4	3	3	3	10
% share	0%	33%	27%	23%	23%	37%

Table 4. Populations of aurally impaired children in which the forgetfulness coefficient (c) becomes negative by grades 1-3, grades 4-6, entire study group grades 1-6 (n=88)

	Grades 1-3	Grades 4-6	Grades 1-6
Total number of subjects	35	53	88
Subjects with c<0	7	16	23
% share	20%	30%	26%

Our study indicates that the largest population of subjects with negative c relative to the size of their subgroup is found in the 6th grade (37% percentage share). This observation is further confirmed by dividing the population into two age groups (grades 1-3 and 4-6), where the corresponding values of c are 20% and 30% respectively. In younger children a surprisingly large cluster of negative-c subjects is present in the second grade (33%) whereas no such subjects could be found in the first grade. First graders do not yet have experience with revalidation procedures and cannot easily work out strategies for dealing with learning tasks regardless of their complexity. This behavior is fully consistent with accepted theories regarding the formulation of strategies by young children [7].

The presented research enables us to characterize compensatory mechanisms which aid the learning process in aurally impaired children. Table 5. presents mutual correlations between learning coefficients.

Table 5. Correlations of learning coefficients in children with significant and severe aural impairment (n=88)

	q	v	c
q	$q_{avg}=0.465$ $S_q=0.205$	$r_{qv}=0.342$ $p<0.01$	$r_{qc}=-0.617$ $P<0.01$
v		$v_{avg}=0.61$ $S_v=0.204$	$r_{vc}=0.577$ $P< 0.01$
c			$c_{avg}=0.14$ $S_c=0.243$

An important extension to the presented research in the scope of cognitive psychology is to apply the Kolmogorov equivalence test to compare distributions of learning coefficients in two groups of 44 subjects each. Results indicate significant divergence in the distributions of q (working memory capacity) and v (rate of learning), whereas c (storage persistence) exhibits normal distributions in both groups. Within the study group most distributions are biased towards relatively poorer results, while similar tests performed for children without hearing loss produce normal distributions.

4. Conclusions

Results of our research suggest that the mental capacity and information processing faculties in children with significant and severe aural impairments remain unaffected compared to children without similar handicaps. It is, however, noted that hearing loss often results in serious developmental obstacles which must be taken into account when devising learning strategies and study aids for such children.

Comparing the distributions of learning coefficients using Kolmogorov's method highlights the differences between the study group and the general population. In children with aural impairments the learning coefficients do not follow normal distributions (with the exception of c – information storage persistence). This observation applies specifically to q (working memory capacity) and v (rate of learning), showing the relative unpredictability of test results within the study group, as well as the large variability of skills exhibited by handicapped subjects.

As indicated by our tests, the most consistent results are obtained for v (rate of learning). q (working memory capacity) shows greater variance while c (storage persistence) is the most variable of all learning coefficients in the study group. The rate of learning was decidedly lowest in the first grade, as was the persistence of information storage. Results improve during subsequent years of education although they are not a linear function of the student's grade. For instance, learning coefficients are markedly better in the 2nd grade but then continue to deteriorate all the way up to the 6th grade. These changes are relatively small relative to the values of each coefficient, yet they are statistically relevant and exhibit cyclical variability. One possible conclusion is that the school environment initially exerts great influence on the cognitive development of young children but later on ceases to play such a crucial role. This suggestion is supported by the fact that – among primary school graduates – a significant portion of students (37%, according to published studies) possess more extensive knowledge and skills than what is evident to teachers. Such skills need to be brought to light, either through suitable testing or by unlocking internal cognitive pathways. The responsibility for achieving this goal rests with teachers.

Our research into compensatory mechanisms indicates that aural impairment induces a stronger relationship between the rate of learning and working memory capacity than would otherwise be the case. Consequently, the link between knowledge assimilation and storage persistence is weakened, although it remains evident and its importance can best be described as moderate. Hearing impaired children compensate for the reduced rate of knowledge assimilation by ensuring that information is stored more persistently – and the other way around. In fact, these correlations are mutually interdependent. For instance, if a child with severe hearing loss exhibits low persistence of information storage, this is typically counterbalanced by either better memory capacity or faster information processing rate. The role of storage capacity in this process is actually greater than that of the learning rate. By the same token, children who were slow to learn often benefitted from more durable memory (even though the compensatory effect associated with lower q is of lesser importance than that which follows from more favorable c). In conclusion, a hearing impaired child who experiences problems related to the expected rate of memorization often tries to address them by ensuring that information is stored more persistently and by optimizing the use of the available working memory.

5. Implications of results

Revalidation activities based upon information processing theories, wherever practical, may significantly improve the effectiveness of teaching. Aurally impaired children possess similar mental skills as their unimpaired counterparts, although such skills may prove more difficult to unlock. In order for the child to assimilate knowledge in an efficient manner learning tasks must be clearly defined and followed up with specific learning strategies.

Another area where the presented research may be of use is development of learning curricula for aurally impaired children with deference to compensatory mechanisms. The general conclusions presented above, coupled with specific test results, reveal prospective approaches which can be exploited in the learning process, including such details as the number of repetitions or recapitulations needed to ensure effective assimilation of knowledge.

The aptitude test discussed in this paper yields specific guidelines which enable teachers to render effective aid to aurally impaired students. It should be noted that similar tests based on the deductive/autocreative learning model (as well as the assumption that the assimilation of information – or lack thereof – can be expressed in probabilistic terms) may be applied to patients with various sensory impairments, not necessarily limited to loss of hearing.

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