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A Plateau and Spurt Pattern of Neurological Maturation, Scientific Reasoning Development and Conceptual Change in Korean Secondary School Students

Kwon, Yong-Ju · Anton E. Lawson[1]
(Kyungpook National University) · [1](Arizona State University)

중등학교 학생들의 신경기능 성숙, 과학적 사고 발달 그리고 개념 변화에서 밝혀진 비선형적 발달의 정체와 급등 현상

권 용 주 · Anton E. Lawson[1]
(경북대학교) · [1](애리조나 주립대학교)

요 약

신경생물학적 연구들에 따르면 청소년들의 두뇌 발달은 선형적이며 규칙적으로 발달하는 것이 아니라, 정체(plateaus)와 급등(spurts)을 거치면서 비선형적이고 불규칙적인 발달과정을 거친다. 따라서 본 연구는 이러한 신경생물학적 연구결과를 바탕으로 하여 청소년들의 전두엽연합령 기능의 발달이 정체와 급등의 시기를 거치는 비선형적 발달을 보이며, 이는 다시 과학적 사고의 발달과 이론적 과학개념의 습득에 영향을 미친다는 가설을 테스트하였다. 이 가설을 테스트하기 위하여 13세에서 16세 연령대에 있는 206명의 중등학교 학생들에게 4가지 전두엽연합령 기능 검사, 과학적 추론 검사, 그리고 수업을 통한 분자의 운동에너지 개념의 획득능력에 대한 검사를 실시하였다. 이 연구의 결과는 14세 학생들의 전두엽연합령 기능, 과학적 추론 능력, 그리고 수업후의 개념변화에서 일련의 정체 시기를 보여주었다. 반대로 15세와 16세에서는 다시 증가하는 시기를 보여주었다. 더 나아가, 본 연구에서는 13세에서 16세의 중등학생들이 순환학습을 통한 체계적인 교수-학습에도 불구하고 소수의 학생들만 효과적으로 이론적 과학개념을 습득하였음을 보여주었다. 본 연구는 이러한 결과들을 바탕으로 이론적 과학개념의 효율적인 교수-학습에 관해서도 논의하였다.

핵심어 : 발달의 정체와 급등현상, 과학적 추론발달, 전두엽연합령 기능 발달, 개념변화, 억제능력, 설계능력.

Ⅰ. Introduction

Based on measured increases in brain weight and skull circumference, Epstein (1978) argues that brain growth during childhood and adolescence occurs in a series of plateaus and spurts. With respect to early adolescence, Epstein and Toepfer (1978) state… "in perhaps 85% of all youngsters between ages 12 and 14, the brain virtually ceases to grow." (p.657). According to Epstein and Toepfer, the early adolescent plateau, which coincides with

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the onset of puberty, is followed by a spurt between the ages of 14 to 16. The plateau and subsequent spurt may be related to learning capacity. For example, Epstein and Toepfer cite data establishing a peak in fluid intelligence around age 11 (presumably when the brain is growing) followed by dip around age 13 to 13.5 (presumably when the brain has stopped growing). Further, they claim that overall brain growth coincides with the four classical stages of Piaget's cognitive developmental theory. In their words, "These brain growth periods may turn out to be the biological basis of the Piaget stages" (p.657). More recent electroencephalographic data tend to corroborate the link between Piaget's stages and brain growth. Interestingly, five growth spurts, not four, have been found, with the last occurring at about 18 years of age (Epstein, 1978; Hudspeth & Pribram, 1990; Thatcher, Walker & Giudice, 1987).

Although the maximum number of neurons are probably present at birth, existing neurons in the prefrontal lobes continue to grow throughout adolescence and perhaps even into early adulthood (Schade & Van Groenigen, 1961). More specifically, Blinkov & Glezer (1968) found that pyramidal neurons in the prefrontal lobes increase more in length and width during adolescence than do neurons in the pre-motor area and the sensory-motor area. Dendrites of the prefrontal pyramidal neurons also continue to grow after birth. Dendritic arbors, which are relatively rudimentary in newborns, continue to grow throughout the teenage years resulting in increases in total dendrite length and number of branches (Schade & Van Groenigen, 1961). Increases of the neuronal myelinization in the prefrontal lobes also continue during the teenage years. In contrast, myelinization of the sensory-motor cortex is mostly complete by age two (Yakoblev & Lecours, 1967). Also, spurts of electroencephalographic activity during adolescence are centered in the prefrontal lobes (Thatcher *et al.*, 1987). Therefore, it seems reasonable to suspect that the age 14 to 16 brain growth spurt occurs primarily in the prefrontal lobes.

Although research has yet to establish a clear link between the apparent age 14 to 16 brain growth spurt and prefrontal lobe activity, the published data (Heaton, Chelune, Tally, Kay & Curtiss, 1993) on children's and adolescents' ability to inhibit previously relevant, but currently irrelevant, cues to correctly sort cards in the Wisconsin Card Sorting Test were also reanalyzed in this study. Several neurological studies, many dealing with patients with prefrontal lobe brain damage, have linked Wisconsin Card Sorting Test performance to prefrontal lobe activity (e.g., Knight & Grabowecky, 1995; Luria, 1980; Milner, 1963; Weinberger, Berman & Zec, 1986). In the analysis, the Heaton and his colleagues' data shows that inhibiting ability, as measured by the Wisconsin Card Sorting Test, increases with age with the exception of a rather pronounced performance regression from age 10 to about 13 years. Is this apparent regression in inhibiting ability caused by a lack of prefrontal lobe brain growth during this age period? Is the apparent regression also linked to other cognitive abilities, which are also centered in the prefrontal lobes, such one's ability to plan a series of moves to reach a goal, one's ability to find a simple pattern embedded in a complex background, and one's ability to mentally coordinate separate bits of information? [See Kwon (1997) for a review of neurological studies that place these cognitive abilities in the prefrontal lobes].

Assuming that the apparent age 12~14 plateau and age 14-16 spurt can be linked to such prefrontal cognitive functions, can they also be linked to one's ability to reason scientifically and to learn theoretical science concepts (i.e., concepts such as atoms, molecules, and photons whose defining attributes are not directly perceptible)? A few previous studies are suggestive of such links. For example, Lawson, Karplus and Adi (1978) found little or no difference between sixth graders (mean age = 12.9 years) and eighth graders (mean age = 14.3 years) use of proportional and probabilistic reasoning. But they found huge advances in the use of proportional and probabilistic reasoning from eighth to tenth graders (mean age 16.1 years). Also in a sample of 6130 Korean students, Hwang, Park & Kim (1989) found generally similar performances on measures of proportional, combinatorial, probabilistic and correlational reasoning among 12, 13 and 14-years-olds. But they found huge performance improvements by the 15-year-olds. And several studies have established a clear link between scientific reasoning ability and concept learning (e.g., Baker, 1994; Choi & Hur, 1987; Kim & Kwon, 1994; Lawson, 1985).

Although the analysis of the Heaton *et al.* data and these science education studies suggest that the early adolescent brain growth plateau and spurt may impact several important cognitive abilities and what students may or may not learn as a consequence of science instruction, to date no study has sought to test this brain-growth hypothesis in a systematic fashion. Hence, the primary purpose of the present study is to do so. To accomplish this goal, tests of four prefrontal-lobe cognitive functions were administered to a sample of students ranging from 13 to 16 years of age (grades 8, 9, 10 and 11). A test of scientific reasoning ability was also administered as was a test of student understanding of air pressure concepts derived from kinetic-molecular theory. Then an identical series of 14 two-hour, inquiry-based lessons introducing and applying air pressure concepts were taught. To assess the extent to which students at differing ages and with differing cognitive abilities profited from instruction, the concept understanding test was re-administered following instruction.

If the hypothesis is correct that an early adolescent brain growth plateau exists, which is followed by a prefrontal brain growth spurt beginning at about age 14, then the measured prefrontal cognitive functions and scientific reasoning ability should show performance plateaus among perhaps the 14-year-old students. These performance plateaus should then be followed by performance spurts among the older students. Further, science instruction should be relatively ineffective among the younger students, but should be increasingly effective among the 15, and 16-year-olds. On the other hand, if increases in the prefrontal cognitive functions, and scientific reasoning ability depend primarily on experience, which presumably increases linearly with age, then no performance plateaus or spurts should be found and instruction should be increasingly effective in a linear fashion across age.

Ⅱ. Method

1. Design

Prior to instruction, students were individually administered tests of inhibiting ability(Wisconsin Card Sorting Test: WCST) and planning ability (Tower of London Test: TOL). Testing took place in private offices provided by the schools. Testing of each student took about 10 minutes for the Wisconsin Card Sorting Test and about 20 minutes for the Tower of London Test.

Written tests of disembedding ability (Group Embedded Figures Test: GEFT) and working memory or mental capacity (Figural Intersection Test: FIT) were administered to students prior to instruction during their regularly-scheduled classes. The Group Embedded Figures Test took approximately 20 minutes to administer. The Figural Intersection Test took approximately 15 minutes to administer.

Also prior to instruction, students were administered a written test of scientific reasoning ability and a test of air pressure concepts during their regularly-scheduled classes. The scientific reasoning test took approximately 50 minutes to administer. The air pressure concepts test took approximately 20 minutes to administer.

At the conclusion of pretesting, students were taught the series of 14 lessons, one lesson per week, over a 14 week period based on the weekly schedule displayed in Table 2. All lessons were taught by the same instructor (researcher). At the conclusion of instruction, the test of air pressure concepts was re-administered to each class during their regularly-scheduled classes.

2. Subjects

Two hundred six (206) students ranging from 13.1 to 16.9 years of age from two junior high schools and two senior high schools in Korea participated in the study. One junior and one senior high school were located in city of approximately 100,000 people. The other junior and senior high school were located in a city of approximately two million people. Each student was enrolled in one of eight all male or all female eighth through eleventh grade science classes as shown in Table 1.

Table 1 Sample description

Age range (years)	N	Mean age (years)	SD
13.1 to 13.9	48	13.6	0.23
14.0 to 14.9	53	14.5	0.26
15.0 to 15.9	64	15.4	0.30
16.0 to 16.9	41	16.3	0.26

3. Instruments

Planning Ability. Planning ability was assessed by the TOL. The TOL requires planning in terms of means-ends analysis to successively solve a set of increasingly difficult tasks (Kwon, 1997; Shallice, 1982). To solve each task, students must plan and execute a series of moves with success being defined in terms of task completion within a minimum number of moves. In a pilot test of 30 9th-grade students, a Cronbach alpha of 0.61 was obtained.

Inhibiting Ability. Inhibiting ability was measured by perseveration error on the WCST (Heaton *et al.*, 1993; Kwon, 1997). The WCST consists of four stimulus cards and 128 response cards. The first stimulus card showes one red triangle. The second shows two green stars. The third shows three yellow crosses. And the fourth shows four blue circles. The 128 response cards have different shapes (crosses, circles, triangles, or stars), colors (red, yellow, blue, or green) and number of figures (one, two, three, or four). he number of perseveration errors for each category were summed to obtain a total number for each student. Data analyses were then run using these numbers. However, note that inhibiting ability is inversely correlated with the number of perseveration errors. In other words, students that make fewer perseveration errors are assumed to have more inhibiting ability.

Disembedding Ability. Disembedding ability was assessed by use of the GEFT (Witkin, Moore, Goodenough & Cox, 1977). The Korean version of the GEFT used in the present study consisted of 16 figures in each of two sections (Jeon & Jang, 1995). Students were given 10 minutes for each section. Subjects were given 10 minutes for each section. Reliability of the GEFT used in a population of Korean secondary student was Cronbach's alpha coefficient=0.70 (Ahn, 1995).

Mental Capacity. The FIT developed by Pascual-Leone & Smith (1969) has been used to assess students mental capacity (c.f., Pascual-Leone & Smith, 1969; Ahn, 1995). The FIT used in the present study was a group test consisting of 32 items. For each item, the subject had to place a point marking the intersection of up to two through eight overlapping figures. No time limit were given. The possible maximum score for the test was 32 point. A Cronbach's alpha reliability of the FIT used in a population of Korean secondary school students was 0.88 (Ahn, 1995).

Scientific Reasoning Ability. A 14-item written test was used to assess scientific reasoning ability (Kwon, 1997). All items required students to respond to a question or make a prediction in writing and to either explain how they obtained their answer, or in the case of quantitative problems, to show their calculations. Items were judge correct (a score of 1) if the correct answer plus an adequate explanation or set of calculation was present. Incorrect answers were scored 0. A Cronbach alpha reliability coefficient of 0.75 was obtained in a pilot study of 37 10th-grade students.

Air Pressure Concept Test. A test was constructed by the researcher to assess students' understanding of air pressure concepts. The test consists of six short-answer essay items concerning the causes of: 1. a milk shake traveling up in a straw when you "suck", 2. water rising in a cylinder inverted over a burning candle sitting in a pan of water, 3. a collapsing soda can submerged in cool water, 4. a peeled, hard-boiled egg entering a bottle that previously contained a burning piece of paper, 5. a rising hot air balloon and, 6. air entering your lungs. For example, Item 1 read: When drinking a milk shake with a straw, you can "suck" the milk shake into your mouth through the straw. How does "sucking" on the straw cause the milk shake to move up the straw? And Item 5 read: When you heat a hot-air balloon from below, th balloon rises. Explain why heating causes the balloon to rise.

Correct written responses were awarded 2 points each for a total of 12 possible points. Partially correct responses were awarded 1 point. Incorrect responses received 0 points. Content validity and item clarity were established through content-expert analysis prior to administration. A Cronbach's alpha reliability coefficient of 0.69 was obtained in a pilot study of 37 10th-grade students.

4. Instructional Treatment

Instructional treatment consisted of 14 two-hour, inquiry-based lessons using the learning cycle method of instruction (Lawson, Abraham & Renner, 1989). Lesson 1 introduced students to the scientific method through use of examples of prior scientific research. Once the pattern of scientific research was introduced (i.e., ***causal question→ alternative hypotheses→planned tests→expected results→ actual tests→actual results→conclusions***), students were given an opportunity to apply th pattern in the context of earthworm responses to various stimuli.

Lessons 2-4 provided students with an opportunity to apply th scientific method to generate and test hypotheses about why empty soda cans collapse when submerged in cool water. Following the test of several student-generated hypotheses, the instructor introduced relevant postulates of kinetic-molecular theory to explain the cause of greater air pressure outside the can, thus its collapse. Students were then challenged to apply the introduced concepts to predict and explain what will happen to air-filled balloons when cooled.

During lessons 5~7 students explored what happens when burning pieces of paper are dropped into bottles and then peeled hard boiled eggs are placed on the bottle openings. Based on their observations, students raised causal questions (e.g., What causes the eggs to move into th bottles?) and then generated and tested alternative hypotheses. The relevant postulates of kinetic-molecular theory were applied to explain the phenomenon. Students were then challenged to apply the theory to remove the eggs from the bottles and to explain what they did and why it worked.

Lesson 8~10 allowed students to explore what happens when an inverted cylinder is placed over a burning candle sitting upright in a pan of water. Students generated and tested several hypotheses in response to the question: What causes water to rise in the inverted cylinder? Again followed student hypothesis testing, relevant concepts of kinetic-molecular theory were applied to derive an explanation consistent with the students' observations.

During Lessons 11~12 students explored the causes liquids (e.g., milk shakes) moving up straws when students "sucked" on th straws. After again using air pressure concepts derived from kinetic-molecular theory to explain liquid movement, students were challenged to explain how syringes can be used to "draw" blood samples.

Lessons 13~14 challenged students to explore and explain how air passes into and out of one's lungs during breathing. Again relevant air pressure concepts were employed.

Ⅲ. Results

1. Prefrontal Lobe Functions Across Age

Figure 1a-d shows student performance on the four measures of prefrontal lobe functions across student age groups (Note: These agewise analyses were conducted by grouping students as follows: ages 13.0 to 13.9=age group 13, ages 14.0 to 14.9=age group 14, etc.). As you can see in Figure 3a, inhibiting ability decreased from age group 13 to 14 and then improved linearly from age group 14 to 16. Overall group differences were statistically significant ($F_{3,202}=3.728$, $p<0.01$). To determine which specific age groups differed in inhibiting ability, a post hoc test (Tukey's test) was conducted. The test showed that the difference between age groups 14 and 16 was statistically significant ($p<0.01$).

As shown in Figure 1b, planning ability decreased

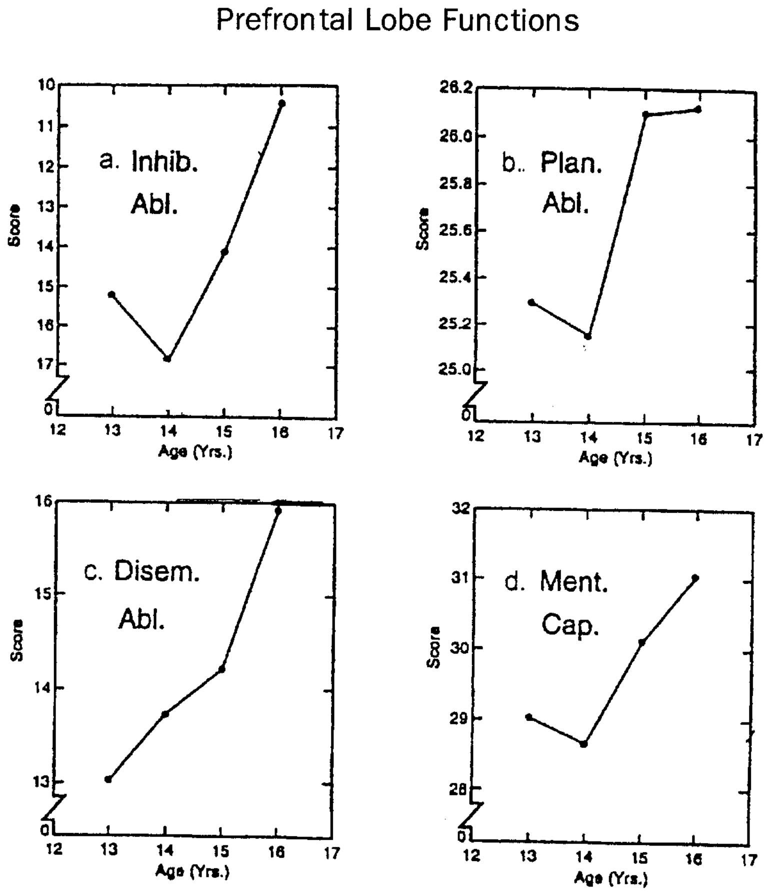

Fig. 1 Prefrontal lobe functions across age

from age group 13 to 14, then improved dramatically in age group 15, and then only slightly in age group 16. Overall improvements with age were not statistically significant ($F_{3,202}=1.30$, $p>0.25$).

Figure 3c shows that disembedding ability increased in a generally linear, but not significant, fashion across all age groups ($F_{3,203}=1.93$, $p>0.10$).

Finally, as seen in Figure 3d, mental capacity decreased from age group 13 to 14 and then increased linearly from age group 14 to 16. Overall group differences were statistically significant ($F_{3,202}=4.06$, $p<0.01$). The post hoc Tukey's test showed that mental capacity differences between ages 14 and 16, and 13 and 16 were statistically significant ($p<0.01$).

2. Scientific Reasoning Ability Across Age

As you can see in Figure 2, scientific reasoning ability increased in a generally linear fashion across age. A slight increase in rate of improvement can be seen after age 14. Overall age-group improvements were statistically significant ($F_{3,202}=14.58$, $p<0.01$). Tukey's test revealed statistically significant differences between ages 13 and 15, 13 and 16, 14 and 15, and 14 and 16 ($p<0.05$), but not between age 13 and 14.

3. Concept Acquisition Across Age

Figure 3 shows student performance on the test of air pressure concepts across age groups. Pretest mean scores, posttest mean scores, and mean gain scores (i.e., posttest minus pretest scores) are shown. As you can see, both pretest and posttest mean scores improved with age. Both main effects were statistically significant ($F_{3,202}=7.172$, $p<0.001$ and $F_{3,202}=11.418$, $p<0.001$, respectively). Agewise improvement in mean gain scores was also statistically significant ($F_{3,202}=5.483$, $p<0.01$). The gain scores for the 13 and 14-year-old groups were nearly identical (3.5 and 3.6 points respectively), while the 15-year-olds showed somewhat greater gains (4.5 points) and the 16-year-olds showed still greater gains (about 5.3 points). Tukey's test showed that the gains between ages 13 and 16, and 14 and 16 were statistically significant ($p<0.05$). Importantly, in terms of the study's central hypothesis, the difference between age 13 and 14 gains was not statistically significant.

Ⅳ. Discussions

The present study showed an interesting results in students' performance pattern on tests of prefrontal lobe functions, reasoning and conceptual change across age. That is, reasoning or learning capacity during around age 14 showed a plateau phase, rather than linear increase. For example, the data presented in Figure 1a and 1d show that inhibiting ability and mental capacity dropped from age 13 to 14 and then showed the expected increases at ages 15 and 16. The performance pattern for planning ability (Figure 1c) is also largely as expected with the exception of the unexplained performance plateau between ages 15 and 16. The performance pattern for disembedding ability (Figure 1c) is not the expected one based on the brain-growth hypothesis. But notice that neither is it the linear one expected based on the alternative experience hypothesis. Whether or not the apparent increase in rate of disembedding improvement seen after age 15 is real, or merely an artifact of the present sample, is an issue that remains for future research. Nevertheless, the data in Figure 3 in large part support the hypothesis that prefrontal cognitive abilities are acquired during early adolescence in a non-linear manner, hence are under the influence of neurological maturational.

Figure 2 shows a generally linear increase in scientific reasoning ability with age. However, the rate of improvement appears to accelerate after age 14 and, as mentioned, the difference between the 13 and 14-year-olds' scores was not statistically significant. This pattern, which appears to be a "hybrid" between the linear experiential pattern and the pla-

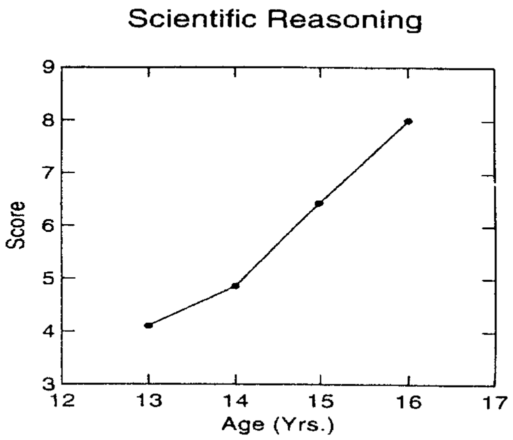

Fig. 2 Scientific reasoning ability across age

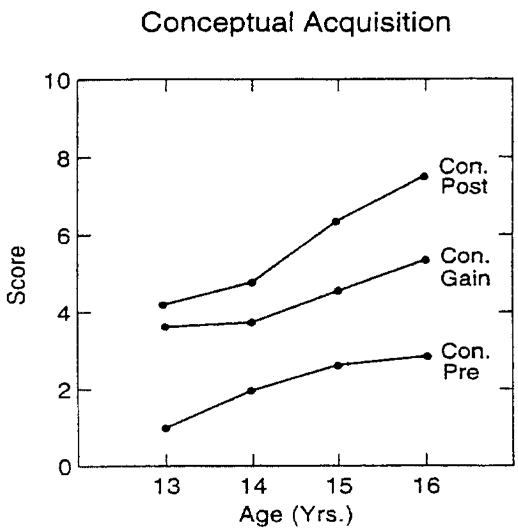

Fig. 3 Concept acquisition across age

teau/spurt maturational pattern, supports the hypothesis that improvement in scientific reasoning ability is a product of both neurological maturation and experience (physical and social). The failure of the 14-year-olds to outperform the 13-year-olds is similar to the result reported by Piburn & Enyeart (1985). They administered a test of logical syllogisms and propositional logic to students in grades 4 through 12 and found that performance dropped from 8th grade (mean age=13.2) to 9th grade (mean age 14.4) and then improved slightly among the 10th graders (mean age 15.4).

Figure 3, which shows student performance on the concept pretest, on the concept posttest and concept gains, reveals the expected improvements with age. Importantly, learning capacity as evidenced by the gain scores shows the expected plateau and spurt pattern as the gain scores of the 13 and 14-year-olds were virtually identical (3.5 and 3.6 respectively). The failure of the 14-year-olds to outperform the 13-year-olds is similar to the result reported by Choi & Hur (1987). They administered a test of biology, chemistry and physics concepts to students in grades 7, 8 and 9 and found that performance dropped from 7th grade (mean age=12.9, mean score=11.8) to 8th grade (mean age 13.9, mean score=10.7) and then improved slightly among the 9th graders (mean age 14.8, mean score=12.8).

Finding additional evidence of a brain growth plateau during early adolescence is not too surprising given that developing individuals have only so much energy to spare. Thus, when a considerable amount of energy is being devoted to achieving sexual maturity, it only stands to reason that the development of other body systems, such as the brain and nervous system, would be temporality "put on hold." It also stands to reason that the rate of cognitive development and learning during this time would also be slowed.

As mentioned in the introduction, once puberty is over, brain growth resumes with increases in prefrontal neuron size, connectiveness and myelinization. Increased myelinization means faster transmission of nerve signals and increased connectiveness implies increased cognitive connectiveness and coordination. The neurological details of how this plays out in terms of the acquisition of theoretical concepts is a matter of speculation. However, based in part on Grossberg's neural modeling principles (Grossberg, 1982), Levine and Prueitt (1989) have found evidence for a neural model of performance on the Wisconsin Card Sorting Task, a model that appears applicable to descriptive concept acquisition (Lawson, 1993) and perhaps to theoretical concept acquisition as well. One of Grossberg's principles and a key feature of the Levine & Prueitt model is that signals from the prefrontal lobes must be sent to "bias nodes" to suppress their influence on future behavior. If their signals are too weak, prior biases (i.e., prior misconceptions) are not suppressed and behavior will not change (i.e., perseveration errors persist). Thus, it is possible that increased myelinization might strengthen the signals enough so that they can inhibit the prior biases /misconceptions enough so that alternatives can be considered.

Another of Grossberg's principles used in that model is that keeping ideas /information active in working memory requires neural activity that decays at a constant rate. Thus, when a string of information units (e.g., random numbers) enters working memory, the string length is limited because the first items that enter begin to decay (i.e., start to be forgotten) while the later ones are being added. For mature adults the maximum number of separate information items that can simultaneously be held in working memory is about seven (Miller, 1956). But for children and young adolescents, the number is less. In short, what may be occurring during neural maturation is that biological changes (e.g., increased myelinization) result in faster neural transmission, which allows for more information to be plugged into working memory before decay becomes a problem. This implies that more complex and longer arguments can be assimilated, which suggests that more abstract /theoretical concepts can be understood.

For example, the entire argument that may have to be assimilated to reject the oxygen-consumption hypothesis in the candle burning experiment might go something like this:

If…water is sucked up because oxygen is consumed creating a partial vacuum (oxygen-consumption hypothesis),

and…the height that water rises with one, two, three, or more candles is measured (proposed test),

then…the height of water rise should be the same regardless of the number of burning candles (expected result). This result is expected presumably because there is only so much oxygen in the cylinder. So more candles will burn up the available oxygen faster; but they will not burn up more oxygen. Hence, the water level should rise the same (theoretical rationale).

But…when the actual experiment is conducted, we find that more candles make the water rise higher (actual result),

Therefore…the oxygen consumption hypothesis has been contradicted and should be rejected (conclusion).

If we assume that the entire argument must be retained in working memory for its assimilation, then it seems that working memory capacity must be fairly large. Just how large must it be? Perhaps retaining the hypothesis occupies one unit of working memory. If so, then the proposed test may occupy a second unit and the expected result may occupy a third. The theoretical rationale may then occupy a fourth unit. The actual experiment and its result may occupy a fifth and a sixth unit. This leaves the seventh and final unit for drawing the conclusion. Thus, if no prior chunking of these units occurs, a student may need a mental capacity of at least e+7 units to assimilate the entire argument.

While most of the older students (age 16+) in the present study had measured mental capacities of e+7, as mentioned, many nevertheless failed to offer completely satisfactory explanations on posttest Item 2 (the item asking for an explanation of water rise in the burning candle experiment). Perhaps this difficulty remains because, as mentioned, conceptual change not only requires the assimilation of complex many-step arguments, it also requires the initial inhibition of prior biases /beliefs /misconceptions. Most certainly, conceptual change also requires the assimilation of new alternative beliefs/conceptions. In this case, those new conceptions involve a whole host of complex and theoretical notions, thus conceptual change in the present context may simply be too much for the developing neural mechanisms of most of our students to deal with. In other words, the learning challenge presented by lessons of the present study probably stretched the students to the very limits of their still developing neural mechanisms, if not beyond.

V. Conclusions and Implications

The present study provides support for the hypothesis that an early adolescent brain growth plateau and spurt exist (c.f., Epstein, 1978). Support was also obtained for the corollary hypothesis that this plateau and spurt influence students' ability reason scientifically and to learn theoretical science concepts.

Also, the present conclusion draws into question the value of trying to teach young adolescents theoretical concepts such as those taught in the present study. For example, based on posttest scores on Item 2, which asked students to explain why water rises in the burning candle experiment, it appears that not many of our students had sufficient inhibiting ability, representing ability and reasoning ability to undergo the conceptual change necessary to provide the correct scientific explanation. Even after 14 two-hour lessons, all focused on air-pressure concepts, success on Item 2 among the 8th graders was an abysmal 9% and it topped out at only 26% among the 11th graders. Clearly we have to conclude that for most students, our instruction was not entirely successful. It is hard to imagine many teachers willing to put forth a more concerted effort to teach such concepts (not to mention students willing to put up with such an effort). Therefore, it seems reasonable to simply delay trying to teach such concepts until students are more mature and more experienced, thus better able to profit for such instruction (c.f., Epstein & Toepfer, 1978; Cramer, 1981). Admittedly this is a rather pessimistic recommendation given the understandable desire to teach advanced material to students as soon as possible. But most educators agree that if the cognitive characteristics of students are not taken into consideration, the result is rote learning and more often than not, intellectual stagnation rather than intellectual development. Thus, perhaps the recommendation is not so pessimistic if it forces teachers and curriculum developers to think more deeply about how theoretical concepts are being taught, why they are being taught and to what ages of students they should be taught.

Abstract

The present study tested the hypothesis that adolescent's prefrontal lobe growth plateau and spurt exists and that this plateau and spurt influence students' ability to reason scientifically and to learn theoretical science concepts. In theory, maturation of the prefrontal lobes during early adolescence allows for improvements in students' abilities to inhibit task-irrelevant information and coordinate task-relevant information, which along with both physical and social experience, influences scientific reasoning ability and the ability to reject scientific misconceptions and accept scientific conceptions. Two hundred six students ages 13 to 16 years enrolled in four Korean secondary schools were administered tests of prefrontal lobe functions, scientific reasoning, and theoretical concepts derived from kinetic-molecular theory. A series of 14 lessons designed to teach the concepts were then taught. The concepts test was then re-administered following instruction. As predicted among the 14-year-olds, performance on the measures of prefrontal lobe functions, scientific reasoning, and conceptual change remained similar or regressed. Performance then improved considerably among the 15 and 16-year-olds. Because so few of the present

students were able to undergo this apparently necessary conceptual change, the value of introducing theoretical concepts to early adolescent is questioned.

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