The Relationship between a High Level of Physical Fitness and Working Memory in Blind, Deaf, and Non-disabled Adolescents

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Abstract : This research investigated the working memory of blind, deaf, and non-disabled adolescents after performing long term physical activity. A group of 72 male adolescents (aged from 15 to 18 years) was divided into groups with high oxygen consumption (H-) and groups with low oxygen consumption (L-) (10 subjects in each group HB, HD and HN vs LB, LD and LN). Neuropsychological tasks including non-verbal, verbal, and tactile memory tests were adapted and tested for reliability in 30 male normal extra-subjects of which the results were 0.97, 0.83 and 0.82 respectively. We found that blind individuals with a high fitness level (HB) responded with higher tactile memory scores ($P < 0.001$) while deaf individuals with a high fitness level (HD) had shorter non-verbal memory times ($P < 0.05$), compared to their control groups. Moreover, disabled students with a high level of fitness (HB and HD) displayed cognitive capacities close to non-disabled with a low fitness level (LN) students ($P > 0.05$). In conclusion, the opportunity for sensory-motor integration into working memory through intact vision or hearing can be enhanced by a suitable amount of exercise.

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การวิจัยนี้แสดงให้เห็นถึงการปรับตัวทางสมรรถภาพร่างกายและระบบความจำ โดยศึกษาวัยรุ่นชายอายุ 15-18 ปี จำนวน 72 คน ที่มีความบกพร่องทางการมองเห็นหรือทางการได้ยินตั้งแต่กำเนิด และวัยรุ่นที่ปกติ นำมาจัดกลุ่มตามระดับการใช้ออกซิเจนสูงสุดและต่ำสุด จากนั้นใช้แบบทดสอบความจำ ซึ่งคิดค้นใหม่และได้รับการหาความเที่ยงตรงของเครื่องมือจากอาสาสมัครที่ไม่ใช่กลุ่มทดลองอีก 30 คน เมื่อเปรียบเทียบข้อมูลทางสถิติกับกลุ่มควบคุม พบว่า กลุ่มที่มีความบกพร่องทางการมองเห็นและมีสมรรถภาพทางร่างกายสูง สามารถพัฒนาระบบความจำจากการสัมผัสได้ดีกว่า (p<0.001) ขณะที่กลุ่มที่มีความบกพร่องทางการได้ยินและมีสมรรถภาพทางร่างกายสูงสามารถพัฒนาระบบความจำจากการเขียนได้ดีกว่า (p<0.05) นอกจากนี้กลุ่มที่มีความบกพร่องทางการมองเห็นหรือการได้ยิน ที่ออกกำลังกายอย่างสม่ำเสมอ จะมีระบบความจำที่ดีใกล้เคียงกับกลุ่มที่ไม่มีความบกพร่องและไม่ค่อยออกกำลังกาย (p>0.05) ดังนั้นการจัดสภาพแวดล้อมที่มีระดับการออกกำลังกายที่เหมาะสม ช่วยพัฒนาระบบความจำผ่านระบบประสาทการเคลื่อนไหวจากการมองเห็นหรือการได้ยินที่ปกติได้

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INTRODUCTION

The human brain has followed various adaptations based on continuous pressure to provide heterogeneity of its capacity for survival[1,2]. Information on the basic capacities of the visual system in relation to memory of motor skills is still unknown and there have been not many measurements of functional changes in the brain relating to behavior and psychological processes[1,3,4]. The psychophysiological benefits on the central nervous system of exercise are also not clear[5].

Mental capacity in terms of memory level affects motor skill performance or programming physical activities[6]. The frequently observed psychological changes that occur with acute exercise sessions that have already been observed should be further investigated in subjects with sensory deprivation along with the response to aerobic exercise in population with a low level of fitness[7,8]. It is considered the best strategy to combine specific training for the handicap with general education making use of the most-effective channels, namely, the visual channel in those with defective auditory perception, and the auditory channel in those with defective visual perception[9]. In the past there have been only few researches concerning the fields of cognitive psychophysiology in either the blind or the deaf who needs to be encouraged in their capacities to perform daily activities similar to normal populations.

MATERIALS AND METHODS

Subjects

Seventy two congenitally blind (B), deaf (D), and non-disabled (N) students whose ages ranged from 15-18 years were studied. Ninety percent of the subjects were right-handed and had studied to the same educational level (grade 9-12). They attended the Bangkok School for the Blind, the Sethsatian School for the Deaf, and the Ramkhamhaeng Demonstration School. The medical history of their disabilities was reviewed from the medical records and the exercise prescriptions were obtained from the physical education teachers at each special school. The blind students were allowed to touch and hear the instructions, and the deaf students were given the instructions in touch-sign-written languages. All subjects were healthy, normal IQ with the school evidences, free of other disabilities. All subjects and their high school principals signed the consent forms allowing them to be subjects of the study. This research was approved by the Committee on Human Rights Related to Human Experimentation (No.26/1998) of Mahidol University. They were then asked about the frequency of their sports activities in the past three months. The subjects were allowed to rest for about 3-5 minutes between each test.

Maximal aerobic capacity measurement

A nomogram was used to predict the VO_2max from their heart rate responses to a 6-minute submaximal work load test that selected a heart rate between 130-150 bpm. A nomogram was used to estimate the initial work load for men by plotting the subject's body weight and heart rate response after 1 minute of 100 w (600 kg.m/min) cycling at 50 rpm[10]. The heart rate was recorded every minute, and its average was recorded at the fifth and sixth minutes. If the difference between these two heart rates exceeded 5 bpm, the work load was prolonged until a steady-state heart rate was achieved. If the heart rate was less than 130 bpm at the end of the exercise session, another 6 min was performed after increasing the work load by 50 w (300 kg.m/min). The modified Astrand-Ryhming nomogram[11] was used to estimate the VO_2max from the submaximal heart rate and the work load on the bicycle ergometer, adding an appropriate age-correction factor for 15-20 years old which was 1.10. After the measurement, blind (-B), deaf (-D), and non-disabled (-N) subjects were grouped from the amount of exercising background and the level of VO_2max into the high (H-) fitness level (HB, HD and HN) and the low (L-) fitness level (LB, LD and LN) respectively.

Cognitive memory tests

A tactile memory test was modified from SCSIT-Manual Form Perception[12]. In all groups, the subject's dominant hand was allowed to touch 12 sand-textured plastic, geometric forms while wearing a shield to occlude vision and earphones for about 2 min. Then, the subject was instructed to change hand to receive the 10 forms (two of the forms were used to discriminate whether the subject clarified the forms accurately) and to locate each form's position in the memorized discrimination. The time in seconds required for the subject to reach a decision on each item was recorded in the protocol booklet, allowing 30 seconds to correct each item. The sum of the correct responses of the left hand was 2 and the right hand was 3. The total score was deducted from the raw score for which 1 point was given every 25 seconds of the total time taken.

Verbal and non-verbal memory tests with calculations were modified from the PASAT-Auditory serial addition test[13]. Normal and blind subjects were required to comprehend the auditory or visual inputs and to respond verbally (with or without blindfolds). Normal and deaf subjects were required (with or without earphones) to understand visual inputs and to respond by writing on paper. A prerecorded tape or preprinted card delivered a random series of 61 numbers from 1 through 9. The subject was instructed to add pairs of numbers such that each number was added to the one immediately preceding it; the 60 numbers were presented at 2.0 - second intervals. The numbers of correct and incorrect responses were recorded (maximum score = 60) that was later converted to time per correct response.

We tested our modified neuropsychological assessments (verbal, non-verbal and tactile memory tests) on 30 students from the Suankularb Vittayalai School in Samut Prakarn. These individuals were not involved in the exercise experiment. In order to normalize the data, they were all 15 years old in a science program at grade 10. Also these tests were performed by one tester for all students on one day in a quiet room. The calculated reliability values were 0.83 for the verbal memory test, 0.97 for the non-verbal memory test, and 0.82 for the tactile memory test.

Statistical analysis

SPSS 9.0 for windows was used to perform statistical analysis. Statistical significance was tested at p value of 0.05 and 0.001. For normally distributed populations, the distribution of the sample mean and variance were used to test the hypothesis (Independent Sample t-test (between group) and one way ANOVA (within the group)).

RESULTS

Effect of high physical fitness on working memory for each type of sensory deprivation

Comparing disabled individuals with control (Table 1), both blind students with a high level of fitness (HB) and deaf students with a high level of fitness (HD) had a significantly higher oxygen consumption ($p < 0.001$) since all high-fit students performed a higher percentage of the sports activities than the groups with a low level of fitness. There was a significant difference in tactile memory scores in the blind groups (14.85 ± 5.52 scores in HB vs 5.58 ± 8.28 scores in LB, $p < 0.001$), whereas the deaf with a high level of fitness had significantly faster non-verbal memory values than the deaf with a low level of fitness ($p < 0.05$); and there was no significant difference in all three memory tests in the normal groups (HN and LN).

Effect of high physical fitness on working memory in subjects overall

Comparing the blind, deaf and non-handicapped students (Table 2), there was no significant difference among the three high-fit students in tactile memory score; however, the highly-fit deaf students had significantly lower oxygen consumption than the blind and normal groups ($p < 0.001$). With regard to verbal memory time, only the highly-fit blind students were slower than the highly-fit normal students ($p < 0.05$) whereas there was no significant difference in non-verbal memory time between the highly-fit deaf students and highly-fit non-disabled students.

Effect of sensory deprivation on working memory

In the blind group, verbal memory scored 8.53 ± 6.40 sec and tactile memory scored 5.58 ± 8.28. While in the deaf group, the non-verbal memory score was 4.16 ± 1.89 sec and the tactile memory score was 13.15 ± 4.90 (Table 1). The deaf group had a significantly lower tactile memory score than the blind group ($p < 0.05$), but there was no significant difference when compared with the non-disabled group. The blind group achieved a significantly lower tactile memory score, and a slower verbal memory test than the non-disabled group ($p < 0.05$). Beside

Table 1. Statistical differences of mean (± SD) between the effect of high (H-) and low (L-) physical fitness on cognitive memory tests within the blind (-B), deaf (-D), and non-disabled (-N) groups.

	Group (n = 10 in each group)					
Parameter	**HB**	**LB**	**HD**	**LD**	**HN**	**LN**
VO_2max (ml/kg/min)	63.41±6.72**	37.72±7.41	54.35±5.89**	36.91±7.07	66.85±5.07**	49.67±4.57
Sports activity (% frequency)	56%	25%	64%	43%	56%	47%
Verbal memory (sec)	5.06±2.14	8.53±6.40	no test	no test	3.50±0.91	3.87±1.15
Non-verbal memory (sec)	no test	no test	2.57±1.15*	4.16±1.89	2.14±0.33	2.61±0.92
Tactile memory (score)	14.85±5.52**	5.58±8.28	13.49±7.78	13.15±4.90	14.83±6.72	16.57±3.81

Significant differences between HB:LB, HD:LD, and HN:LN at P< 0.05* and P < 0.001**

Table 2. Statistical multiple comparison of physical and cognitive parameters in overall groups of disabled and non-disabled.

	Compared group							
Parameter	**HB:HN**	**HB:LN**	**LB:LN**	**HD:HN**	**HD:LN**	**LD:LN**	**HB:HD**	**LB:LD**
VO_2max	NS	HB>LN**	NS	HD<HN**	NS	NS	HB>HD**	NS
Memory								
- verbal	HB>HN*	NS	LB>LN*	x	x	x	x	x
- non-verbal	x	x	x	NS	NS	LD>LN*	NS	NS
- tactile	NS	NS	LB<LN*	NS	NS	NS	NS	LB<LD*

Significant differences at P<0.05* and P<0.001**. NS = not significant; x = no test.

the non-verbal memory test, the deaf also scored a significantly slower rate than the non-disabled group ($p < 0.05$) as shown in Table 2.

DISCUSSION

We can see the effect of exercise from this study on the subjects' daily activities, of which the maximal oxygen consumption was used as an indicator of the fitness performance. The differences in aerobic capacity may reflect the reactive background of aerobic exercise of each group of subjects. The low VO_2max of the blind may indicate their "slow motion-like" movement in their daily life since they can not see. Therefore they often move slowly and minimally. This phenomenon may be partly due to a low level of physical activity and neuromuscular adaptation rather than slowness because of not being able to see. We can interpret the differences for higher memory processing skills like verbal memory, non-verbal memory, and tactile memory when compared with the exercise non-disabled group, even though their results were the same as the handicapped groups. Visual deprivation may be responsible for affecting the auditory system by generalized nerve damage or other congenital lesions.

The memory system adjacent to the auditory cortex may play a major role even in the functioning of visual memory, but memory will support all the brain's activity; actually, this special ability takes up quite a large area of the brain[1]. Stimulation on the superior temporal plane (primary auditory cortex) evoked impressions such as tones, buzzes, or knocking sounds, but stimulation in lateral portions of the temporal lobe seemed to arouse memory sequences that had auditory components as well. All sequences had a spatial, spectral, and temporal form[14]. The long term storage of individual experience becomes increasingly more important in the nervous system where the linkage to cognition is complex, and where experience can alter the contingencies signaled by a sensory event. Word comprehension is also an object recognition task; explicit memory and lexical knowledge can share common organizations by providing another potential mechanism in the temporal pattern while a digit span task reflects the integral working memory. For example, mental reconfigurations of visual percepts could serve non-verbal thinking, whereas the mental activation of auditory word-forms and related associations may support our speech and verbal thinking[2,15].

It therefore appears that the hippocampi, mammillary bodies and adjacent reticular information, are essential for the registration of new memories, and the mechanism of memory storage may thus depend upon neurons being altered anatomically or chemically, or on being maintained in a state of activity so that the memory will not be lost[16]. Amygdala may perform a critical function in linking the sensory information too[17]. One important function of the frontal lobe is related to the integration the interoceptive and exteroceptive information to produce an appropriate motor response[18]. One possibility is that competition between the hemispheres is mediated between intact subcortical systems leading to changes in attention biases as a function of a specific stimulus[19]. Data strongly support the principle that prefrontal neurons adopt the receptive field properties of neurons providing their direct input is from the posterior sensory association cortex[20].

Exercise may stimulate the autoregulatory mechanism which maintains the level of blood flow to the brain. Furthermore, physical activity can influence a trophic factor which may enhance synaptic transmission and its involvement in behavior may provide a molecular basis for the enhanced cognitive function associated with an active lifestyle[5,21]. Physical activity may increase the availability of brain-derived neurotrophic factor (BDNF) to these cells by upregulating its expression in the hippocampus, and supporting the neuronal growth function[22]. Human movement is finely regulated by a neural control mechanism located in the central nervous system. This provides important sensory feedback during physical activity[23]. All forms of muscular exercise increase the metabolic rate and therefore it is of particular interest to be able to analyze the involvement of the oxygen transport system. Oxygen uptake provides an accurate measure of aerobic power, and is strongly related to cardiac output[11]. The intensity and duration are two important factors in rating and difficulty of a particular task with great variability in daily energy expenditure or ATP production. The contribution of anaerobic and aerobic energy transfer depends largely on the intensity and duration of exercise[23].

If intensity, duration and frequency are held constant, training improvements are similar regardless of training mode (type of sports), as long as the exercise involves large muscle groups activated in a rhythmic and aerobic nature. Astrand[11] explained how the submaximal exercise test had proven to be a very useful tool with a high correlation between cardiac output during exercise and oxygen uptake. In fact, a greater maximal stroke volume is a major adaptation whereas the heart rate is lower in the trained individual and the cardiac output may be on the same level or lower than the untrained individual[24]. Auditory and visual reaction times develop parallel to the fitness tests and the proprioceptive contribution is maintained by auditory and visual feedbacks. There is also indirect evidence of a relationship between exercise and psychomotor performance, as well as other cognitive functions[5,25,26].

Consequently, our study found a trend of enhancement in verbal or non-verbal memory in the blind and deaf compared to their control; however, all three groups had taken part in sports or recreational activities since they were young. This study can promote more information about disabled psychomotor performance to supplement the short study by Spirduso[5]. The deficiency in cardio-respiratory fitness was not associated with deafness or blindness for a student attending an adequate physical education program which might compensate for an otherwise sedentary life[27]. Finally, disabled adolescents were able to improve their working capacity. The deaf depend mainly on visual and neuromuscular feedback whereas the blind must rely more on auditory and neuromuscular feedback. All disabled students may be helped by enhancing the adapted exercise programs[28,29]. Therefore, we can conclude that the neuro-psycho-physiological benefits of exercise will affect blind, deaf and non-handicapped adolescents in relation to their own learning experiences since birth.

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