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ACTIVE INHIBITION

IN A

MENTAL ATTENTION REVERSAL - SHIFT TASK

IRINA VALENTIN

A thesis submitted to the Faculty of Graduate Studies in
partial fulfillment of the requirements
for the degree of

Master of Arts

Graduate Program in Psychology
York University
Toronto, Ontario

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Active inhibition in a mental attention reversal-shift task

by Irina Valentin

a thesis submitted to the Faculty of Graduate Studies of York University in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

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Abstract

Central to the understanding of the development of cognitive processing is the exploration and elucidation of the mechanisms involved in inhibition and interference. This study investigated whether there are differences in the development of active inhibition and interference. The negative priming (NP) paradigm, the delay in response to previously irrelevant stimuli, was used to test inhibition. The reversal shift (RS) paradigm, the delay in response due to the shifting of the relevant colour, was used to test interference. Twenty children in each of grades 2, 4, and 6 were tested with the computer-based Mental-Attention Reversal Shift (MARS), task designed for the present study. In the MARS task the subjects were asked to respond by pressing keyboard buttons corresponding relevant animal shapes presented, along with distractors, on a computer screen. Relevance was determined by animal colour (red or blue) which had to match the colour of a "wand" displayed at the top of the screen. The number of relevant animal shapes (item class) varied randomly from one to four, and they were located randomly among the same number of animals in the irrelevant colour and letters of the English alphabet. The total number of shapes in any one testing trial of the MARS task was 26, and the total number of red shapes was equal to the number of blue shapes. All shapes were randomly located in an invisible circle in the center of the screen. Analysis of time of first keypress indicated that there were significant delays in the negative priming (NP) and reversal shift (RS) displays relative to the control condition; responses in RS displays were slower than in NP. Children were less accurate in RS, but not in NP, compared with the control condition. Overall grade 2 children were slower to respond, but not less accurate, than were the older children. A mixed models analysis indicated that negative

priming delays were restricted to class 4 items. In contrast, grade 4 and 6 children showed delay in RS among all item classes. Younger children (grade 2) showed RS delay in responses only in item class 3. On the basis of these results it was concluded that inhibition and interference are different mechanisms of interruption.

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Contents

Introduction 1
What Happens to Irrelevant Information: From Precategorical Selection to Active Inhibition 1
Facilitatory and Inhibitory Models of Attention 5
Development of Operators with Age 14
Interference vs. Inhibition 22
Capacity Limitation of Inhibition 25
Statement of the Problem 27
Purpose of the Present Study 28
Method 40
Participants 40
Stimuli 40
Procedure 44
Apparatus and Materials 45
Statistical Analysis 47
Descriptive Analysis of Latency 48
Analysis of Accuracy 54
Analysis of Variance 57
Analysis of Correlation 64
Mixed Models Analysis 65
Discussion 69
References 76

Appendixes
A - Sample Items from the MARS task 84
B - Administration Procedure for the MARS task 90
C - Introduction and Training Sequence Control File for the MARS Task 96
D – Descriptive Data for the MARS task 101
E – Results of Mixed Model Analysis of Latency 1 113

Tables

1. Predicted Maximum M-power Values as a Function of Age, and Their Correspondence to the Piagetian Substage Sequence 16

2. Positive and Negative Instances of Cues in the CSVI Task 17

3. The Difference in Individual Means for Latency 1 Between the Control and the Negative Priming Conditions and the Control and the Shifting Colour Conditions 52

4. Percentages of Omitted and Incorrect First Responses 56

5. Repeated Measures Analysis of Variance of Latency 1 57

6. Repeated Measures Analysis of Variance of Accuracy 1 58

7. Repeated Measures Analysis of Variance of Overall Accuracy 58

8. The Results of Mixed Model Analysis of Latency for Correct Responsees After log-transformation and removing outliers 68

Figures

1. Pascual-Leone's model of mental attention 10
2. An example of a prime trial, class 1, in the MARS task 31
3. An example of a probe trial, class 1, negative priming condition 31
4. An example of a prime trial, class 2, in the MARS task 32
5. An example of a probe trial, class 2, shifting colour condition 32
6. An example of a prime trial, class 4, in the MARS task 33
7. An example of a probe trial, class 4, control condition 33
8. Stimuli (animals) and corresponding responses (labeled keyboard keys) of the MARS task 43
9. Plots of latency 1 for negative priming condition, class 2 for one of the subjects in grade 4 49
10. Histograms and density curves of latency 1 for correct responses after removing outliers for grade 4 before the log-transformation of the latencies and density curve after the transformation 50
11. The difference in individual means of latency 1 for subjects in grade 4 for different conditions 53
12. Overall accuracy, as function of grade 54
13. Overall accuracy, as function of class 55
14. Overall accuracy, as function of condition 55
15. Means of latency 1 medians, as function of grade 59
16. Means of accuracy, as function of grade 59
17. Means of latency 1 medians, as function of class 60
18. Means of accuracy 1, as function of class 61
19. Means of latency 1 medians, as function of condition 62
20. Means of accuracy 1, as function of condition 63
21. Means of latency 1 medians, as function of condition, item class, and grade 67

Introduction.

Inhibition is a topic of great interest in current cognitive psychology. This is in part because of the "discovery" of the so-called negative priming effect (NP), or the delay in response to previously irrelevant stimuli. Negative priming is considered a function of selective attention. Inhibition in general, and negative priming specifically, is a topic of interest now not only in cognitive science but also in the field of artificial intelligence. Up until now inhibitory process have been absent in computer analogies and algorithms. A major problem is to determine exactly how inhibition works. To find the answer to this question, inhibition should be distinguished from other processes such as stimulus identification, interference and memory. Especially interesting are processes involved in the development of inhibition, and their relation to other functions of attention. The following literature review is designed to provide a broad perspective on the work done to date on inhibitory processes.

What Happens to Irrelevant Information:

From Precategorical Selection to Active Inhibition.

The history of attempts to find answers to the question of what happens to irrelevant information begins during the Second World War and fully emerges in the 1950s. The earliest and best-known work that deals with this question is referred to as *early selection theory*, or Broadbent's (1958) *Filter theory. Early selection* conveys the idea that all selection occurs early in the stream of processing; selection is said to precede stimulus identification. Broadbent's basic hypothesis was that all stimuli reaching the sensory system are processed to the point at which certain physical attributes (e.g., location, loudness, and pitch of auditory stimuli) are analyzed and

explicitly represented. He suggested that the processes involved in identifying stimuli (e.g., recognizing an individual letter or word and comprehending its meaning) are capable of handling only one stimulus at a time. A filtering device, analyzing simple physical attributes, is responsible for determining which stimuli are to be processed further. Therefore, according to early selection theory, perceptual processes operate in parallel; more elaborate processing involved in the identification of stimuli occurs serially, with one stimulus analyzed and then the next.

The most extreme alternative to Broadbent's early selection theory is what is usually called *"late selection theory"*. Deutsch and Deutsch (1963) proposed well-known versions of this theory, as did Norman (1968), and more recently Duncan (1980). The basic idea underlying the late selection theory is that the processes involved in recognizing stimuli as belonging to familiar categories are activated for all incoming stimuli, to the degree the sensory input is adequate to permit it. One cannot voluntarily choose to identify or recognize something, according to this theory. Therefore, the late selection theory, in contrast to early selection theory, suggests that the processes involved in identifying stimuli (e.g., recognizing an individual letter or word and comprehending its meaning) are activated in parallel at any particular time, unselectively and without any capacity limitations. However, only the stimuli attended to are selected and processed in parallel for access to a system required for awareness and response. Related to this theory is the *mediational* theory of discrimination (Zeaman & House, 1963) that, in contrast to the single-unit model, involves an additional link that transforms incoming stimulation into some internal representation that leads to the response (S-r-s-R).

These two models, early selection and late selection, may represent, however, different strategies for schema choice (criterion of relevance) in a task. Early selection is more likely when

the task is very well defined in advance and quite familiar. Late selection is more likely in not well defined tasks or unfamiliar cues.

In contrast to *early selection* theory, according to which selection is precategorical and attending to relevant stimuli does not affect irrelevant S-R, late selection is categorical and posits an interrelationship between relevant and irrelevant stimuli. Treisman (1960) proposed that unattended, and therefore attenuated, stimuli, which are reduced in quality or intensity, would not produce enough activity to cause the corresponding detector to reach its threshold. However, when the detector represents a concept that is somehow related to concepts that have recently been activated, which Treisman called *priming,* partial activation might be enough for recognition. According to the *"passive decay" model* (e.g., van der Heijden, 1981) irrelevant activation from unattended objects passively decays, whereas the activation level of the representation of the relevant object is maintained or accentuated.

One of the models described by Kendler and Kendler (1975) suggests that the strengthening of relevant stimuli leads to the weakening of irrelevant stimuli. An alternative model is the *activation-suppression model* (Keel & Neill, 1978; Neill, 1977; Tipper & Driver, 1988). The activation-suppression model proposes that following automatic activation, the internal representations of task-irrelevant, to-be-ignored objects are actively inhibited. Compared with other theories, the activation-suppression model predicts that recently irrelevant information may be less readily available for future processing than information that was not recently suppressed.

The critical evidence for the processing of rejected stimuli consists of changes in the speed, or accuracy, of responses to the target as a function of the relationship between the rejected stimulus and the target. The Stroop (Stroop, 1935) and "flanker" (Eriksen & Hoffman, 1973)

effects are the best known examples of this relationship. In the Stroop effect, when the word spells out the name of an incompatible color (e.g., GREEN printed in red ink) one is substantially slower to respond to the ink colour (e.g.,"red") than in a neutral condition (e.g., CHAIR printed in red ink). The difference is often over 100 msec.

Analogous to the Stroop effect are so-called *"flanker" effects.* Eriksen and Hoffman (1973) had subjects make a speeded response to a central letter, pressing the left key for an *A* or a *U* and the right key for an *H* or an *M*, for example. Next to these letters were other letters that the subject attempted to ignore. When these "flankers" were associated with the opposite response from the correct one on that trial (e.g., an H surrounding a target A), RT's to the target letter (here, A) were slowed, compared with the case when the distractors were associated with the correct response. Closely analogous "flanker" effects have also been observed in tasks involving words. Shaffer and LaBerge (1979) presented two identical words above and below a central target word. The subject's response depended on the semantic category of the central word. When the flanking words were drawn from a different category than the target, RTs were slowed by about 40 msec.

Evidence for active inhibition has come from studies following a seminal study by Dalrymple-Alford and Budayr (1966) that tracked the fate of irrelevant material once it had been selected again. Neil (1977) exploited this strategy using a variation of the Stroop colour/word task. Neil compared two conditions: trials in which the current ink colour did not match the distractor word in the proceeding trial and trials in which it did. An example of the latter is: If on a given trial GREEN was printed in red ink, the next word (e.g., BLUE) would be printed in green ink. His results showed that saying the hue of a Stroop stimulus is especially difficult when the to-be-named colour was the preceding colour word. It follows that if a suppressed colour word

immediately thereafter becomes task-relevant (i.e., the ink colour to be named), it should be relatively more difficult to access than some other colour name.

Tipper demonstrated the same delay in a letter-naming task, and named this effect *"negative-priming"*. Tipper and Cranston (1985) showed subjects two letters, one red and one green that were slightly superimposed. The task was to read aloud the red letter as accurately as possible. When the red letter on trial n+1 had been the green letter on trial n, it was named more slowly than if the green letter on the previous trial had been a control letter. Despite the fact that Tipper explained this result using an inhibitory-based model, he later admitted that "...attempts to account for all of NP with a single, elegant theory may be what has led to the present state of complexity. Understanding may be served if researchers acknowledge that two (or more) separate and independent mechanisms may be responsible for NP" (Tipper & Milliken, 1996).

Facilitatory and Inhibitory Models of Attention.

At the outset of this literature review it was pointed out that one of the reasons for such special interest in active inhibition is the absence of computer analogies and algorithms of inhibitory processes of irrelevant information. While discussing the difference between computer processing models and the human mind, Neill and his colleges note that the computer models work according to a "facilitatory model of attention" (Neill,Valdes, & Terry, 1995). Further they refer to two concepts of attention: attention as facilitation and attention as inhibition. These models have one part in common: information first is processed automatically to some level without need for attention. Attention then step in, and only selected, relevant information is further processed. From then on the two models differ: In the facilitatory model ignored stimuli are not processed further, and their effects dissipate passively over time. In the inhibitory model

the mechanism of attention inhibits the processing of irrelevant information (Van der Heijden, 1981).

There are several questions raised by these models. The first question is whether the human mind has both facilitatory and inhibitory attentional processes. If the answer is "yes", then how are they sequenced (alternated) in processing. The second question concerns how attentional processes select information that is relevant and distinguishe it from information that is irrelevant. The third question is whether or not "passive" irrelevant information interferes with the processing of relevant information. One answer to the first question, whether or not the human mind has both processes of attention, can be found in Pascual-Leone's Theory of Constructive Operators (TCO) (Pascual-Leone, 1970,1987).

According to Pascual-Leone the human mind, in contrast to the computer models, has both facilitatory and inhibitory attention, which can be applied depending on whether the situation is facilitating or misleading (Pascual-Leone & Johnson, 1999b). A situation is *facilitating* whenever it evokes only responses that lead to a correct response. Pascual-Leone and Johnson (1999a, p.16) give the definition of misleading situations as those "that activate mutually incompatible schemes, where the initially stronger schemes are unsuitable for the task at hand. In misleading situations mental attention often must be used to generate an adaptive, mindful performance. Mindlessness is the consequence of failing to use mental attention to inhibit the initially dominant (often automatized) misleading schemes, in these situations."

Pascual-Leone suggests that there are two subsystems that work for different situations. He speculates that these subsystems are organized in different cerebral hemispheres: the right hemisphere (RH) is optimal for coping with facilitating situations and the left hemisphere (LH) is specialized for misleading situations. "Coordination of this RH/LH dialectical system is carried

out by the prefrontal lobe, which contains the executives (i.e., executive shemes) and the mental attentional mechanisms (see below) that serve to select the suitable LH strategy (Pascual-Leone, 1989, 'X-strategy') and provide the mental attentional effort needed to overcome RH strategies (Pascual-Leone's 'Y-strategies') when they are misleading." (Pascual-Leone & Johnson, 1999a, p.11)

According to Pascual-Leone the two subsystems differ in semantic-pragmatic components ("software") which can be modified through experience, and neuroanatomic structures ("hardware") which cannot. The individual "software" components are informational units called *schemes* that are subjective and specific to given situations or types of situations, and embody invariants from/for experience and performance. "These schemes are very active and self-propelling. When they are compatibles and relevant within a task, they dynamically construct together, via overdetermination, the subject's performance" (J. Pascual-Leone, personal communication, December 1, 1999). There are six different categories of schemes, among them *figurative* schemes for the state description of data, *operative* schemes that embody blueprints for concrete actions, and *executive* schemes (Pascual-Leone & Johnson, 1999a). Executive schemes carry plans or cognitive goals abstracted from actual performance by monitoring and controlling the activation and application (to produce the performance) of figurative and operative schemes. In this enterprise of constructing/synthesizing performance the task-relevant executive schemes, working together as a unified operator (i.e., the E operator mentioned below), utilize two major attentional resources, a mental-activation resource (called below M operator) and a mental-inhibition resource (called below I-operator; J. Pascual-Leone, personal communication, December 1, 1999).

In facilitating situations task-relevant schemes are activated externally and are based on content representations or direct perception. Content representations, "which are either innate or reductively abstracted from experience, ... act as signifiers (signals) for other schemes (figurative or operative) that in praxis are related to the content representations either indexically (i.e., via associative learning) or iconically (i.e., via a configural similarity relation produced ...)" (Pascual-Leone & Johnson, 1999b, p.7). Content representations differ from direct perception. While they are both based on perceptual signals, direct perception is based on relations found within a context, and encode real, particular objects of experience without reduction of information. In contrast, content representations are found across contexts and are concepts, based on reduction of information, and " driven by ecological relations ...found across contexts" (Pascual-Leone & Johnson, 1999b, p.8).

In misleading situations task-relevant schemas are activated externally (bottom-up process) and/or internally (top-down process). In the case of the bottom-up process of associative learning, schemes not relevant to the task may be also activated, and "as a result, highly activated schemes, even if they are misleading, tend to dominate and determine performance. This is why purely associative organisms or machines are so limited in truly novel, creative problem solving" (Pascual-Leone & Johnson, 1999b, p.15). In contrast, in the case of internal activation, the subject's mental attention (effortful attention) is applied, and processed representations are extended to using executive representations that refer to future or possible outcomes, and are based on symbols instead of signals. In the case of top-down process subjects use problem-solving, "non-automatized methods (invention, creatively-synthesized truly-novel performance) to cope with task demands and do so by way of dynamic syntheses. ... In these syntheses, task-

relevant schemes not activated by the situation are internally activated by the subject's mental attention" (Pascual-Leone & Johnson, 1999b, p.15).

Mental attention can be used to hyperactivate task-relevant schemes that are not highly activated by the situation using the M-operator ("mental" operator) identified above as "hardware", or inhibit schemes that are task-irrelevant using I-operator ("interruption" operator). This process is monitored by the E-operator (executive operator) (Pascual-Leone, 1970,1987). The Executive (E) operator, a hardware and software hybrid operator, uses the other resources (M and I) and has a higher order planning function, which includes the appropriate timing and sequential application of action schemes. The F-operator serves to help organize the task as a whole such that the individual conceptualizes the task as a unitary construct rather than as its individual parts, and may minimize certain schemes as a result by developing new and more productive strategies for solving the task. These resources act together to produce mental attention, and are governed by the principle of Schemes' Overdetermination of Performance (SOP). According to this principle the response is synthesized by a dominant (most activated) cluster of compatible activated schemes available in the brain at the time of responding.

Figure 1 illustrates Pascual-Leone's model of mental attention. Pascual-Leone and Johnson (1999a, p.20) describe this model as follows:

> The hardware operators E, M, and I, all mechanisms related to the prefrontal lobe, are represented in Figure 1 as a "flashlight" of mental attention that directs its beam to the repertoire of substantive ("action") schemes located in other cortical regions. The inner ellipse of its mental-attentional "light" we call the M-space; it represents the processes that we actually keep in mind – the set of schemes to which mental-attentional energy, i.e., M capacity, is allocated to

hyperactivate schemes.... In misleading situations the I-operator is often willfully (effortfully!) mobilized and allocated first to schemes that are clearly irrelevant (misleading or distracting) for the task at hand. Then, only after, M capacity is mobilized and allocated to relevant schemes. ...Notice that often there are hyperactivated schemes that are not being activated by mental attention (i.e., not part of M-space). These otherwise hyperactivated schemes we represent in Figure 1 as being inside the second ellipse. The mental space demarcated by this second ellipse (which of course includes the M- space) is, we believe, what most psychologists mean by "working memory"....

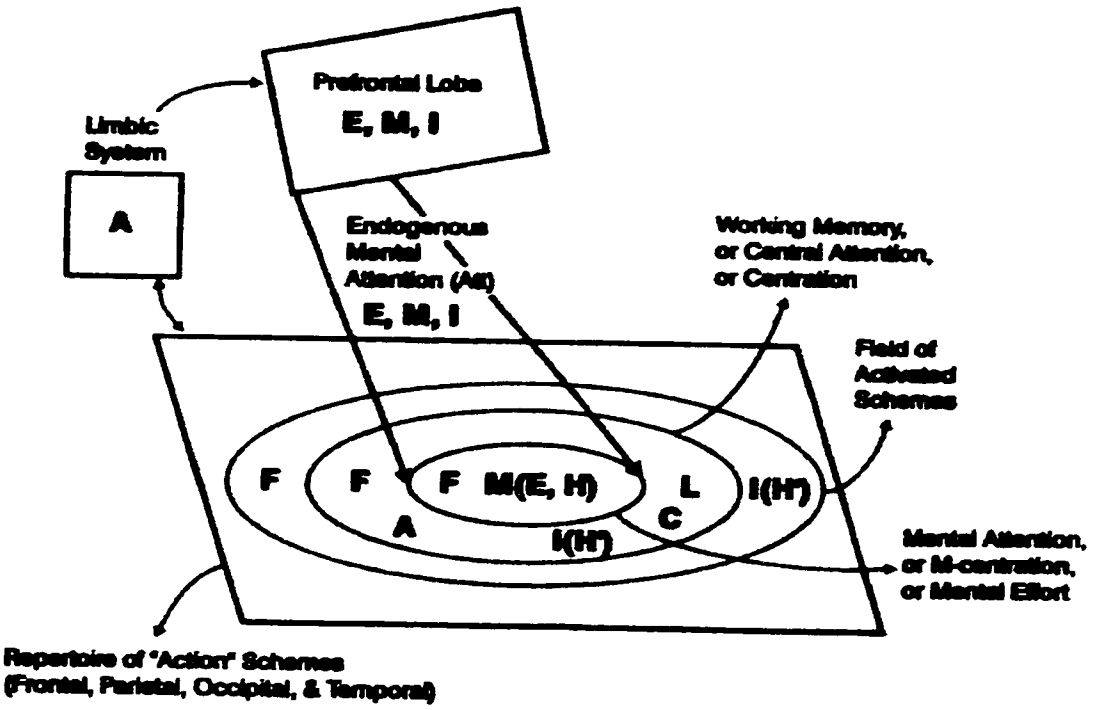


Fig.1

Pascual-Leone's model of mental attention

Memory and the I, E, M Operators of Attention.

As has been discussed above, one of the mechanisms of attention, according to Pascual-Leone, is the executive operator (E). Executive functions are widely discussed in the current literature where they are often connected to working memory. One reason for this is the popularity of Baddeley's model of working memory (Baddeley & Hitch, 1994; Baddeley & Della Sala, 1998), according to which working memory is a system for holding and manipulating information while performing a wide range of tasks. According to Baddeley, working memory, contains storage and control modules and has three functions: temporary retention of verbal material, temporary storage of visual images, and executive functions for control and manipulation of information.

In contrast to Baddeley's model, Pascual-Leone sees working memory as a set of hyperactivated schemes in the subject's repertoire, whether these schemes are endogenously boosted into hyperactivation by mental-attentional capacity or whether they are, instead, externally boosted by the situation via affective processes, or elicited automatized schemes, or perceptual salience. He also distinguishes between working memory and executive functions. Whereas Baddeley includes executive functions in the concept of working memory, Pascual-Leone sees them as separate processes. According to Pascual-Leone, the executive operator E, as well as M- and I- operators, are applied to activated task-relevant schemes, which are initially not part of working memory (i.e., not hyperactivated enough) and "bring them" into the "working-memory space". Control and manipulation of the set of activated schemes is provided by the goal-carrying E-operator (using M and I operators) by monitoring the attentional focusing on the requisite task relevant schemes at each specific step of the task, and concurrently inhibiting irrelevant schemas (J. Pascual-Leone, personal communications, December 4, 1999).

It can be difficult to separate retrieval from memory from application of the I-operator. One example of this might be the difficulty with retrieval older people sometimes have. Pascual-Leone (1983) suggests that failure of effortful retrieval from memory, or the failure of divided or selective attention, is due to the failing I-operator. He explains that in memorial recall the executive functions attempt to get from memory as many schemes as possible in order to evaluate them; and if the schemes are irrelevant, they have to be inhibited in order to make another retrieval operation. Consequently, when this effortful inhibition is defective due to a deficiency of the I-operator, retrieval from memory becomes more difficult.

The same problem, that of distinguishing between retrieval executions from memory and the I- operator, can be found in the discussion of reasons why the negative priming effect occurs. Neill explains the negative priming effect using an episodic-retrieval account in contrast to an inhibition-based account (Tipper & Milliken, 1996). According to the episodic-retrieval account, irrelevant information is tagged in memory with a no-response label as a unique episodic trace; and the no-response label should conflict on the next trial with the appropriate response to that item when the item has just become relevant. In contrast, the inhibitory account offered by Tipper and colleagues suggests that inhibitory mechanisms leave the mental representation of an irrelevant item (i.e., the perceptual scheme in question) in an active state, but inhibit access of that active representation by the response systems (i.e., they interrupt the activation of the task-relevant scheme in question). One of the results that support the episodic-retrieval account is the fact that the negative priming effect depends on the relative duration of exposure in prime (first display) and probe (the next display) trials (Neill & Valdes, 1996). The greatest negative priming effect (NP) occurs when the exposure time of the prime display is long compared with the exposure time of the probe display (4,000 ms vs. 500 ms gives 39 ms of priming effect in

comparison to 20ms of delay for 4,000/4,000 ms and 26 ms for 500/500 ms. (Neill, 1997). Tipper and Milliken (1996) admitted that it is difficult to explain this result from an inhibition-based account of NP and suggested that the field of NP cannot be explained from a single account because of the complexity of the process. It should be, however, emphasized the Pascual-Leone's model of constructive operators (i.e., of schemes and hardware operators) can in principle explain the results of Neil and Valdes (1996) by assuming that the active inhibition of irrelevant schemes during the prime trial, which the I-operator carries out, would be exerted throughout the time interval of stimulus.

Conway (1999) failed to show the largest amount of negative priming in the 4,000 ms vs. 500 ms condition and the smallest amount in the 500 ms vs. 4,000 ms, as is predicted by the episodic-retrieval account (ETR). Conway (1999, p.582) concluded that "...a focus of future research should be on factors that contribute to ETR. Particularly important are the implications for findings of individual and developmental differences in NP." He and his colleagues (Conway, Tuholski, Shisler, & Engle, in press) examined university undergraduate students and found that selective attention ability depends on individual working memory; only students with high working memory span demonstrated significant negative priming. Subjects' span was measured using an operation-word span task, which requires solving simple math problems (e.g., (6/2) + 2 = 5 ?) while trying to remember words (e.g., DOG). The number of operation-word pairs per series varied from 2-6. The span then was calculated as the sum of correctly recalled words from the series in which the subject repeated all words in their correct order and without intrusion in recalling words (Conway et al., in press). The results of the experiments did not answer, however, the question what causes what: Do inhibitory mechanisms contribute to performance on

the working memory task, or are individuals with high span more likely to inhibit irrelevant information (Conway et al., in press)?

Development of Operators with Age

The possibility that mental attention, the maximum number of items to which a person can attend at one time, might be related to qualitative differences in thought and reasoning was recognized by Piaget (1921, 1923). Piaget, however, assumed that the growth of this "working memory" (Piaget called this "field of equilibrium") is not the cause but is the consequence of cognitive-developmental changes (J. Pascual-Leone, personal communication, November 19, 1999). The theories that focus on the quantitative relationship between developmental changes, and mental capacity or working memory are usually referred to as neo-Piagetian theories and were originated by Pascual-Leone. Two of these theories, Case's theory of executive structures (Case, 1985), and Halford's theory of commutative systems (Halford, 1982) will be discussed briefly in this chapter. Pascual-Leone's theory of constructive operators (Pascual-Leone, 1970, 1987) has been already mentioned, and will be discussed in more detail in this and in subsequent sections.

In Case's (1985) theory of executive structures, four stages of intellectual development are distinguished, which correspond very generally to Piaget's stages. However, each of Case's stages is subdivided further into four substages. The same sequence of substages is found within each stage, such that the fourth substage within a given stage coincides with the first substage in the next higher stage. Whereas the stages differ qualitatively, the substages differ quantitatively. At each stage, the substage of operational consolidation involves the application of the strategy specific to that stage; and each subsequent substage involves the addition of another step to that

strategy until the accumulation of quantitative changes results in a qualitative change in strategies. According to Case, the pool of mental capacity is limited and does not change throughout life. In contrast, efficiency and processing speed do improve, according to Case, with the development of cognitive strategies (Case, Kurland, & Goldberg, 1989).

In Halford's (1982) theory of commutative systems, there are three general levels of deduction that differ from each other in terms of the number of task-relevant facts considered, and accordingly, in the number of symbolic representations required. Level 1 reasoning is characterized by unary operations and univariate functions, both of which involve one task relevant fact or two symbolic representations. Level 2 reasoning is characterized by binary operations and bivariate functions, involving two task-relevant facts or four symbolic representations. Ternary operations, or six symbolic representations, characterize level 3 reasoning. Therefore, cognitive development occurs through the development of encoding systems, different weights of which require increasing the amount of information to be encoded.

While both Halford's theory of commutative systems and Case's theory of executive structures see the increasing capacity of information processing through changes in "software", as applying efficient strategies or encoding information, Pascual-Leone's Theory of Constructive Operators sees it as development of both "software" (schemes) and "hardware". Pascual-Leone proposed a method of task analysis that counts the number of separate constraints (schemes) the subject applies in order to solve the task (Pascual-Leone & Johnson, 1999b). This allows one to measure quantitatively the development of mental attention operators with age.

Development of the M operator

Pascual-Leone's theoretical prediction of the development of the M-operator with age has been supported empirically, using a number of different tasks, such as a simple motor performance, visual-information processing, and metaphoric understanding (Pascual-Leone & Goodman, 1979; Pascual-Leone, 1987; Johnson, Fabian, & Pascual-Leone, 1989; Pascual-Leone, Johnson, Baskind, & Dworsky, 1998). Capacity to simultaneously activate relevant schemes in misleading situations (i.e., apply the M-operator) has been found to increase by one unit scheme every second year from 3 to 15 years of age, producing a latent step-wise pattern (when the M-operator capacity is assessed in terms of the number of distinct schemes simultaneously activated by the M-operator). Predicted maximum M-power, in terms of the maximum number *k* of knowledge structures that the subject can simultaneously boost with his/her mental capacity, are presented in Table 1 (from Pascual-Leone, 1987), where *e* is a constant representing the mental capacity available at the end of the second year of life and subsequently used to activate the task executive.

Table 1

Predicted Maximum M-power Values as a Function of Age, and Their Correspondence to the Piagetian Substage Sequence

M-power *(e + k)*	Piagetian substage	Normative chronological age
e+1	Low preoperations	3,4
e+2	High preoperations	5,6
e+3	Low concrete preoperations	7,8
e+4	High concrete operations	9,10
e+5	Substage introductory to formal operations	11,12
e+6	Low formal operations	13,14
e+7	High formal operations	15-adults

One of the tasks that was used to obtain these results was a Compound-Stimuli Visual Information Task (CSVI) (Pascual-Leone, 1970, 1978). The CSVI task has a two-step procedure, training and testing. During the training procedure the subject learns the repertoire of simple stimulus-response (S-R) units, where stimuli are physical cues of different dimensions, like size, shape or colour; and responses are the pressing of buttons associated with each stimulus. The buttons are located on the computer keyboard or specially designed panel and differ in colour and shape, and stimuli are presented on the computer screen or as a sequence of cards. During the training procedure the subject also learns to respond only to positive cues and not to respond to negative ones. The list of positive and negative cues for each dimension is presented in Table 2. Since one positive cue is presented at the same time with negative cues, the subject learns to apply M power in order to hyperactivate the schema of the positive cue and respond to this one cue.

Table 2

Positive and Negative instances of Cues in the CSVI Task.

Dimension	Positive cues	Negative cues
Shape	Square	Circle, triangle, cross
Color	Red	Blue, yellow, green
Size	Large	Small
Underline	Present	Absent
Closure	Open spaces in contour	Closed
Circle in the center of the figure	Present	Absent
Outline X in the center of the figure	Present	Absent
Frame around figure	Present	Absent
Dots on background	Present	Absent

During the testing procedure compound stimuli are presented, composed of two to eight positive cues, and the subject is asked to respond to as many positive cues as he or she can detect.

The subject has to boost multiple schemes of positive cues so as to respond to them and may, therefore, miss responding to some cues due to his/her limited M capacity. Since there are no interfering responses to cues, the subject uses facilitatory attention and does not apply the I-operator.

Development of the I- operator

There exists already much research suggesting that the efficiency of inhibition increases from childhood to adulthood and that young children have inefficient inhibition (Pascual-Leone,1980; Pascual-Leone & Goodman, 1979; Johnson et al., 1989; Pascual-Leone, 1989; Dempster, 1992; Harnishfeger & Bjorklund, 1994; Tipper et al., 1989). Diamond (1988), for instance, argues that the infant's failing in the Piagetian A-notB task is an example of this. In the Piagetian A-notB task, after an infant has learned to reach into a covered well (well "A") to retrieve a hidden toy, the toy is hidden in full view of the infant in a different well (well "B"). Infants younger than 1 year usually continue to reach into well "A".

Lorsbach, Katz, and Cupak (1998) examined whether children abandon their initial misinterpretation of garden path passages. Twenty four subjects at each of three age levels (3rd grade, 6th grade, and college) listened to either expected or unexpected (garden path) versions of passages that differed in the degree to which they provided contextual support for the final, correct interpretation. The first half of garden path passages initially led the listener to generate an incorrect interpretation. The second half of the passages provided information that clearly supported the correct inference and required one to abandon the previous misinterpretation. Correct target inferences were formed and were equally available to all age groups. However, both groups of children were more likely than college students to accept competing inferences as

being consistent with their understanding at the conclusion of garden path passages. The results suggest that developmental differences exist in the ability to inhibit thoughts that are no longer relevant in a listening comprehension and memory task.

Tipper and his colleagues (Tipper et al., 1989) used the Stroop task with 20 second-grade children, with an average age of 7 years 7 months, and 20 adults, with an average age of 19 years. They analyzed in the first experiment four conditions:

(1) Neutral: items in the list consisted of rows of X's ranging from three to six X's per display presented in the different ink colours;

(2) Stroop Control (interference): word names were written in conflicting ink colours (for example, GREEN in red ink followed by BLACK in orange ink);

(3) Repeted Ignored: word names in each item were the same through-out the list. Blue, red, and green were used as word names (distractors) under this condition (for example, BLUE in green ink followed by BLUE in red ink);

(4) Ignored Repetition (negative priming): throughout the list, the word name in the previous display were the same as the subsequent ink colour (for example, BLUE in yellow ink followed by ORANGE in blue ink).

Tipper and his colleagues found that children were slower than adults, and that reaction time for different conditions had the following pattern: Neutral < Stroop Control < Repeted Ignored < Ignored Repetition. Negative priming was significant in adults, but was not significant in children. Comparison of Neutral and Stroop Control conditions indicated a significant interference effect in both children and adults. It was also found that children and adults' responses were faster under the repeated word names than the Stoop Control condition, though the effect was relatively larger in children than adults.

In the second experiment Tipper and his colleagues compared children with adults on a task that differed from the paradigm used in the first experiment. Simple pictures of everyday objects were presented to fixation for naming while irrelevant distractors (one per the display) were in the periphery. Under the control condition, the pictures in the prime and probe (following prime) displays were completely unrelated. The neutral condition consisted of a prime display that was similar to the control condition, while in the probe display the ignored distractor was a meaningless stimulus corresponding to one of the six target stimuli in terms of features. Under the negative priming condition, the ignored distractor on the prime display was the same as the target stimulus in the probe display. Children did not show significant interference or negative priming effects. Adults showed no significant interference, but exhibited a significant negative priming effect. It was concluded that "habituation and inhibition are separate and independent mechanisms in attention..., children show an increase in habituation effects relative to adults, whereas they demonstrate a decline in inhibition (negative priming)" (p.374).

Harnishfeger and Bjorklund (1994), in order to investigate the development of efficient retrieval inhibition, tested young children (Kindergarten) and found that they performed more poorly on a memory task than did older children (Grade 3 and 6). This was partly because of their inability to inhibit irrelevant information (information that was not on the to-be-remembered list). On the basis of these results, which indicated that memory intrusion of irrelevant information decreases as children get older, Harnishfeger and Bjorklund concluded that efficiency of inhibition increases with development. This conclusion was supported by Harnichfegar and Pope's (1996) results. They tested 23 first graders (mean age 7.2 yrs), 24 third graders (mean age 9.5 yrs), 23 fifth graders (mean age 11.5 yrs), and 24 college students (mean age 19.3 yrs) using a blocked-cueing directed-forgetting task. Subjects were given a forget cue

(FC) or a remember cue (RC) halfway through an unrelated free-recall list, and were asked either to remember all the words or to remember only RC words. Results suggest that the ability intentionally to inhibit the maintenance and recall of irrelevant information improves gradually over the elementary school years. Children were less able than adults to inhibit FC words, and they were less able to withhold production of remembered FC words.

Im-Bolter (1999) investigated whether inhibition changes developmentally between 6-8 years and 9-11 years. She tested 151 children between the age of 6 to 11 years, who where in intellectually gifted (n=59) or mainstream (n=92) academic programs using Location-selection and Stroop tasks. The Location-selection is a computer negative priming task in which the subject has to move a joystick in the directions of the relevant coloured X and ignore the X in irrelevant colour. Im-Bolter found a significant negative priming effect for all groups of children in this task. In the Stroop task all groups demonstrated a significant stroop effect (interference), but only the older children showed a significant effect in the negative priming condition (inhibition) of this task.

There are not a lot of studies investigating the development of inhibition with age, but even among them the variety of interpretations of inhibition is very wide. These studies led to labeling inhibition according to processes involved: behavior inhibition (Piagetian A-notB task), inhibition of selective attention (negative priming effect), memory retrieval inhibition, etc. (for review: Harnishfeger, 1995-b). The most confusing interpretations, however, are those which do not clearly differentiate between the processes of interference and inhibition. The difference and similarities between these two concepts are discussed below.

Interference vs. Inhibition

While the investigation of active inhibition is a relatively new area, investigation of inhibition related to interference is not new. In learning and memory, interference is a competition or conflict between two incompatible sets of schemes that compete for the determination/control of the subject's performance; for instance, the habitual schemes that embody information in memory and schemes that carry current information (J. Pascul-Leone, personal communication, November 19, 1999). Several types of interference are distinguished (Reber, 1985). *Proactive interference* is the interference of material previously learned on material currently being learned. Proactive interference builds up fast, particularly when a person undertakes several highly similar tasks in a short period of time, and performance may drop off precipitously. *Reproductive interference* is a decrease in the ability to reproduce previously learned material resulting from the interpolation of some other activities or material between the learning and the time of recall. *Retroactive interference* is the interference that the learning of new material has upon the recall of material learned previously.

The first publication on interference appeared in 1894 by Bergstom, who reported the effects of interference on the execution of experimentally acquired habits (Dempster & Brainerd, 1995). In the same year, Muller and Schumann published the results of retroactive interference of the learning of a second list of items with memory of the first list. In 1932 McGeoch concluded that retroactive interference was a significant cause of forgetting. Underwood, in 1957, demonstrated that proactive interference also contributes to forgetting. Following McGeoch, most psychologists used the term "interference" to refer to the cause of the decrement related to task irrelevant material, and used "inhibition" to refer to the observed decrement in retention of the

original material (Dempster & Brainerd, 1995). Pascual-Leone, however, disagrees with these interpretations of interference and inhibition. According to J. Pascual-Leone (personal communication, November 19, 1999) inhibition is a much broader concept than interference. Interference is the local inhibition that a dominant scheme exerts onto another local scheme. Inhibition, as a psychological construct, can also occur from a central, executive-driven process to a local, habitual process. This sort of inhibition is distinct from interference (which always occurs between two local, competing processes) and an instance of it is the central, attentional inhibition, or interruption.

One of the tasks that allows us to investigate interference is the reversal shift task. Kendler and Kendler (1975) describe reversal shift (RS) tasks as those in which a shift in response occurs between levels of the same dimension of two-dimensional items. For example, if items have as two –dimensional characteristics different shape and colour, a shift in response from one level of the same dimension to another (e.g., from response to white colour to response to black colour), irrespective of shape (circle or triangle) is a reversal shift. In contrast to RS between levels of the same category, a shift between categories (from response to one of the colours to one of the shapes) is labeled extradimensional shift (EDS). A modified discrimination-shift paradigm (RS, EDS) was used in the current study to examine the relationship between negative priming and interference.

On the basis of their RS paradigm Kendler and Kendler (1975) showed how interference works. "A reversal shift should retard problem solution. ...The correct habit (response to black) is gradually strengthened whereas the incorrect habit (response to white) is gradually weakened. Reversing the reinforcement contingencies would retard learning because the effects of prior learning would now have to be overcome" (p.200). They found that the prediction that RS is

slower than EDS was true for animals and young children(learning was retarded), but not for college students. This result was explained using a mediational S-R mechanism that intervenes: when subjects use this mediational mechanism, information is processed as a conceptual category. In contrast, in the single-unit mechanism information is processed as discrete stimuli (Kendler & Kendler, 1975). Children develop a mediational mode of processing with age and, therefore, show different speed in RS as compared with EDS with development. Kendler and Kendler (1975, p.210) report that fast learners among kindergarten children "found a RS easier, whereas the slow learners exhibited less difficulty with EDS". They concluded that "fast learners were operating in a mediational manner, but the others, the slow learners, were functioning in a single-unit model" (Kendler & Kendler, 1975, p.210).

According to Logan (1988), habit develops through accumulation of instances. Information about responses that were executed in the past enables the avoidance of slow computation in response to the same stimuli. Neill and Valdes (1996), adopting Logan's assumption, suggest that negative priming occurs when the retrieved episode contains irrelevant, rather than relevant, response information.

According to Harnishfeger (1993-a) interference and inhibition are related constructs and differ in approaches of investigation or predictions. She defines inhibition as an active suppression process that keeps irrelevant information from entering and being maintained in working memory and interference as cognitive competition among multiple stimuli, processes and responses that does not necessarily involve the active suppression process. Dempster (1995) avoids distinguishing between inhibition and interference and looks instead at what he calls "resistance to interference", a function of the frontal lobes that develops with age. He suggests

that tasks of shifting attention or responses, selective attention tasks and tasks with competition among stimuli or responses demonstrate sensitivity to inhibition.

It is not clear from these previous studies how interference and negative priming are related to each other. Neill and Valdes (1996) suggest that if the function of inhibition is to protect ongoing cognitive processes from interference by irrelevant, distracting information, there should be a negative correlation between negative priming effect and interference (the stronger active inhibition, the less interference of irrelevant information).

Capacity Limitation of Inhibition

There are several theories that refer to capacity limitation for processing information. Townsend (1974), for example, showed that mean response times in visual search tasks could be accounted for in terms of capacity shared among different perceptual analyses. Shaw and Shaw (1977) proposed somewhat similar formulations. It is not clear, however, whether unattended and attended stimuli have the same or different demand on mental capacity.

Tipper (1985) conjectures that the inhibition mechanism operates according to spreading inhibition-based suppression. According to this hypothesis, the amount of delay in response to the item that had just been a distractor depends on the number of items that require energy in order to inhibit, and this reduces when those items are increased. Available inhibition energy should be divided among the distractors in a given display. That is, the more irrelevant items there are to be inhibited, the less strength of inhibition there should be available to be applied to any one of these items.

To test this hypothesis experimentally Neumann and DeSchepper (1992) modified the letter-naming task (which was described at the end of the first chapter of this thesis) by adding

distractors, one of which becomes a subsequent target. Subjects were required to say aloud a list of red target letters while ignoring either one, two, or three task-irrelevant letters in other colours Results were analyzed according to stimulus type, that is, whether a distractor letter became the next target letter (distractor repetition condition) or not (control condition). Neumann and DeSchepper showed that the negative priming effect is attenuated as the number of distractors in the previous display are increased. Therefore, in their conclusion they claimed that there is a limited capacity for inhibition.

In contrast to the task of Neumann and DeSchepper, where the limitation of mental energy was tested by increasing the items to inhibit, Engle, Conway, Tuholski, and Shisler (1995) tested the hypothesis of capacity limitation of inhibition by increasing the demand on mental activation. They measured the negative-priming effect as a function of mental workload. Paired prime-probe trials of the letter-naming task were presented in sets of five, with a different word-to-be-remembered presented after the first through fourth pairs. Within sets, trials were randomly set to be control versus inhibition (negative priming). The subject was asked to recall the words after the last trial. It was shown that with increasing memory load the negative priming effect decreased. At load 0 (no words to remember) and load 1 (one word to remember) negative priming delay was at 40 msec, at load 2 (two words to remember) the delay was at 15 msec. At load 3 the priming became facilitating (responses were 15 msec faster compared with the control condition). At load 4 the facilitating effect decreased to approximately 8 msec. It was concluded that "suppression of the unattended letter was a controlled attentional process that was less likely to occur as the recall task required more attention" (Engle et al., 1995, p.125). Engle and his colleagues (Conway et al., in press), however, later replicated this experiment and found negative

priming only at load 0 and only for subjects (college students) who scored high in a working memory span task.

Statement of the Problem

The above review of research on inhibition in relationship to the subjects' mental capacity and to interference reveals that there is limited theoretical formulation and empirical research in this area, especially in research with children addressing questions of development. There is a tendency to confuse interference with inhibition processes, because of the lack of theoretical clarity in describing these cognitive processes. Furthermore, there are very few empirical studies investigating the impact of the activatory requirements of a task on inhibition (Engle et al., 1995; Neumann & DeSchepper, 1992).

The confusion of processes underlying inhibition and interference, as well as the lack of theoretical formulation and experimental research in this area, makes the interpretation of results difficult. It is critical to understand better the mechanisms involved in these two processes, but comparison of these processes is difficult since they have been investigated using different methodologies (Im-Bolter, 1999). Therefore, there is a need for a task that measures both processes in a competitive way in order to determine whether interference and inhibition are, in fact, different processes.

The research that has been completed suggests that activatory and inhibitory processes share the same pool of mental energy (Engle et al., 1995; Neumann & DeSchepper, 1992). It has been shown that, with increasing demand in activatory processes and the same demand on inhibitory process, the level of inhibition declines (Engle et al., 1995). It has also been shown that with increasing demands for inhibitory processes while the demand for activatory processes is

constant the strength of inhibition decreases (Neumann & DeSchepper, 1992). There are, however, no empirical research studies investigating the relationship between inhibitory and activatory process when demand on both increases. There is not yet an experimental situation that can be used to test this relationship.

The assumption that inhibitory and activatory processes share the same pool of mental energy is based on data obtained from a task that requires the subject to shift between two sub-tasks: a memory task and the letter-naming task (Engle et al., 1995; Neumann & DeSchepper, 1992). Im-Bolter (1999) has used several tasks, some of them to test inhibitory processes and some to test activatory processes, to investigate the relationship between these processes. The difference in the tasks, however, made it difficult to draw a conclusion about whether activatory and inhibitory processes are related. No research has been done to investigate the validity of the assumption that inhibitory and activatory processes share the same pool of mental energy by using a single task that combines both activatory and inhibitory processes within it. There is a strong need, therefore, for the development of this kind of task, which I am now proposing.

Purpose of the Present Study

The purpose of this study is to examine the relationship among interference, inhibitory and activatory processes, and how this relationship changes with age. This study is unique in several ways. First, the study is guided by a specific theory, namely Theory of Constructive Operators (TCO) that has been developed by Pascual-Leone (1970, 1987). Second, the present study is the first attempt to measure interference, inhibitory and activatory processes within the same task in order to examine the theoretical predictions based on the TCO.

The present study also attempts to address some of the other limitations and methodological problems of earlier research. It investigates whether interference and active inhibition are related to activatory processes in the same way and if so whether they are related. Interference, effortful mental inhibition (i.e., what Pascual-Leone calls attentional interruption), and mental activation (i.e., Pascual-Leone's attentional M-capacity) were evaluated concurrently in different age groups of children to discover whether there are developmental changes in these processes.

Theoretical Predictions of the Study

In situations that elicit the activation of schemes that are inconvenient for the task at hand (i.e., misleading situations) both attentional interruption and attentional activation (i.e., M capacity) must be used by the subject in order to succeed. In this case, if attentional interruption and activation share the same pool of mental capacity, as Engle has suggested (Engle et al., 1995), one must expect, as the demand on activation (M-capacity) increases in the task, that the power of interruption will decline; and thus when the task's mental demand is equal to the subject's mental (M) power of attentional activation, the subject's power of attentional interruption will have disappeared. However, if the subject can demonstrate attentional interruption within task items where the mental demand is above the subject's mental power, we may conclude that the pool of mental capacity for activation is (at least in part) different from that of interruption.

To investigate these theoretical hypotheses a new Mental Attention Reversal Shift (MARS) task has been designed. In this task the subject is asked to respond by pressing keyboard buttons associated with different animals that are presented in a relevant colour (blue or red; the colour is indicated by a colored rod or "wand") in a series of displays (trials). The relevant animals are located randomly within a virtual circle, interspersed among irrelevant animals (e.g.,

animals in the currently irrelevant colour) as well as blue and red letters. The total number of items in each display is 26. The number of animals in the relevant colour (this number defines the class of the trial) is equal to the number of animals in the irrelevant colour, and varies from one to four (see Figures 2-7 for examples). Children learn in the introduction which keyboard key to press for each and every particular animal that can be presented (nine animals).
All items of the task contain the various relevant kinds of misleading or distracting features (letters in both colours and animals in the irrelevant colour).

According to Pascual-Leone's theory the sorts of inhibition (i.e., dynamic, central inhibition of task irrelevant, distracting or misleading schemes) elicited by this task are:

1. Interruption, to avoid distraction by distractor shapes (letters) that are presented along with the set of task variable shapes (animals). This interruption will occur in all items and, therefore, we shall not be able to measure it within the present experiment.

2. Interruption caused by a negative priming of animals that in the first or prime trial were non-relevant (e.g., red deer, where blue is the relevant colour, Figure 2) but in the current trial, have become task relevant (e.g., blue deer, blue colour is still relevant, Figure3). This inhibition of animal schemes in the first/prime trial lowers the activation potential of the scheme in question and consequently demands in the second/probe trial a longer time (longer latency) before mental attentional capacity can boost into hyperactivation these schemes so that they control the performance. This longer latency of response detected in responses to animals that were irrelevant in the prime trial but relevant in the current (probe) trial is what is called negative priming.

3. Interruption caused by a reversal shift of the item's currently relevant animal shapes from one colour (e.g., red camel, red elephant, where red is the relevant colour) to another colour (e.g., blue duck , blue rhinoceros, where blue is now the relevant colour). This particular kind of interruption

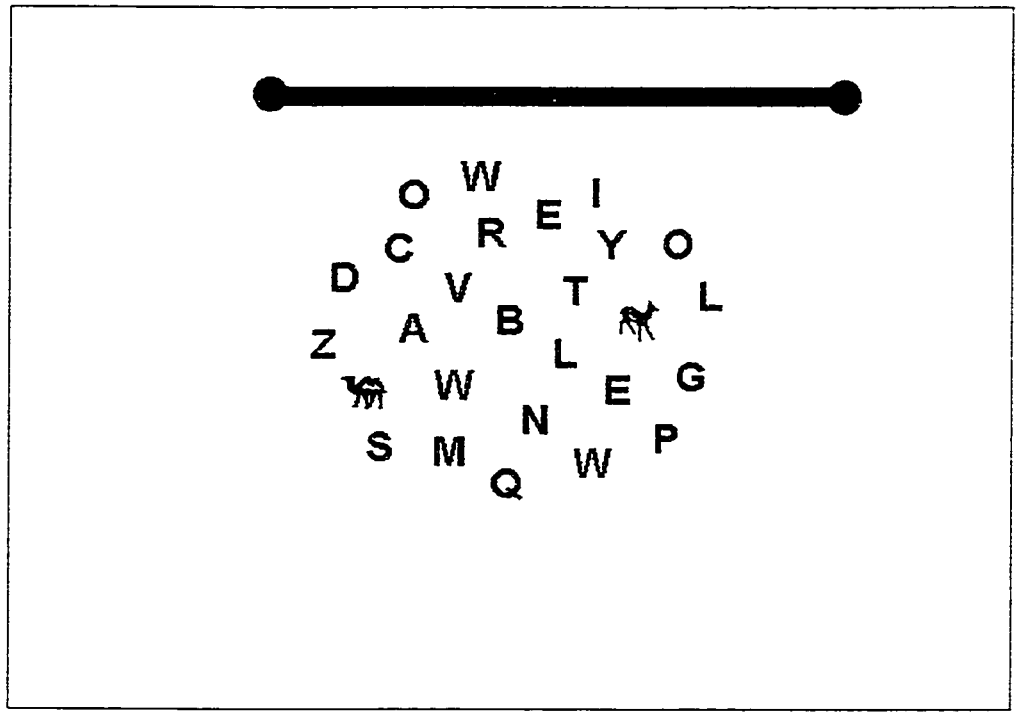


Figure 2
An example of a prime trial, class 1, in the MARS task.
This trial is followed by the trial presented in Figure 3.

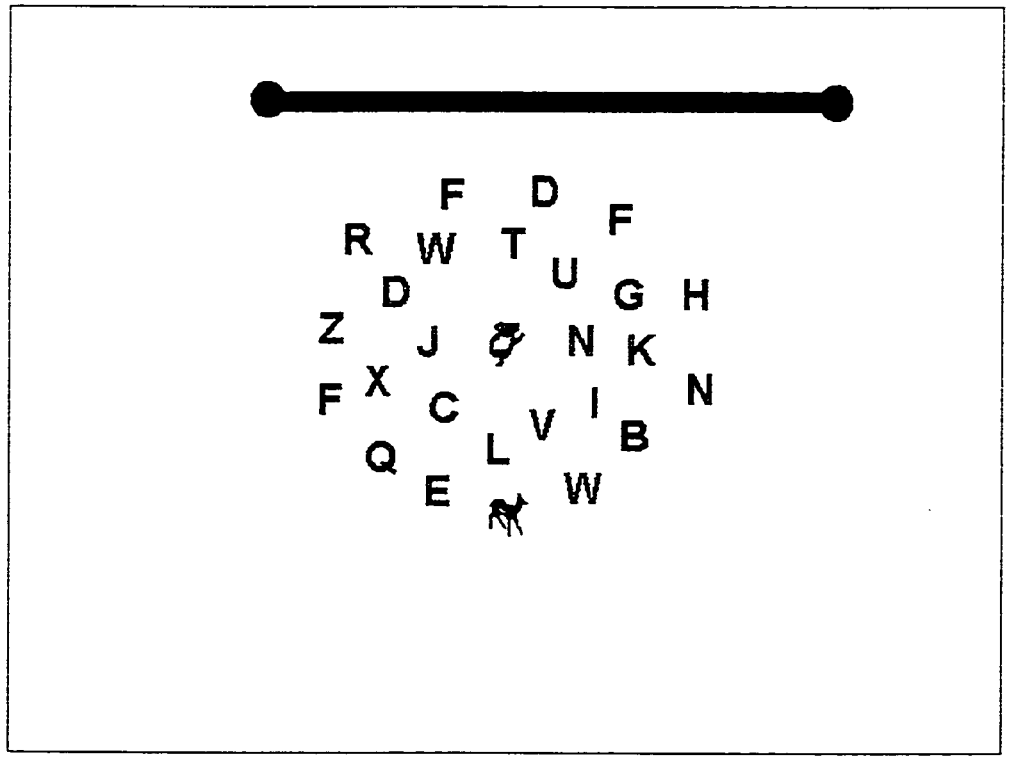


Figure 3
An example of a probe trial, class 1, negative priming condition.

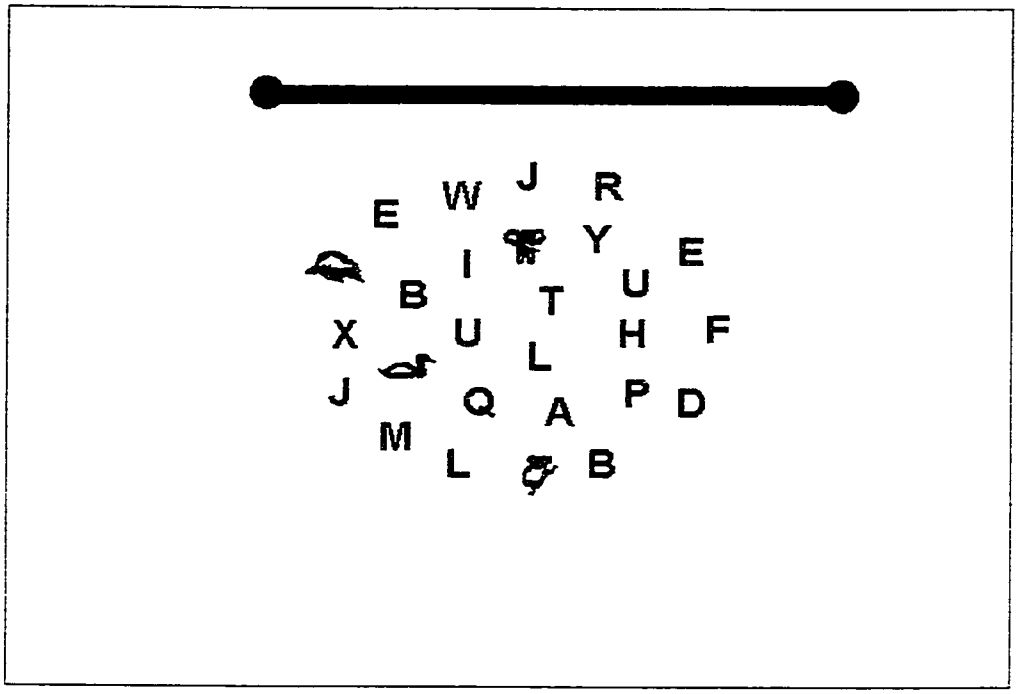


Figure 4
An example of a prime trial, class 2, in the MARS task.
This trial is followed by the probe trial presented in Figure 5.

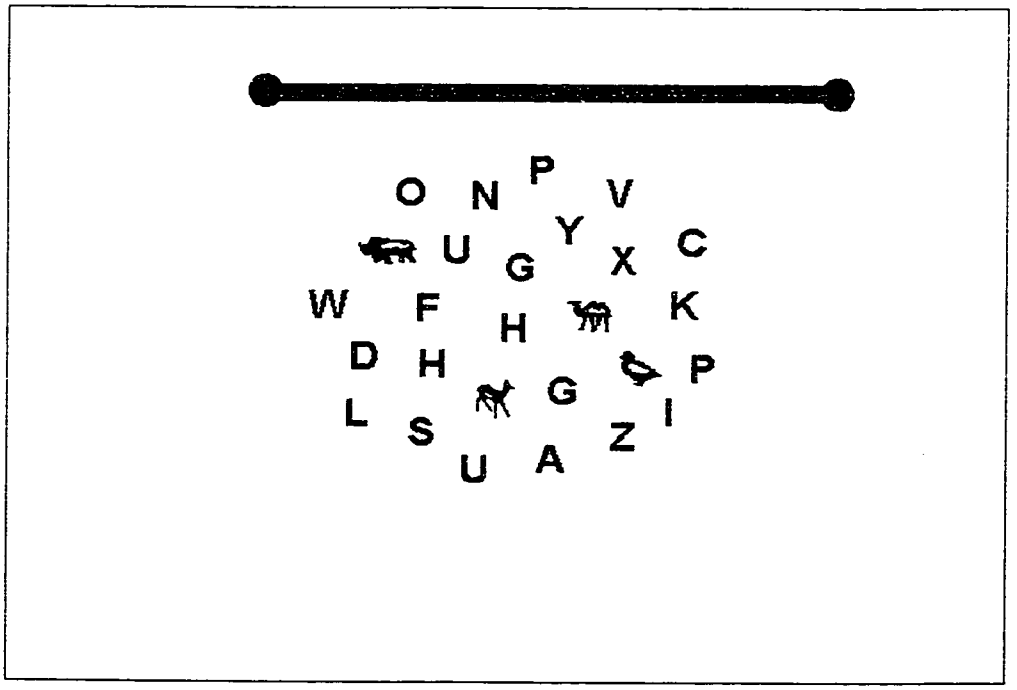


Figure 5
An example of a probe trial, class 2, shifting colour condition.

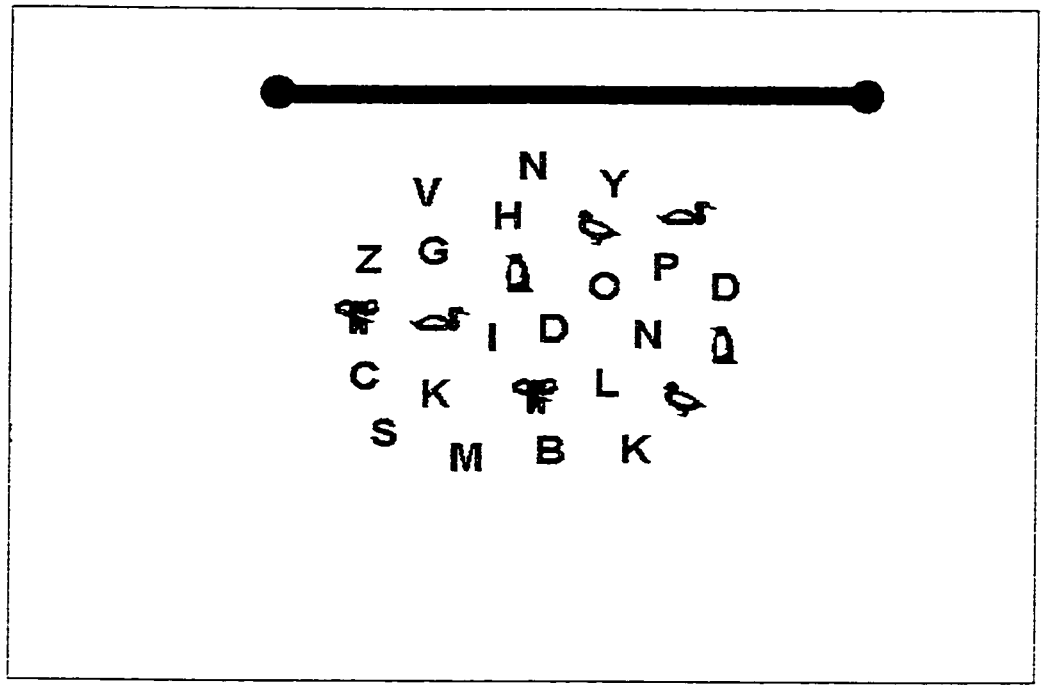


Figure 6
An example of a prime trial, class 4, in the MARS task.
This trial is followed by the trial presented in Figure 7.

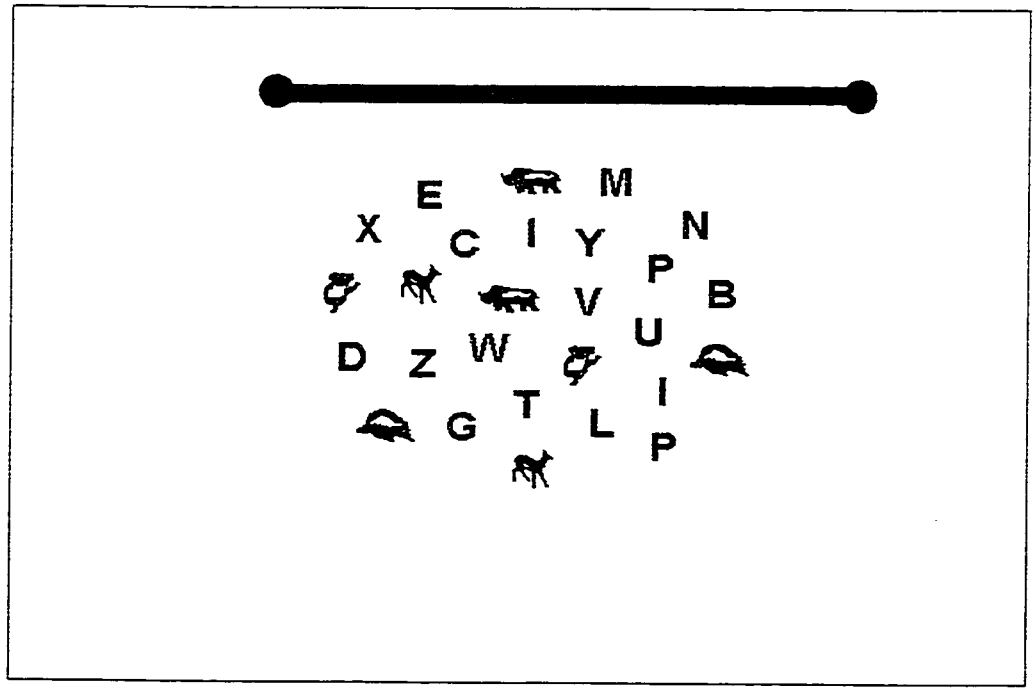


Figure 7
An example of a probe trial, class 4, control condition.

corresponds to what Dempster (1995) and others might call inhibition of (or "resistance to") interference.

Thus a comparison of the data from conditions (2) and (3) will allow us to investigate whether active central inhibition and the control of interference are the same or different processes.

The reversal shift (Kendler & Kendler, 1975) paradigm is being used in the MARS task in a modified manner (i.e., in a randomly-occurring reversal shift within the colour dimension, and in the series of randomly ordered items, items which - under an assumption of advanced response planning - differ in mental demand). This reversal shift plays here the function of ensuring that the subject has to invest mental attentional energy (M-capacity activation) in selectively noticing and responding to the relevant animal shapes. Under these conditions, task analysis suggests that to cope with this task (MARS) the child must be able to coordinate in mental attention (i.e., "keep in mind") at least three different sorts of scheme processes:

1. the procedures for perceptually identifying the currently relevant animal shapes, and then pressing keyboard buttons corresponding to relevant animals;
2. a parameter needed by the procedures just mentioned, i.e., the current colour of the item's wand;
3. the object or objects on which the procedures should apply, i.e., the actual currently relevant animals.

Displays with different number of animals are randomly presented which might differ in their mental (M) demand relative to the subject's expected M-power (i.e., mental attentional capacity). But these differences in item's M-demand relative to the subject's M-power are to be expected only in the event that subjects use an executive strategy based on advanced processing of responses; that is, a task strategy where they not only perceptually examine the display, and

identify all relevant animals in it, but also plan the corresponding keyboard responses before they actually produce the first keyboard response. If instead of this *parallel-processing strategy* subjects use a *sequential-processing strategy*, with no advanced processing of responses, then the mental demand of items will not differ. Indeed, even when the perceptual identification of relevant animals is done in advance of the first response, if the sequence of responses is not planned in advance, then the mental demand of a task's item should not change with one or two or three or four relevant animals to be responded to. To repeat, only if children plan in advance these responses the M-demand of the item should increase parametrically from item of class 1 (i.e., one relevant animal) to class 4 (i.e., four relevant animals). Whether the one or the other alternative is the case requires empirical evaluation, since this is a task paradigm never before studied.

Notice that if the child plans in advance all her/his responses to the animals, then the mental demand of an item will have to be equal to two plus the number of relevant items present in the item display in question, i.e., two plus the class number of the item. In this case if may be possible to evaluate empirically whether the various inhibitory processes change in strength with the increment of mental demand relative to the subject's mental-attentional power (M-power), or whether they are independent from this M-demand/M-power differential (Pascual-Leone & Baillargeon, 1994). If, however, the child plans the responses sequentially then the mental demand of all items will be the same, namely two plus one, i.e., equal to three, in the case of sequential-processing strategy.

Notice that in the MARS task we should predict that interruption items, the items that require interruption (I-operator), will behave differently (both in accuracy level and latency of responses) for the reversal-shift items than for negative priming items. This difference is predicated on the idea that in negative priming items the source of slow responding is the

interruption action that took place in the previous item, whereas in reversal shift items it is the interruptive action required to control interference that takes place in the current item. Further, since in the reversal shift items there is a scheme process currently interfering with the actual responses, but this is not so for the negative priming items, our theory predicts that in reversal shift items children will exhibit much less accuracy than either the control condition or the negative priming condition. Finally, since in negative priming there is no disruptive interference in the current item (only a lower-activation rate of one of its relevant-animal schemes caused by the negative-priming interruption during the previous item) one expects that accuracy in the negative priming condition will not be much different from the control condition.

Formulated in general terms, i.e., from an exploratory perspective, the proposed research has the following objective, guiding questions, and statistical hypotheses:

Objective :

The objective is to assess latency and accuracy of responses to visual stimuli in a new task paradigm, where the executive demand, and perhaps the M- demand of the task (number of stimuli to be responded to; number of distractors) increase. Different types of interruption (negative priming, reversal shift, and control) are required from a sample of children of different ages. This is accomplished by comparing children in grades 2, 4, and 6 (the means of ages in years accordingly: 7.5, 9.5, 11.5) on the task especially developed for the present research, the Mental Attention Reversal Shift (MARS) task. The following guiding questions will then be addressed:

Guiding Question 1. The MARS task can theoreticaly be solved either using a parallel-processing strategy (i.e., with advanced preparation of the responses) or using a sequential-processing strategy (with successive processing of the different relevant responses). In the first

case the different classes of items should exhibit a different mental-capacity demand (M-demand); in the second case all classes of items should have approximately the same M-demand, and this should be an M-demand ($e + 3$) which is accessible to grade 2 children.

Thus our first guiding question is: Do children approach the MARS task using a parallel- or a sequential-processing strategy? or more concretely stated: Does the accuracy of children's response to the MARS task changes significantly from grade 2 to grade 6? If the answer were no, we should conclude that a sequential processing strategy is being used by children.

Guiding Question 2. Do children of different ages have similar characteristics in responses (latency and accuracy) when task demand and conditions of interruption (negative priming, reversal shift, control) are constant?

Guiding Question 3. Do children of different ages have similar characteristics in responses (latency and accuracy) when task demand (number of stimuli to be responded, number of distractors) is increased while the conditions of interruption (negative priming, reversal shift, control) are held constant? (This question will not be testable if all classes of items have the same M-demand - i.e., if children use a sequential processing strategy).

Guiding Question 4. Do children of different ages show any difference in responses when conditions of interruption differ (negative priming, reversal shift, control) while task demands (number of items to be responded, number of distractors) are held constant?

Guiding Question 5. If there is a difference between responses to different conditions (question 4), does this difference change with increasing task demands? (Testable only if classes of items have different difficulty)

Guiding Question 6. If there are different changes between responses to different conditions with increasing task demands (question 4), is there a difference in these changes with age? (Testable only if classes of items have different difficulty)

These guiding questions will be evaluated in the following statistical hypotheses.

Statistical Hypothesis 1. If children use a sequential-processing strategy, then accuracy of responses to item classes 1, 2, 3, and 4 will be similar; and even grade 2 children will exhibit a developmentally adequate ("passing") accuracy level (about 70% plus/minus 10%). Notice that class 4 items should exhibit greater difficulty (less accuracy) than other classes because even though their mental demand may not be greater, their executive demand is. Class 4 items have greater executive demand than other items for two reasons:

(1) Their display presents many more animal stimuli (4 red and 4 blue) interspersed among the blue and red letters and each of them requires an evaluation of its relevance (whether its colour is the same as that of the current "wand").

(2) The misleading effects of negative priming posed by irrelevant animals are cummulative.

Statistical Hypothesis 2. If children use a parallel-processing strategy, latency and accuracy in responses will differ with increase in age (latency decreases, accuracy increases), when task demand and the conditions of interruption are held constant, up to some asymptotic point when the item's mental demand is much smaller than the child's mental capacity.

Statistical Hypothesis 3. With increasing demands of the task, older children will have less difficulty (lower latency and higher accuracy) for the same conditions of interruption compared with younger children. (Testable only if classes of items have different difficulty)

Statistical Hypothesis 4. The latencies of both reversal shift and negative priming will be longer than the latencies of the control condition because they involve misleading aspects. Since reversal shift will cause interference with the actual relevant responses, the latencies of reversal shift will be much more different from those of controls than those of negative priming. These effects will be much stronger in class 4 and 3 items than in classes 2 and 1 because in these items the slow processing caused by negative priming should cumulate over the four or three irrelevant animal stimuli.

Statistical Hypothesis 5. There will be a significant difference in latency and accuracy between the negative priming and the reversal shift conditions for the same age groups and the same task demand, if the nature of their interruption mechanisms is different. Further, if as predicted the reversal shift items cause interference within the current item (probe trial), latencies will be longer and its accuracy much lower than those of both negative priming items and control items. In contrast, since in our theoretical model, negative priming involves interruption (i.e., reduction via inhibition) of the activation level of currently relevant animal schemes during the previous item (i.e., the prime) with no interference occurring during the current item (i.e., the probe), one has to expect that the accuracy of negative priming probe items will not differ from that of control items. These hypotheses contradict the "episodic-retrieval" account of negative priming proposed by Neill (1997; Neill & Valdes, 1996), because the episodic account does not distinguish between interference caused by schemes learned in a previous trial (as in our reversal shift condition) and negative priming. As construed by this account negative priming is an instance of this kind of interference.

Statistical Hypothesis 6. If there are changes in responses to different conditions with increasing task demands (hypothesis 3), these changes will differ for different age groups.

Generally, older children will show, with increasing mental demand, a greater difference in responses between negative priming and control and between reversal shift and control interruption conditions. This will support the assumption that older children have developed better inhibition mechanisms. (Testable only if classes of items have different difficulty)

Method

Participants

A sample of children in grades 2, 4 and 6 (means are 7.4, 9.7, 11.3 years respectively) were included as subjects. Sixty children, 20 in each age group, were tested in two public and one private schools (in the private school the first language of the children is Russian), in a large urban setting. Information/permission forms were sent to parents with children. Only those children whose parents gave written consent were tested: 15 children in each grade in the public schools and 5 children in each grade in the private school. The number of males and females was equal for each age group. All children were mainstream students with no identified cognitive, perceptual or emotional problems.

Stimuli

The MARS task that was developed for the thesis and is used here for the first time. The task is presented as a computer game. In the MARS task shapes of animals and randomly selected letters of the English alphabet that can be either red or blue in colour are used as stimuli. The total number of shapes in any one testing trial of the MARS task is 26. The proportion of red shapes to blue shapes is 1:1. For example, a class 1 trial with red colour as relevant has 1 red animal, 1 blue animal, 12 red letters and 12 blue letters. The relevant colour is indicated by the colour of a 5-mm thick line ("magic wand") at the top of the screen. All shapes are randomly located in an invisible

circle with a 10-cm diameter. The circle is located in the center of the screen. Examples of trials are presented in Figures 2-7.

There are three experimental conditions in the MARS task: negative priming (NP), shifting colour (SC), and control (C). A pair of each condition is presented in the Figures 2-7. In condition NP (negative priming) irrelevant animals on the previous prime trial (Figure 2) are relevant on the next probe trial (Figure 3). In condition SC (shifting colour), there is shift between trials from one relevant colour to the other (Figures 4 and 5). In condition C (control) all animals in a pair of trials are different and none changes in colour (Figures 6 and 7). The total number of test trials is 129 (Table 1, Appendix A).

Only animals are associated with corresponding response-buttons. The animals and the corresponding keyboard labels (diamonds, circles, and squares in blue, yellow and green colour), which were used instead of keyboard letters are presented in Figure 8. Figure 1 (Appendix A) shows the shapes of the animals, their coding numbers and the letters on the keyboard corresponding to responses. The coding numbers (only known to experimenters) facilitate reading of the stimuli sequences from trial to trial, which are presented in Table 1 in Appendix A; they are not used by the subjects.

The number of relevant shapes on each trial in the MARS task varies from one to four. This number might index the mental demand of a trial, or M-class. We say "might" because the number of relevant shapes will index mental demand only if the subjects do not use an executive strategy of breaking down the item's task into subtasks (i.e., sequencing) and instead use a parallel-processing strategy. There are seven pairs of trials in each class of items within each condition. Figures 2 and 3 are examples of prime-probe trials of class 1, Figures 4 and 5 are examples for class 2, and Figures 6 and 7 are examples of class 4.

Notice that in the MARS task not every stimulus present in the display that has a corresponding response-button is a relevant stimulus of the trial. Only animals that have the colour of the wand are relevant stimuli; other present stimuli, such as letters or animals of the other colour, must be ignored or their responses inhibited. In the MARS task the selection occurs within two acts of choice. The first choice consist of two sub-categories: shape (animals vs. letters), and colour (red vs. blue). The second choice of categories consists of nine distinct animals.

In some displays of item classes 3 and 4 some of the relevant and irrelevant animal shapes may be identical. In item class 4, 75% of the displays contain two pairs of different animal shapes (e.g., two red ducks and two red chicks in Figure 6), and 25% of the displays contain no repetition or only one repetition (e.g. two red camels, one red duck, and one red chick). In item class 3, 75% of displays contain three different animal shapes, and 25% of displays have one repetition.

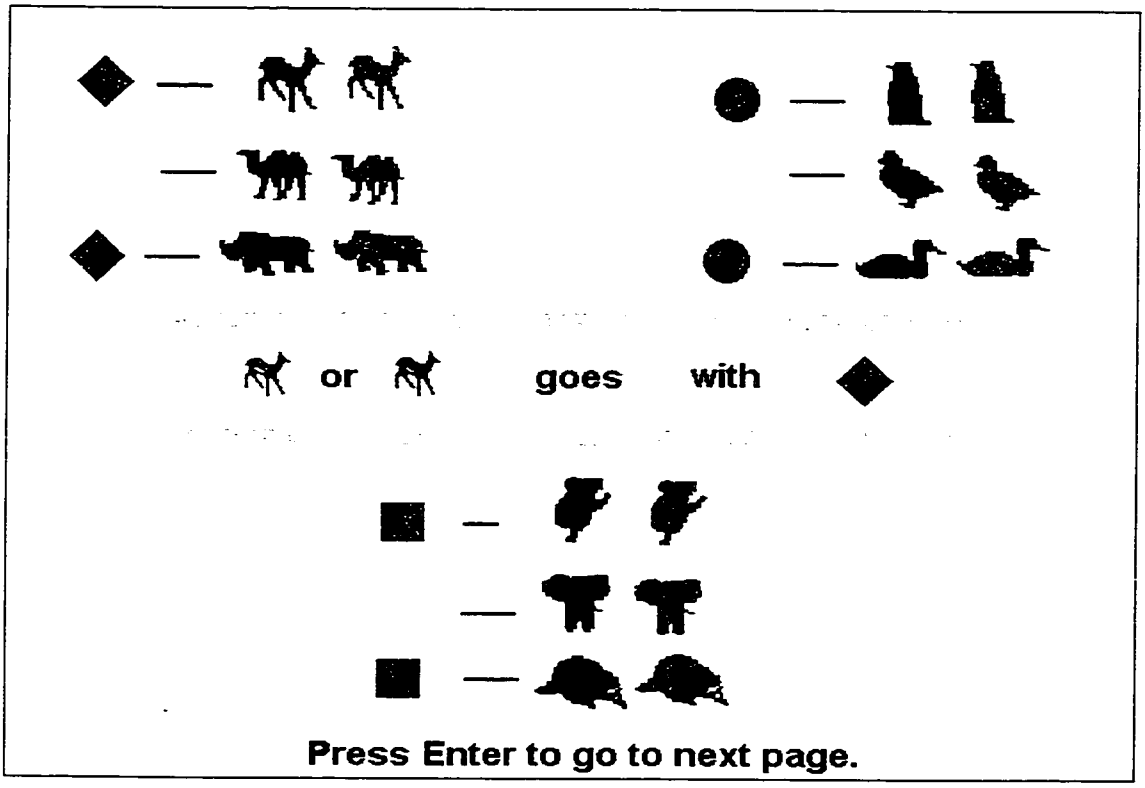


Figure 8

Stimuli (animals) and corresponding
responses (labeled keyboard keys) of the MARS task.

Procedure

All participants were administered the MARS (Mental Attention Reversal-Shift) task. Testing took place in the participants' school during school hours. The MARS test took, on average, approximately one hour.

The task had three components: introduction, training and testing. During the introduction the rules of the games and stimuli were presented to participants. All instructions were read aloud by an examiner. During the training time participants had practice with stimulus-response pairs until a criterion 45 consecutive correct responses. After each incorrect response, feedback with the correct response was given. During the actual test the subject was asked to respond to as many relevant stimuli as were presented. This time no feedback was given. The administration procedures for the MARS task are given in Appendix B.

The training session of the MARS task was embedded into the introduction part. The training part had four subsets. The first three subsets were used for learning each of the three response-button sets (three buttons in each have the same shape, and are blue, green and yellow colours). Each of these subsets began with an introduction of the corresponding animal as is shown in Figure 8. The subject then had to respond to the animal that had been introduced by pressing the corresponding button on two consecutive displays that were different in colour. For example, the subject was asked to respond to a red deer while the wand was red in colour (Figure 2, Appendix A), and then to a blue deer while the wand was blue in colour. Therefore, the subject learned to respond in the same way to the same animal irrespective of its colour, but in accordance to the colour of the wand.

When all three animals of a subset had been introduced, the subject practiced with these three animals until the criterion of 13 consecutive correct responses was met. In the case of an

incorrect response the beep signal and a following picture indicating the correct response, as was used during the introduction of the animal (Figure 8) was shown. The fourth part of the training included all nine animals and continued until the criterion of 40 consecutive correct responses was met. The training part of the task included a short training in responding to only animals that had the same colour as the bar at the top of each trial. This short training consisted of five displays of class 1 (an example is presented in Figure 2). Because some children had difficulty in learning all the S-R pairs, rest periods were allowed before the testing session. The testing session then began with a brief review of rules and stimuli. In this brief review subjects had a short practice with the S-R pairs (Figure 2, Appendix A) until the criterion of 10 consecutive correct responses was met.

During testing, stimuli were presented for an interval of 10 seconds. Subjects were told that they could respond during the display or afterwards, and should press the return key when they wanted to receive the next display. Once the actual testing begun subjects received no further feedback.

Apparatus and Materials

The MARS task is a computer task that has been written in Quick Basic 4.5. The program allows registration of latency with 1-msec resolution. The required hardware to run the tasks is an IBM PC compatible computer, with a colour VGA display adapter and monitor. The program uses the 640 by 480 pixel by 16-colour mode of the VGA display subsystem. The tasks timing routines (written by Mr. Robert England) use PC Hardware Timer 2, and work only when the program is running under the DOS operating system.

The task is based on graphic image files (.pcx). Each graphic image file has a corresponding "answer" file (.ans) that consists of the set of correct response-to-stimulus mapping for the trial. Each of the tasks is controlled as a specified sequence by the "control" file (.seq) that can be modified by the experimenter. SEQ files also include some commands and parameters such as duration of exposure of graphic files. The SEQ files for the introduction and training parts of the MARS task are given in Appendix C.

The responses to MARS trials were made by pressing nine designated keys on the computer keyboard. These response keys were organized by position as three sets that differ in shape (diamond, square, and circle). Each of the sets included three buttons of blue, yellow, and green colours that were repeated in the specified order for each set. The "Enter" button, which is located at the right of the semi-circle of the nine test key-buttons, was used to go to next display.

Subjects' responses were recorded in two different sorts of files. The first sort of file was organized for each subject separately and automatically documented all events as they happened. The file of the second sort cumulated both latency and actual responses of the subjects that were tested during the same month. All response files were coded in ASCII characters.

Statistical Analysis

A within-subjects design was used in which each subject was given all three experimental conditions: control (C), shifting colour (SC) and negative priming (NP) for each of four M-classes. There are, therefore, three independent variables: grade of subjects (3 levels), experimental condition (3 levels), and M-class (4 levels), and two dependent variables: latency (response time) and accuracy. "Latency" (l) is defined as the interval from the time the stimulus becomes visible to the time the subject presses a particular button. For example, the latency for the first button press (l1) of each trial is the latency from the beginning of stimulus display to the moment when the first response button is pressed. The latency for the second button press (l2) is the cumulative time from the beginning of the display to the pressing of the second button. It is similar for latency for the third button press (l3) and for the latency for the forth button press (l4). Accuracy was calculated as proportion of correct responses to expected responses. There were three types of errors: incorrect responses, omitted responses and intruded responses. Omitted responses are failures to respond to cues that were presented; intruded responses are actual responses that have no cue representation in the stimulus display. Omissions were made when high classes where treated as low (for example, instead of making four responses for class 4 only two responses were made); in contrast, intrusions occurred when, for instance instead of making only two responses in class 2 four responses are made. The data were analyzed using the SAS and S-PLUS statistical computer languages.

The first step in analyzing the data was obtaining descriptive data for each grade. The second step was finding accuracy, as a proportion of correct responses to the expected number of responses, for each class and condition. The third step was looking for a relationship between latency and each combination of conditions and classes.

Descriptive Analysis of Latency

The obtained latencies of responses were analyzed in several steps. First, the raw data for latency was analyzed visually after organizing the data by grade, class, and condition. The plots of all obtained latencies 1 through 4 by class and condition are presented in Figures 1.1 to 1.4 for Grade 2, in Figures 2.1 to 2.4 for Grade4, and in Figures 3.1 to 3.4 for Grade6 in Appendix D. The analysis of the plots gave a general idea about the obtained data, such as distribution, outliers and general difference between classes, conditions and grades. It also allowed us to see the intruded responses (e.g., dots in the first panels, class 1, for latencies 2 in Figures 9.2, 10.2, 11.2), and outliers: while most latencies had a maximum value of about 20000 msec, a few had up to 35000 msec. Analysis of the histograms and normal quantile comparison plots showed that latency distributions are not symmetrical and are positively skewed.

The second step was to analyze plots of latency for each individual to see whether the extreme scores were in the individual pattern of responses. An example of a plot for one of the subjects in grade 4 for latency 1, negative priming condition, class 2 is presented in Figure 14. These plots also allowed us to see the distribution of latencies for correct responses, which are indicated in Figure 9 by dots at the bottom of the plot, and incorrect responses, which are indicated by dots at the top of the plot. On the basis of this analysis the extreme scores that were clearly not in the subject's pattern of responses were removed (treated as missing data).

The following number of observations were removed:

Grade 2 – 20 of 1680 total observations

Grade 4 - 4 of 1680 total observations

Grade 6 – 6 of 1680 total observations.

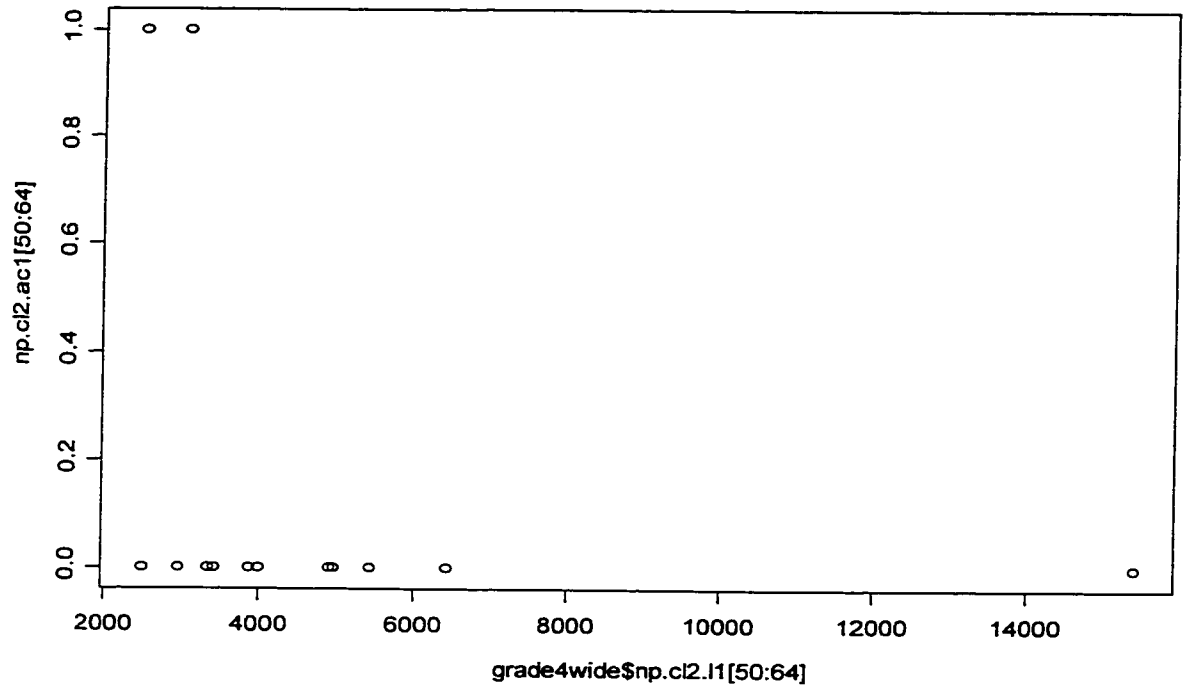


Figure 9

Plot of latency 1 (in msec) for negative priming condition, class 2 for one of the subjects in grade 4. The dots at the bottom of the plot are latencies for correct responses and two dots at the top of the plot are latencies for incorrect responses. Note the extreme score at the right bottom corner.

Further on only latencies for correct responses, after removing the extreme outliers, were analyzed. Histograms and normal quantile comparison plots of latency for correct responses, after removing the extreme scores, showed that latency distributions were still not symmetrical and were positively skewed. Two approaches were used to deal with skewness of this data. The first one was to reduce the data to the subjects' medians. This method is widely used in the field of negative priming and appears in many publications. The subjects' latency 1 medians are presented in the Table 1-3 in Appendix D. The means and standard deviations of the medians are presented in these tables as well. This data was used further for ANOVA. The second approach

was to analyze all subjects' data, without reducing it to single representative numbers such as medians, and to deal with the skewness by transforming latencies with log–function. Histograms of latency after log-transformation showed that the data become nearly symmetrical. Figure 10 is an example of those histograms. Density smooth curves of latencies (broken lines) for correct responses after removing extreme scores are presented before log-transformation and after log-transformation (solid lines). Plots in Figure 10 are ordered by class (1,2,3,4 in columns) and condition (control, negative priming, shifting colour in rows). Latencies after log-transformation were further used for mixed models analysis.

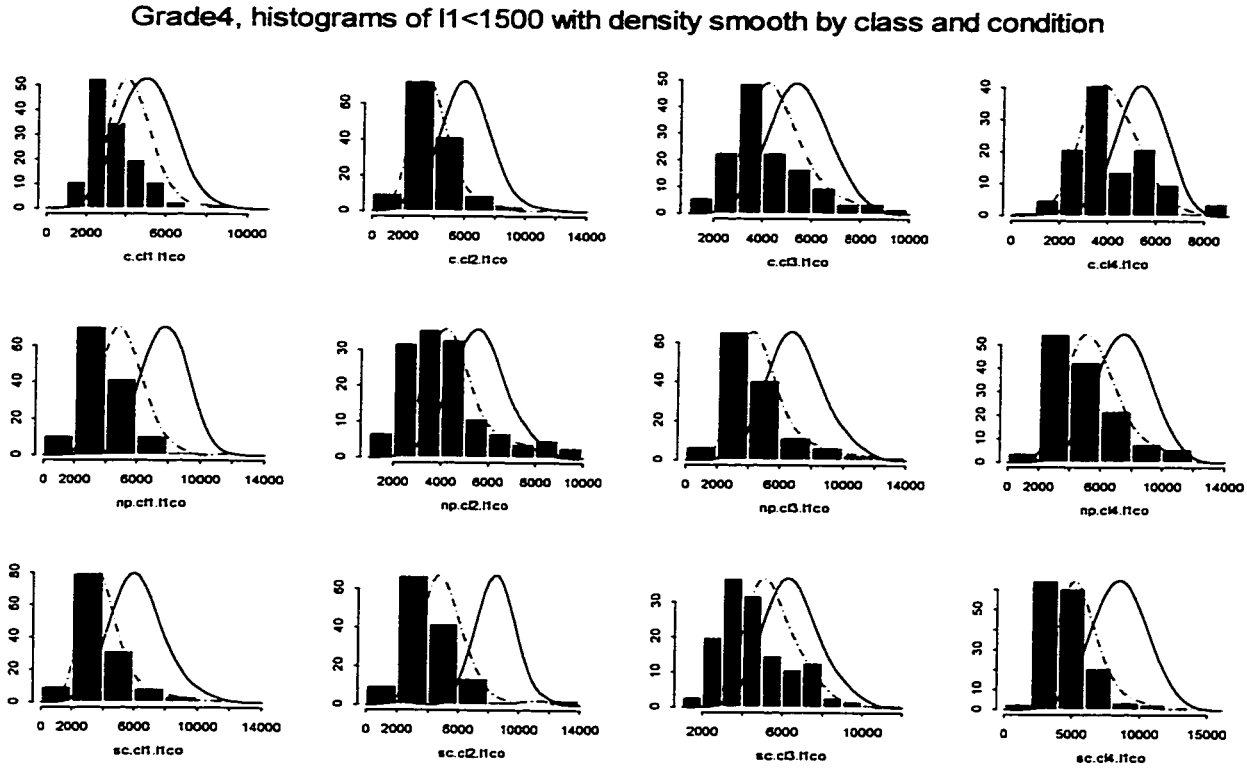


Figure 10
Histograms and density curve (broken line) of latency 1 for correct responses after removing outliers for grade 4 before the log – transformation of the latencies and density curve (solid line) after the transformation. Plots are ordered by class (1,2,3,4 in columns) and condition (control, negative priming, shifting colour in rows). Note that after the transformation the distributions are almost symmetrical.

Mixed models consider the random effect of individuals in the calculation of the effects for the population. Table 3, as an example of individual difference in means between the conditions for grade 4, supports the notion that there is a random effect for individuals. Table 3 consists of differences between the individual means for latency 1 (l1) in msec for the control condition (c) and the individual means for latency 1 for the negative priming (np) and shifting colour (sc) conditions respectively by each class. For example c.np.cl1.l1 represent difference in means of latency 1 (l1) for the control (c) and negative priming (np) conditions by class 1 (cl1)). Only latencies for correct responses and without outliers were used to find the means. The minus sign appears when there is a delay in negative priming or shifting control trials compared with the latencies in the control condition. It is clear that some subjects show delay, some not.

In Figure 11 this difference in the individual means is shown graphically. In Figure 11 latencies 1 in msec are plotted on the axis Y, and series of the three condition (control, negative priming, shifting colour respectively) for each class starting from 1 are plotted on the axis X. Therefore, the first three columns of the individual means are related to the first class, three columns between numbers 20 and 30 on the axis X are related to the second class, and so on. Lines connect the individual's scores. It is clear from this example that there are individual random differences in responses that should be counted while estimating whether there is any delay in responses for the population. The plot allows us to see that for some classes the difference varies less than for the other classes. For example, the most lines between the two first columns of points (the first column is for the control condition, the second column is for the negative priming condition, both for the class1) have positive skewness. It means that the most subjects had a delay in responses for the negative priming condition compared with responses in

the control condition. At the same time some subjects did not show the delay. The pattern is not so easily traced for the other classes.

Table 3

The difference in individual means for latency1 between the control and the negative priming condition (c-np) and the control and the shifting colour condition (c-sc).

Subject	c-np.cl1.l1	c-sc.cl1.l1	c-np.cl2.l1	c-sc.cl2.l1	c-np.cl3.l1	c-sc.cl3.l1	c-np.cl4.l1	c-sc.cl4.l1
1	-1167.29	-1221.86	-43.57	906.57	-300.29	-1150.86	23.93	-302.64
2	386.48	880.00	-239.14	-1781.71	-1413.57	788.29	-369.29	1030.86
3	-225.29	38.14	315.71	-296.29	-212.14	489.29	-1689.83	47.88
4	-877.43	-1042.57	-129.29	-1096.86	-181.14	-668.43	-1911.33	1168.38
5	-589.57	-1308.14	-169.43	-177.14	205.86	-1967.86	-1498.60	-734.02
6	-1334.14	-536.57	-12.86	249.29	925.00	-265.57	-624.83	-245.40
7	-1494.71	-1700.43	406.76	-436.86	-2480.86	82.00	-1125.36	-1531.21
8	-130.00	-498.16	-265.36	-296.85	-968.38	-276.85	-555.94	-337.17
9	350.00	629.00	-1044.71	-581.29	-611.71	29.43	-1006.69	666.03
10	15.00	-429.33	490.60	111.76	-902.17	732.83	-2362.09	-2352.13
11	-903.74	-177.67	-390.29	197.57	222.33	-609.71	329.74	497.67
12	-94.29	754.86	17.29	-1095.57	59.00	-1474.00	73.98	864.26
13	-818.43	-1639.00	-1075.86	263.43	25.43	-1578.00	-194.05	-423.19
14	-330.29	-382.57	-157.86	87.71	-126.14	-1094.57	-436.83	-323.90
15	151.71	-1154.24	349.05	1251.48	1230.71	126.43	-1127.64	732.83
16	273.86	-276.86	-942.43	738.57	-139.86	-1306.71	-1275.57	569.14
17	-762.86	-59.00	188.43	-2036.57	-551.00	-112.71	-2177.24	-406.67
18	-921.71	-597.29	-232.71	-877.14	-561.86	-816.71	-2096.10	878.90
19	-1061.57	-513.14	-591.86	-1046.71	-124.00	-208.43	1086.31	704.74
20	-191.00	-274.43	-61.14	637.43	1511.00	706.00	-750.64	1772.93

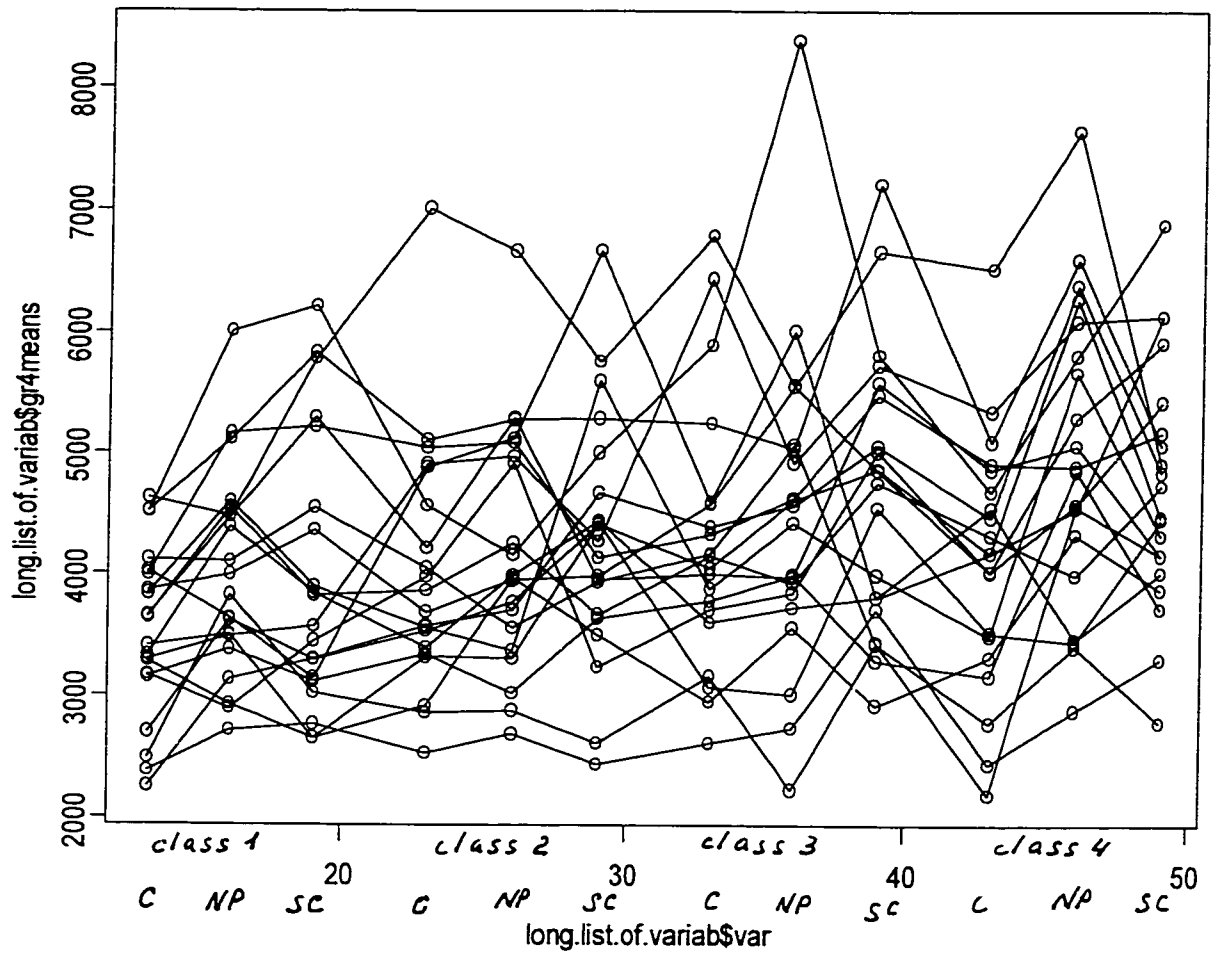


Figure 11

The difference in individual means of latency 1 for subjects in grade 4 for different conditions. The first three columns of the dots show latencies for the class1 for the control, the negative priming, and the shifting colour conditions respectively, the next three columns are for the class 2 for the same order of the conditions, and so on).

Analysis of Accuracy

Accuracy was calculated in the following manner. First, the proportion of correct responses for each response (1, 2, 3, 4) was obtained for each subject (e.g., for class 2 two accuracy were calculated: accuracy 1 (ac1) of correct first responses, and accuracy 2 (ac2) of correct second responses that were made for class 2). Second, an average of those accuracies was found for each subject. Finally, the means of subjects' overall accuracy by class and condition were obtained. The results are presented in Figures 12-14. The graphs suggest that different grades children did not much differed in overall accuracy (Figure 12), the accuracy decreased with increase of item class (Figure 13), and accuracy in the control condition are not much different, but both are higher than accuracy in the shifting colour condition (Figure 14). Percentages of omitted and incorrect responses were calculated and presented in Table 4. Subjects' accuracy is presented in Table 4 in Appendix D. Some simple statistics of data are presented also in Table 5 in Appendix D.

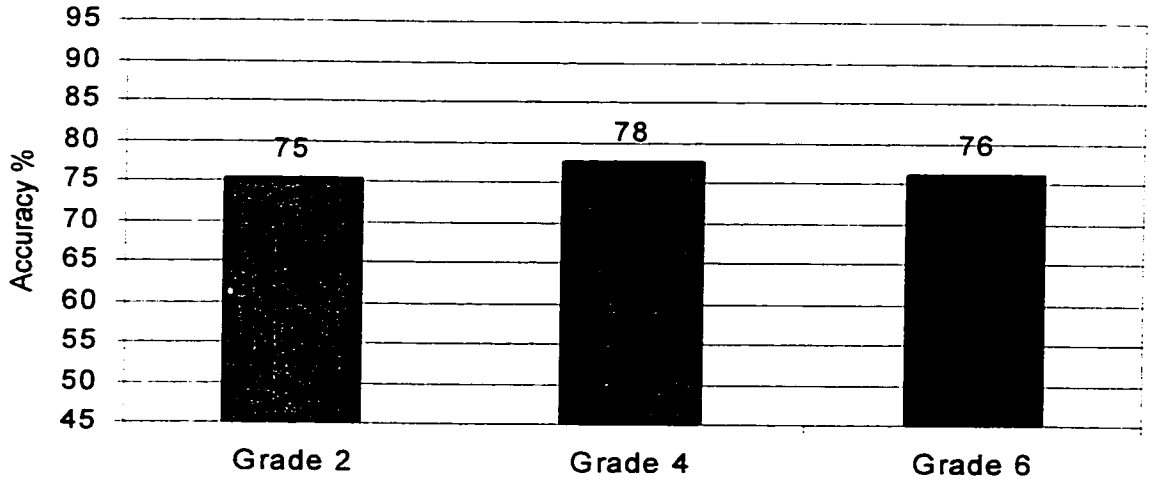


Figure 12
Overall accuracy, as function of grade

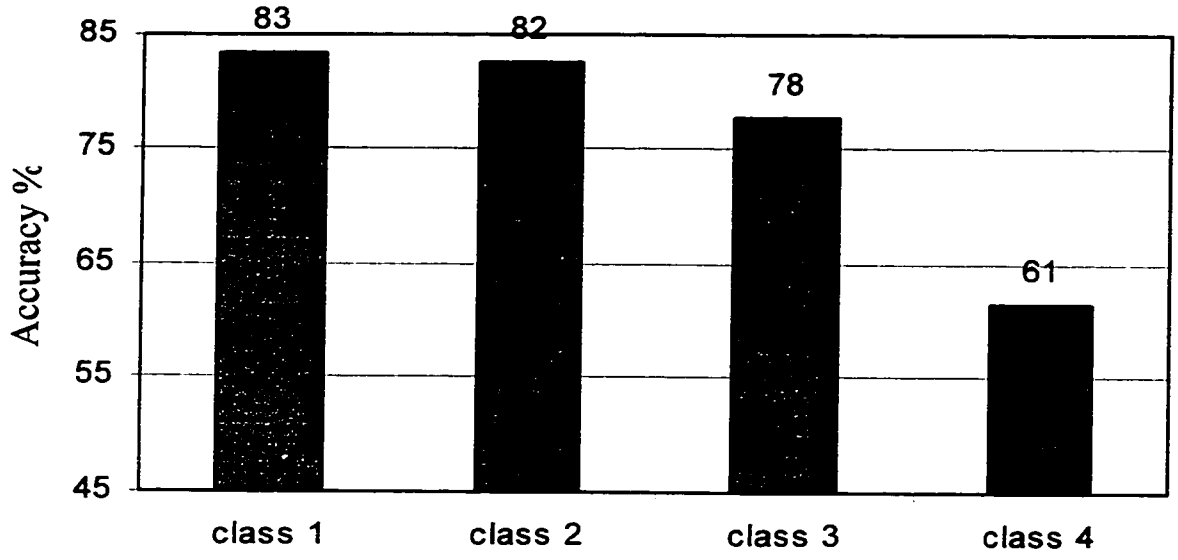


Figure 13
Overall accuracy, as function of class

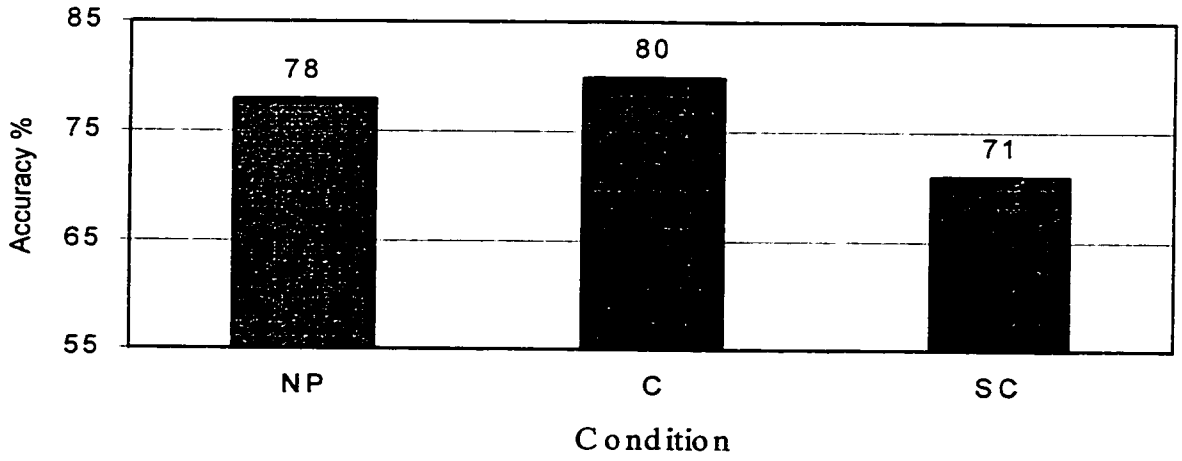


Figure 14
Overall accuracy, as function of condition

Table 4

Percentages of Omitted and Incorrect First Responses

		NP	**SC**	**C**	
Grade 2	Class1	6	5	2	% omitted
		12	*17*	*9*	*%incorrect*
Grade 4		2	1	2	% omitted
		12	*22*	*12*	*%incorrect*
Grade 6		1	1	1	% omitted
		16	*22*	*7*	*%incorrect*
Grade 2	Class2	3	5	4	% omitted
		11	*15*	*6*	*%incorrect*
Grade 4		1	1	1	% omitted
		10	*14*	*6*	*%incorrect*
Grade 6		2	1	4	% omitted
		11	*21*	*7*	*%incorrect*
Grade 2	Class3	1	6	3	% omitted
		13	*23*	*14*	*%incorrect*
Grade 4		1	1	1	% omitted
		10	*19*	*14*	*%incorrect*
Grade 6		1	2	0	% omitted
		14	*26*	*13*	*%incorrect*
Grade 2	Class4	2	4	5	% omitted
		12	*28*	*17*	*%incorrect*
Grade 4		1	1	2	% omitted
		17	*21*	*23*	*%incorrect*
Grade 6		1	3	2	% omitted
		9	*28*	*18*	*%incorrect*

Analysis of Variance

For all variables, group differences in accuracy and latency 1 were analyzed using three-way ANOVA (factors: grade (levels 2, 4, 6), class (levels 1, 2, 3, 4), and condition (levels NP, SC, C)) with repeated measures on two factors, class and condition. In cases where the overall F was significant, means for grades were compared using Tukey's test, and means for class and condition were compared using analysis of variance of contrast variables. An alpha level of .05 was used for all tests. The results are presented in Table 5 for latency 1, Table 6 for accuracy 1, and Table 7 for overall accuracy. Scores for the analysis of latency 1 (latency to the first response) were subjects' medians for latency 1 (for correct responses and after removing outliers) for each class and condition (see Tables 1-3 in Appendix D). The accuracy scores were percentages of correct responses (see Table 4 in Appendix D).

Table 5

Repeated Measures Analysis of Variance of Latency 1

		df	Type III SS	Mean Square	*F* Value	*Pr>F*
Between	**Grade**	2	164215185	8107593	6.51	0.0028*
	Error	57	71888014	12611932		
Within	**Class**	3	64112151	21370717.13	19.66	0.0001*
	Class*Grade	6	4308997.8	718166.3023	0.66	0.68
	Error	171	1883881.6	1086776.68		
	Condition	2	2672778.4	13363839.19	19.9	0.0001*
	Cond*Grade	4	2156713.8	539178.45	0.8	0.52
	Error	114	76566837.1	671639.8		
	Class*Cond	6	818385.35	1363930.89	1.56	0.158
	Class*Cond*Grade	12	6013890.6	501157.54	0.57	0.863
	Error	342	299258876.7	875025.9		

* or bold - significant at alpha level of .05

Table 6

Repeated Measures Analysis of Variance of Accuracy 1

		df	Type III SS	Mean Square	*F* Value	*Pr>F*
Between	Grade	2	848.7194	424.3597	0.19	0.826
	Error	57	126094.2	2212.18		
Within	**Class**	3	5539.877	1846.6092	8.77	0.0001*
	Class*Grade	6	535.9138	89.3189	0.42	0.862
	Error	171	36005.258	210.557		
	Condition	2	1393.6194	6967.8097	36.33	0.0001*
	Cond*Grade	4	1587.13	396.786	2.07	0.0955
	Error	114	21865.25	191.8004		
	Class*Cond	6	2025.88	337.6467	1.89	0.0811
	Class*Cond*Grade	12	1394.7027	116.2252	0.65	0.7969
	Error	342	60971.416	178.278		

* or bold - significant at alpha level of .05

Table 7

Repeated Measures Analysis of Variance of Overall Accuracy

		df	Type III SS	Mean Square	*F* Value	*Pr>F*
Between	Grade	2	661.62	330.81	0.14	0.87
	Error	57	136973.65	2403.04		
Within	**Class**	3	55650.56	18550.18	82.35	0.0001*
	Class*Grade	6	1818.4288	303.0714	1.35	0.24448
	Error	171	38518.7977	225.256		
	Condition	2	12434.838	6217.419	44.17	0.0001*
	Cond*Grade	4	1538.818	384.704	2.73	0.0324*
	Error	114	16046.95	140.767		
	Class*Cond	6	1331.84	221.974	1.58	0.1512
	Class*Cond*Grade	12	2698.16	224.846	1.6	0.0887
	Error	342	47957.94	140.2279		

* or bold - significant at alpha level of .05

Tables 6 and 7 suggest that grade, class and condition have the same effect on accuracy 1 and overall accuracy. The interaction of condition and grade was not significant for accuracy 1, but was significant for overall accuracy.

Results indicated that there was a significant difference between grades in latency 1 (Figure 15), but not in overall accuracy (Figure 12) or accuracy 1 (Figure 16) . Tukey's test showed that grade 2 was significantly slower than grade 4 and 6. There was no significant difference in latency 1 between grade 4 and grade 6.

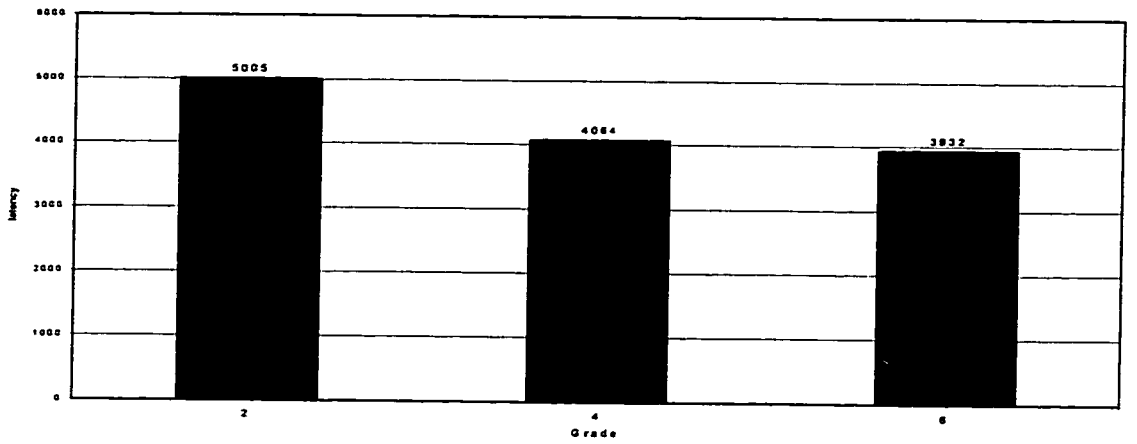


Figure 15

Means of latency 1 medians, as function of grade

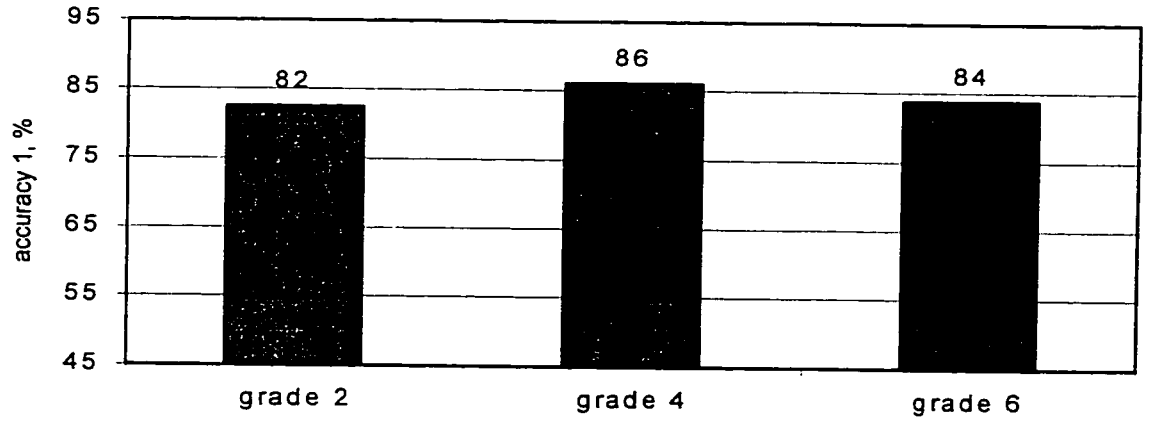


Figure 16

Means of accuracy 1, as function of grade

There were significant main effects for Class and Condition for both latency 1 and accuracy 1. Means of latency 1 medians as a function of class appear in Figure 17. Overall, children were quicker to respond in classes 1 ($F(1,2,57) = 35.34$, $p < 0.0001$) and 2 ($F(1,2,57) = 8.7$, $p = 0.0046$), but there were no significant difference latency 1 between clss3 and class4.

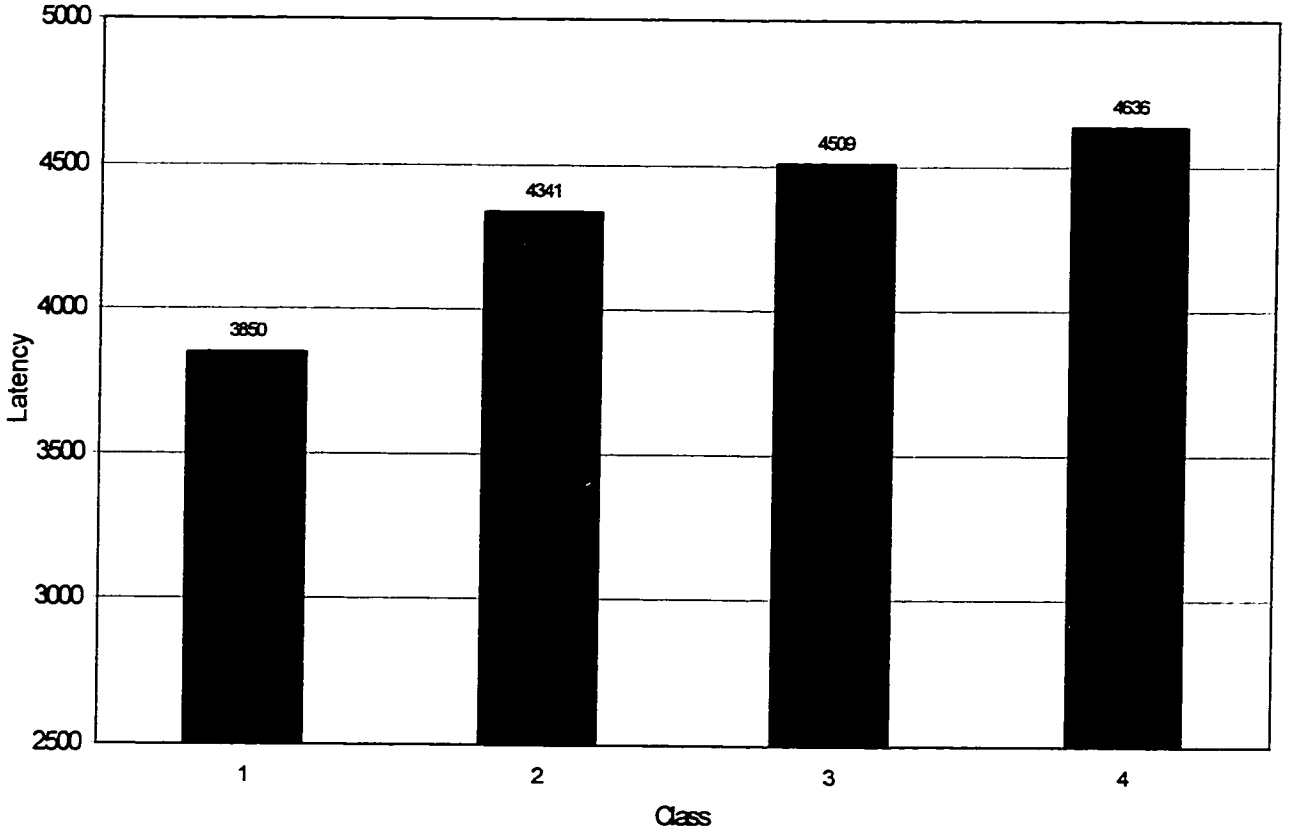


Figure 17

Means of latency 1medians, as function of class

Means for accuracy 1 as a function of class appear in Figure 18. Accuracy increased significantly from class 1 to class 2 ($F(1, 2, 57) = 5.26, p = 0.0256$), accuracy then decreased from class 2 to class 3 ($F(1, 2, 57) = 9.53, p = 0.0031$), and from class 3 to class 4 ($F(1, 2, 57) = 5.10, p = 0.0278$).

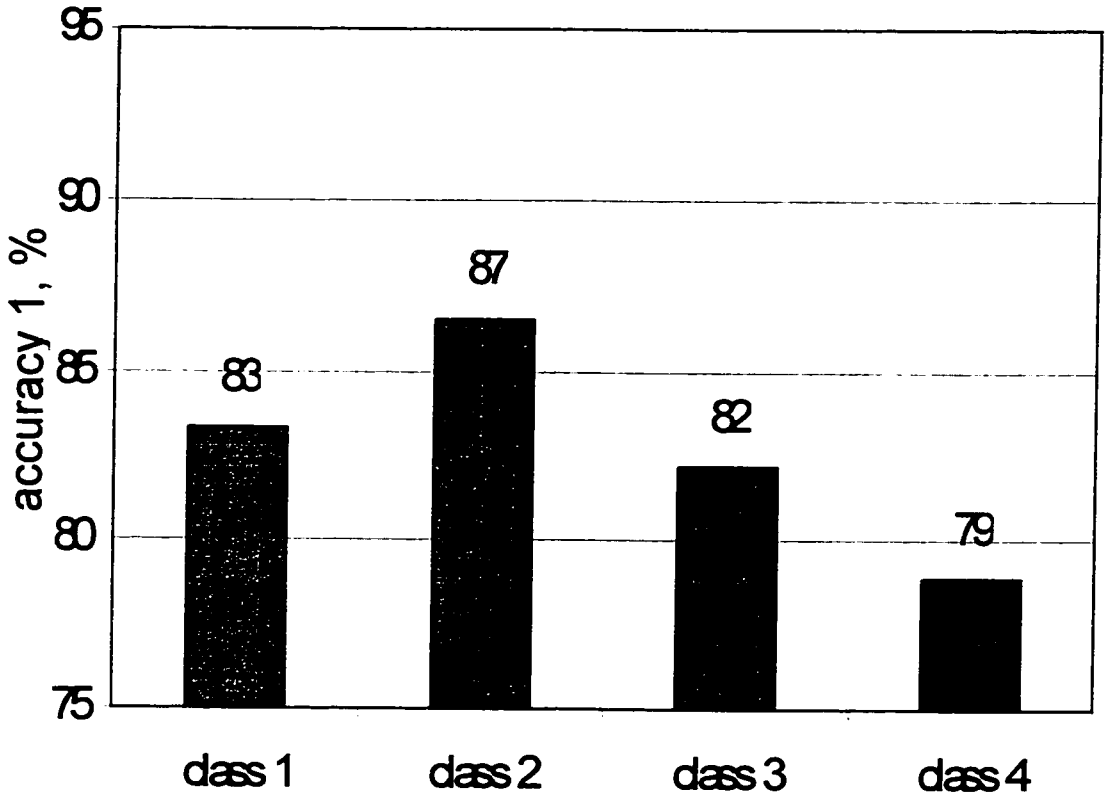


Figure 18

Means of accuracy 1, as function of class

Means of latency 1 medians as a function of condition appear in Figure 19. Analysis of contrast variables indicated that there were significant delays in the negative priming (NP) ($F(1,2,57) = 12.59$, $p = 0.0008$) and shifting colour (SC) ($F(1,2,57) = 34.73$, $p = 0.0001$) conditions relative to control, responses in SC were slower than in NP.

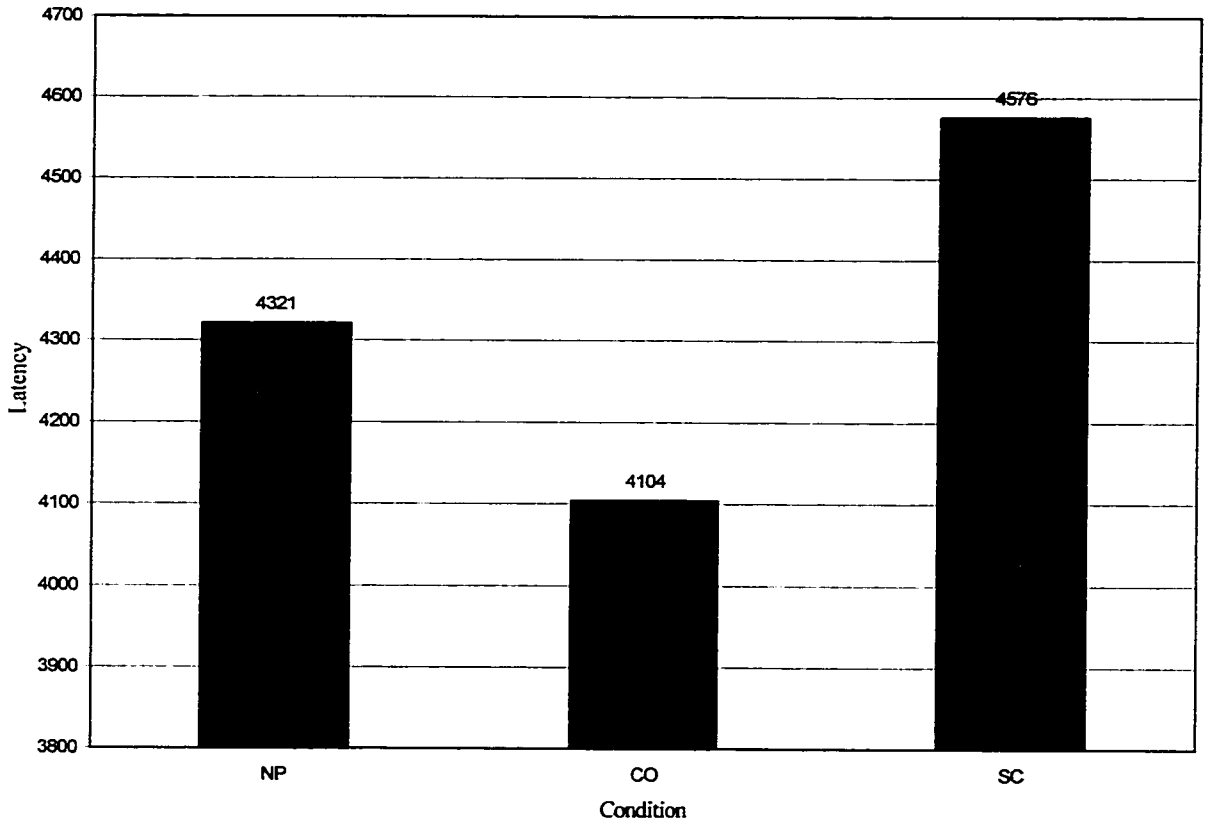


Figure 19

Means of latency 1 medians, as function of condition

Means of accuracy 1, as a function of condition appear in Figure 20. Children were significantly less accurate in SC compared with the control condition ($F(1,2,57) = 41.8$, $p = 0.0001$), but they were not significantly less accurate in NP compared with the control condition ($F(1,2,57) = 0.13, p = 0.7224$)

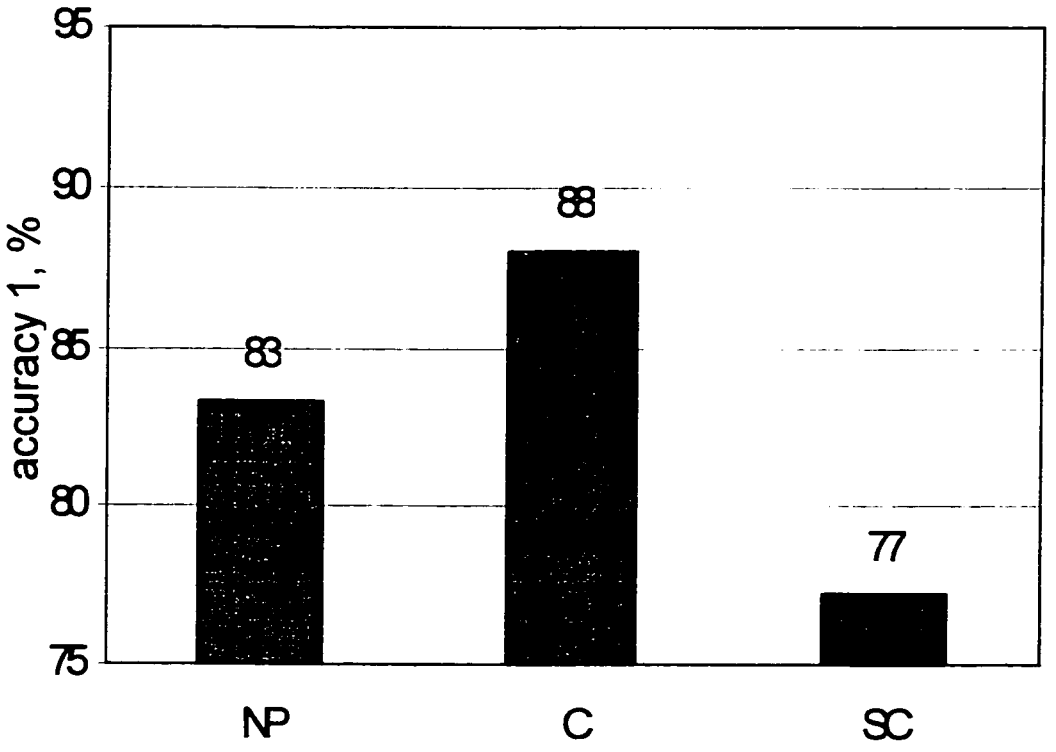


Figure 20

Means of accuracy 1, as function of condition

In sum, grade 2 children were slower than older children in their first response, but they were not less accurate. The absence of a grade effect for accuracy suggests that children were using sequential-processing strategy in the task. Across grades, children were quicker to respond to the lower class items, and they were least accurate in the highest item class. Children showed significant delays in the shifting colour and negative priming conditions, relative to control, with the greater effect in the shifting colour condition. Children's accuracy is reduced in the shifting colour condition, but not in the negative priming condition. The condition effect suggests that (consistent with Hypothesis 5) the nature of the interruption mechanism is different in shifting colour and negative priming.

Analysis of Correlation

Correlations were computed between latency and accuracy scores and with the latency ratios scores SC/C and NP/C. Note that the ratio scores isolate the inhibition delays, while controlling for individual differences in reaction time (control RT). The correlations appear in Table 6 in Appendix D. The correlations showed that latency 1 and accuracy were not related (i.e., they were uncorrelated). NP/C score in class 4 correlated significantly with the overall accuracy score, $r = +.34$, $n = 60$, $p = .0071$, while the SC/C score did not, $r = -.19$, $n = 60$, $p = .1349$. That is, increased negative priming was correlated with higher accuracy.

Mixed Models Analysis

Despite the absence of a Class x Condition interaction for means of latency 1 medians, the condition effect as a function of class was examined further with mixed models to test the theoretical prediction that interference caused by schemes learned in a previous trial (as in our shifting colour condition) and negative priming are different mechanisms of interruption. It was theoretically predicted that delay in responses in the negative priming and shifting colour conditions compared with the control condition would differ with increasing of mental demand (item class). Using subjects as clusters (with 7 row scores in each cluster in our case), which is available in mixed models analysis, increase the power of testing compared with using single values that represent row scores for each subject (subjects' medians in ANOVA above). It should be noticed that analysis of subject's medians, however, is more popular in literature on inhibition compared with mixed models analysis.

Mixed-effects models are used to analyze grouped data according to one, or several factors, because they flexibly model the within-group correlation often present in this type of data (Bruk & Raudenbush, 1992; Ripley, 1999; Singer, 1998). There were several characteristics of the data of latency that made mixed models appropriate application to the obtained data of latency.

1. Data were clustered, a number of observations were obtained on each of a number of individuals (subjects as clusters).
2. There were repeated measures, the data were obtained in a way that induces serial correlation within cluster.
3. Data had different number of observations for each factor because of missing data (unbalanced data).

Latencies after log-transformation for correct responses and after removing outliers were analyzed using the S-PLUS statistical computer language using lme-functions. In mixed models two effects are calculated – fixed, for population, and random, for clusters (individuals). The results of comparison the negative priming and shifting colour condition with the control condition for population was obtained in z-scores. It was found that negative priming and reversal shift (shifting colour condition) showed different patterns with increasing of item class. For the negative priming condition children of all tested grades showed significant delay in first responses compared with the control condition only for items class 4, except grade 4 children who were also slower in class 1. In contrast, grade 4 and 6 children showed delay in the shifting colour condition in all item classes. Grade 2 children showed lower latencies 1 in the shifting colour condition compared with the control condition only in item class 3. The results of mixed model analysis of latencies 1-4 are presented in Table 8 . Although the mixed models analysis was performed on all the individual latencies exhibited by the subjects (after log-transformation and pruning for outliers), the patterns obtained in the mixed models analysis are reflected in Figure 21, where latency 1 medians are plotted as function of grade, class, and condition. The details of mixed analysis of latency 1 can be found in Appendix E.

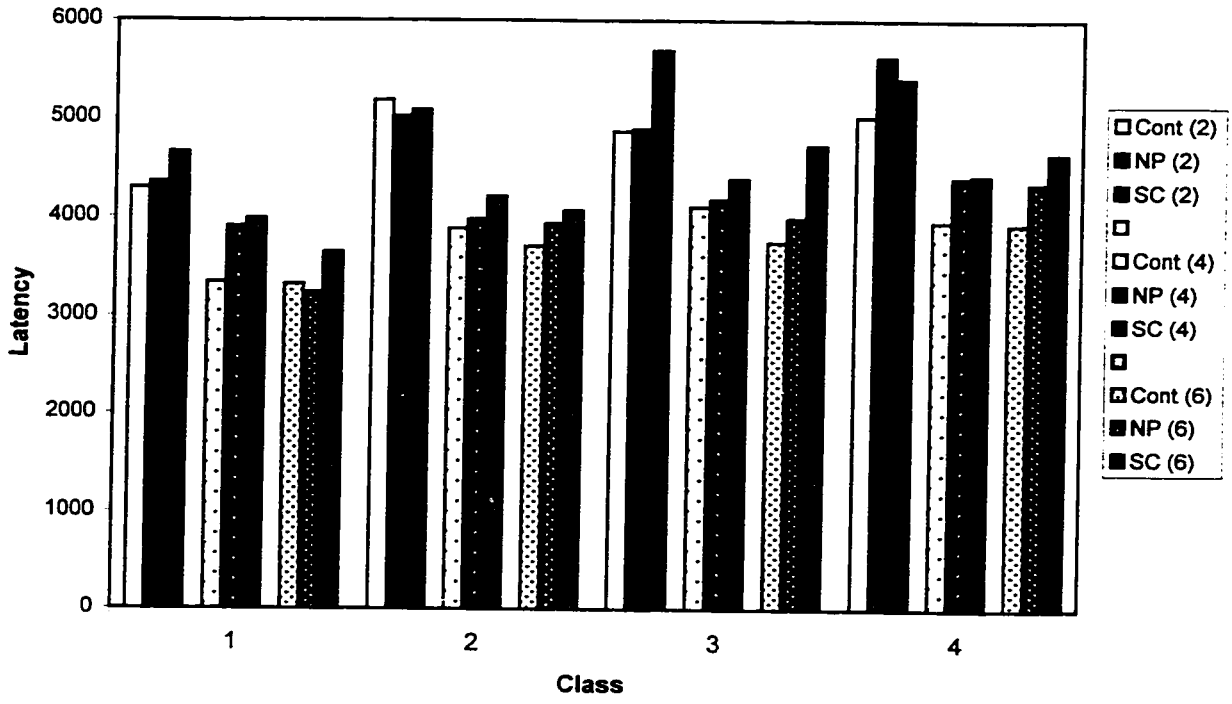


Figure 21
Means of latency 1 medians,
as function of condition, item class, and grade

Table 8.
The results of mixed model analysis of latency for correct responses after log-transformation and removing outliers.

			Class 1	Class 2	Class 3	Class 4
NP vs C	**Grade 2**	Latency 1	-	-	-	*
		Latency 2		-	-	-
		Latency 3			-	*
		Latency 4				-
	Grade 4	Latency 1	*	-	-	*
		Latency 2		-	-	*
		Latency 3			-	-
		Latency 4				*
	Grade 6	Latency 1	-	-	-	*
		Latency 2		-	-	-
		Latency 3			-	-
		Latency 4				-
SC vs C	**Grade 2**	Latency 1	-	-	*	-
		Latency 2		-	*	-
		Latency 3			*	*
		Latency 4				-
	Grade 4	Latency 1	*	*	*	*
		Latency 2		*	*	-
		Latency 3			*	-
		Latency 4				-
	Grade 6	Latency 1	*	*	*	*
		Latency 2		*	*	*
		Latency 3	-		-	-
		Latency 4				-

* significant delay ($p < .05$) in responses for the shifting colour (SC) or the negative priming conditions (NP) compared with the control condition (C)
- no significant difference

Discussion

The Mental-Attention Reversal Shift (MARS) paradigm was designed to investigate two main issues that are crucial for the current understanding of inhibitory processes. First, whether Negative Priming (NP) and other inhibitory processes such as the resistance to (or interruption/control of) interference, are affected by the mental processing difficulty (i.e., mental demand) of the item in question relative to the subject's mental-attentional capacity or mental power (in Pascual-Leone's formulation this is the major developmental – as opposed to learning – factor for the growth of working memory).

The second main issue we intended to investigate is whether NP is a form of inhibition distinct from interference, or whether it is in fact reducible, as Neill (1997) and others are currently suggesting, to a special episodic-memory form of interference. The first issue is important because it will help to evaluate what Engle (1995), Tipper(1985) and others have proposed, i.e., whether NP is caused by a form of active, central/attentional inhibition which, as neoPiagetians often assume, is a developmentally growing limited resource (Im-Bolter, 1999; Pascual-Leone, 1987; Pascual-Leone & Baillargeon, 1994). The second issue is important because a growing current view among experimental psychologists is that NP is not caused by inhibition but by some form of interference, as suggested above.

An ancillary third issue that interested us is the developmental study of the particular version of the MARS paradigm used in this study. The version of the MARS paradigm we have used allows subjects to use a sequential-processing strategy in responding to the relevant animal stimuli, since in logical terms this is essentially a disjunction task (i.e., respond to an animal and/or another ... etc.). This paradigm permits also the implementation of a conjunctive task (i.e., respond to the set of all the present animals at the same time) that does not allow a sequential-

processing strategy and forces subjects to use a parallel-processing strategy; but this alternative version of MARS was not chosen, to maximize the chance that NP would be obtained, since the disjunctive version of the task is more in line with the negative priming paradigms reported in the literature. The theoretical cost of using this disjunctive version instead of a conjunctive one was developmental; from a developmental perspective the disjunctive task is ambiguous because its mental demand should vary depending upon whether subjects are using a sequential-processing strategy (which should keep the mental demand rather constant across classes of items) or a parallel-processing strategy (which would increase parametrically the mental demand with the number of animals present in the display, i.e., with the class of the items). Thus our ancillary issue, which is important for the evaluation of the first issue mentioned, was to determine the developmental characteristics of the MARS disjunctive version we have used, in terms of the accuracy of passing rate of the various school-grade samples; because this age-bound passing rate will tell whether children are using a parallel of sequential-processing strategy.

The ancillary third issue, along with a major condition of the first issue (that the different classes of items be indexing different mental demands), were investigated as formulated in the statistical Hypothesis 1. Namely, if children used a sequential processing strategy then accuracy of responses to classes 1, 2, 3, and 4 will be similar; and all grade samples will exhibit a developmentally adequate passing rate (which is traditionally regarded to be of at least 60% to 75%). The analyses of Accuracy for the three different conditions (i.e., Control, Negative Priming and Shifting Colour) has confirmed the expectation that a sequential-processing strategy was used by the children. The ANOVA on the overall accuracy (on all the responses produced, i.e., 1, 2, 3, or 4) as well as the ANOVA on the accuracy of first responses alone, showed a lack of grade effect (F (2,57)<1). The passing rates for the Conditions x Grades data matrix of overall accuracy

ranges from 68 % (for Shifting Colour, Grade 6) to 80% (e.g., for Control, Grade 2, 4, or 6). Further, as expected, the item Classes 4 and 3 are harder in total accuracy (passing rate of 61% and 78% respectively) than item Classes 2 and 1 (passing rates of 82% and 83% respectively). A similar result obtains for the accuracy of the first responses (Class 4 = 79%; Class 3 = 82%; Class 2 = 86.5 %; Class 1 = 83%). Thus we can conclude that children are using a sequential-processing strategy. This conclusion has as a consequence that we shall not be able to test, in the context of the present disjunctive version of the MARS paradigm, three of our hypothesis, because they are conditional to children using a parallel-processing strategy. Namely, Hypothesis 2 (which emboddies the first issue mentioned above), Hypothesis 3, and Hypothesis 6.

The second main issue mentioned above was formulated in Hypotheses 4 and 5. Hypothesis 4 asserts that because conditions NP (negative priming) and SC (shifting colours) involved some misleading aspects that the Control condition lacks, latencies will be longer in them than in Control; and because these misleading aspects are cumulative over the various relevant animals present in the display, the latencies should tend to increase with the class number (i.e., latencies: Class 4 > Class 3 > Class 2 > Class 1 – here and elsewhere ">" stands for "equal or larger than"). The ANOVA of Table 5 and Figure 17 confirm these predictions.

Hypothesis 5 says that the data patterns of SC (shifting colour) versus NP (negative priming) conditions will be different; SC will exhibit much longer latencies and less accuracy than both Control and NP items but NP will not differ in accuracy from the Control and will show latencies longer than those of Control but shorter than SC. The ANOVAs of Tables 5-7 confirm that the prediction of Hypothesis 5 is upheld in the data. These confirmed predictions of Hypothesis 4 and Hypothesis 5 are consistent with the theoretical model of attention inhibitory mechanisms of the Theory of Constructive Operators, as well as generally consistent with the

models of Engle (1995) and Tipper (1985). They are, however, inconsistent with the "episodic memory" model of NP put forward by Neill (1997; Neill & Valdes, 1996); they are because, as suggested in the Introduction, the "episodic memory" model of NP constitutes in fact another instance of interference within the current (probe) item, and as such it should make the NP data pattern similar to that of the SC data, where task analysis easily demonstrates interference within the probe item caused by the colour change. Thus the different data patterns of NP and SC conditions conform to the dynamic mental-attentional inhibition models that Pascual-Leone, Engle and Tipper have elaborated.

This theoretical conclusion from the results of Hypothesis 4 and 5 are perhaps the theoretically most important results of this thesis, so that it might be appropriate to seek others aspects of the data that could either support via convergent operations (e.g., McCorquodale & Meehl, 1948) the same conclusion or contradict it. No quantitative aspects in the data contradicting this conclusion are visible, but two other quantitative structural results in the data seem to converge in supporting the same conclusion. One is found in the analysis of correlations among the variables of the study. There are two important results in these correlations. The first is that generally the variables dealing with accuracy do not correlate with the latencies. This is expected because latencies here should not reflect the time taken by the solution process but rather the time used in avoiding (these are latencies of correct responses) or interrupting the various "misleading" factors within the situation. The second important result, however, is much more unexpected. When we computed the ratios of means of median latencies for NP and SC versus Control, so as to obtain the ratio latency scores NP/C and SC/C in the various sets of data, and correlated them with other variables, the finding was that NP/C scores generally correlated significantly with the various accuracy scores, while the SC/C scores did not. For instance, the

NP/C_Class4 correlated with the Overall Accuracy score by .34 ($p<.007$) while the SC/C_Class 4 did not correlate with Overall Accuracy (-.19, $p<.13$). Since Class 4 is (and theoretically should be) the most demanding class of items in its executive processing demand, and negative priming effects cumulate over the 4 relevant animals to be identified, the ratio score NP/C_Class 4 should be an indirect estimate of the subject's executive know-how and as such should exhibit a positive correlation with accuracy; but this would not be the case for SC/C_Class 4.

Another not predicted result is interpretable as converging to support Hypothesis 4 and 5. This result was obtained when the correct-responses latency data were normalized via a log transformation after removing outliers, so that linear-mixed-model analyses with clustering by subjects, within grades and latency numbers, could be conducted that compare NP or SC latencies versus the Control latencies. These results are summarized in Table 8. The important finding is that while the NP condition shows significant results for each grade exclusively for latency 1 in Class 4, the SC condition exhibits significant results for each grade in most latencies (1, 2, 3, 4) and most Classes of items (1, 2, 3, 4). These contrasted results are theoretically important because, according to our interruption-mechanism model of NP, there should be no misleading aspect added to the current item processing once the animals to be responded to have been noticed, and thus the only latencies affected by the NP condition should be, for all grades, exclusively those of the first response latency. However, since the SC condition causes interference within the current probe item, which should persist for each and every response, we should expect (although we had not predicted it), for every response number (1, 2, 3, 4) latency and every grade, that the SC latencies will be different from those of the Controls. Consequently these findings converge to add support to our interpretation of the mechanisms operating in negative priming.

There are two predictable but minor findings that are worth discussing. One is the claim that since the mental-attentional demand (i.e., M-demand) of the task, when children use a sequential-processing strategy, is equal to the mental capacity of Grade 2 children (i.e., M-power equal to $e + 3$), and the mental capacity of Grade 4 and Grade 6 children is in excess of this demand, grade 2 children will exhibit in all conditions latencies significantly longer than older children. Figure 15 shows this difference and the ANOVA of Table 5 confirms that there is a main effect for grade. The other predictable minor finding is that with the Class of correct responses (1, 2, 3, 4) the latency of responses should increase and the accuracy should decrease. It should because the executive demand of processing in the task does indeed increase with the Class of responses and, further, in the case of NP the inhibitory effect should cumulate. For the same reasons we expected that, restricted a ceiling effect, the task difficulty would increase and the accuracy decrease inversely to the class number. Figures 17 and 18 and ANOVA of Tables 5-7 confirm these results – result that the episodic-memory model of NP might have difficulty to handle since for it there is less ground for expecting a cumulative effect of difficulty with the Class of responses.

In conclusion, this investigation has established that children utilize a sequential-processing strategy in the disjunctive version of the MARS paradigm we have used. It has also supported, by means of converging sets of results that make a theoretically-coherent predicted complex pattern, our initial claim that negative priming must be explained as resulting from processes of active attentional inhibition (Pascual-Leone's interruption) that take place in the first (prime) item and do not cause interference with the current (probe) items. Thus this study shows that negative priming and interference are distinct forms of active inhibition that should not be confounded and, as byproduct this study has provided new strong evidence that contradicts that

"episodic memory" model of negative priming that Neill and others have put forward. The new research paradigm MARS, which was created for the present investigation, opens a new way of investigating inhibitory processes. A major research project left for the future is to investigate a conjunctive version of the MARS paradigm that should force children to use a parallel-processing strategy and thus should permit the testing of our Hypothesis 2, 3, and 6, which cannot be evaluated when sequential-processing strategy is chosen by children.

References

Allport A., Tipper S.P. & Chmiel, N.R.J. (1985). Perceptual integration and postcategorical filtering. In M.I. Posner (Ed.), *Attention and performance XI* (pp.107-132). Hillsdale, NJ: Elbraum.

Anderson, J.R. (1974). Verbatim and propositional representation of sentences in immediate and long-term memory. *Journal of Verbal Learning and Verbal Behaviour, 13*,149-162.

Baddeley, A.D., (1998). Working memory and executive control. In A.C. Roberts, T.W. Robbins, L. Weiskrantz (Eds). *The prefrontal cortex: Executive and cognitive functions.* New York: Oxford University Press.

Baddeley, A.D., & Hitch, G.J. (1994). Developments in the concept of working memory. *Neuropsychology, 8(4),* 485-493.

Bergstom, J.A. (1894). The reaction of interference to the practice effect of an association. *American Journal of Psychology, 6*, 433-442.

Bhattachryya A.K., & Chattopadhyay R.K.(1983). Response – inhibition deficit in mentally retarded children. *Indian Psychologist, 2(1),* 50-56.

Broadbent, D.E. (1958). Perception and communication. London: Pergamon Press.

Case, R. (1978). Intellectual development from birth to adulthood: A Neo-Piagetian interpretation. In R.S. Siegler (Ed.), *Children's thinking: What develops?* (pp. 37-710). Hillsdale, NJ: Elbraum.

Case, R. (1985). Intellectual development: Birth to adulthood. New York: Academic Press.

Case, R.,Kurland, M., & Goldberg, J. (1982). Operational efficiency and the growth of short term memory span. *Journal of Experimental Child Psychology, 33*, 386-404.

Cattel, J.M.(1893/1947).*Attention and reaction.* Reprinted in James McKeen Cattell, 1860-1944, Man of Science. Lancaster, PA.: Science Press.

Chapman, M. (1990). Cognitive development and the growth of capacity: Issues in NeoPiagetian theory. In M.J.T. Enns, (Ed.) *The development of attention. Research and Theory.* Elsevier.

Chi, M.T.H.(1976). Short-term memory limitation in children: Capacity or processing deficits? *Memory and Cognition. 4*, 559-572.

Conway, A.R.A., & Engle, R.W. (1994) Working memory and retrieval: A resource-dependent inhibition model. *Journal of Experimental Psychology: General, 123*, 354-373.

Conway, A.R.A. (1999). The time-course of negative priming: Little evidence for episodic trace retrieval. *Memory & Cognition, 27 (4),* 575-583.

Conway, A.R.A., Tuholsi, S.W., Shisler, R.J., & Engle, R.W. (in press). The effect of memory load on negative priming: an individual differences investigation. *Memory & Cognition.*

Dalrymple-Alford, E.C., & Budayr, B. (1966).Examination of some aspects of the Stroop color-word test. *Perceptual and Motor skills, 23*, 1211-1214.

Dempster, F.N. (1991). Inhibitory processes: A neglected dimension of intelligence. *Intelligence, 15*, 157-175.

Dempster, F.N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review, 12*, 45-75.

Dempster, F.N.(1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin, 89*, 63-100.

Dempster, F.N., & Brainerd,C.J. (Eds.) (1995), *Interference and inhibition in cognition.* San-Diego, CA: Academic Press.

Deutsch J.A., & Deutsch D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70*, 80-90.

Diamond, A. (1988). Abilities and neural mechanisms underlying A not B performance. *Child Development, 59*, 523-527.

Driver J., & Tipper, S.P. (1989). On the nonselectivity of "selective" seeing: Contrasts between interference and priming in selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 304-314.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological Review, 87*, 272-300.

Engle, W., Conway, A., Tuholski, S., & Shisler, R. (1995) A resource account of inhibition. *Psychological Science, 6*, 122-125.

Eriksen, C.W., & Hoffman, J.E. (1973). The extent of processing noise elements during selective encoding from visual displays. *Perception and Psychophysics, 14*, 155-160.

Greenwald, A. G. (1972). Evidence for perceptual filtering and response suppression for rejected messages in selective attention. *Journal of Experimental Psychology: Learning , Memory, and Cognition, 17*, 245-262.

Halford, G.S. (1982). The development of thought. Hillsdale, NJ.:Elbraum.

Harnishfeger, K.K., & Bjrklund, D.F. (1994). A developmental perspective on individual differences in inhibition. *Learning and Individual Differences, 6,* 331-355.

Harnishfeger, K.K. (1995-a). Development of cognitive inhibition. In: F.N. Dempster, C.J Brainerd. (Eds.), *Interference and inhibition in cognition*. San-Diego, CA: Academic Press.

Harnishfeger, K.K. (1995-b). The evolution of inhibition mechanisms and their role in human cognition and behavior. In F.N. Dempster, & C.J. Brainerd, (Eds.) , *Interference and inhibition in cognition* (pp.141-173). San-Diego, CA: Academic Press.

Harnishfeger, K.K., & Pope, R.S. (1996) Intending to forget: The development of cognitive inhibition in directed forgetting. *Journal of Experimental Child Psychology, 62,* 292-315.

Hasher, L.,Stoltzfus, E.R., Zacks, R.T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 163-169.

Hayes-Roth (1977). Evolution of cognitive structures and processes. *Psychological Review, 84,* 260-278.

Im-Bolter, N. (1999). *Testing theories of development: Inhibition, speed of processing, and mental attention in gifted children.* Unpublished M.A. thesis, York University, Toronto

James, W. (1890/1950). *The principles of psychology, V.1.* New York: Dover.

Johnson, J. M., Fabian, V., & Pascual-Leone, J. (1989). Quantitative hardware-stages that constrain language development. *Human Development, 32,* 245-271.

Kendler, H.H., & Kendler T.S. (1975). From discrimination learning to cognitive development: A neobehavioristic odyssey. In W.K. Estes (Ed.) *Handbook of learning and cognitive processes. V.1.* Introduction to concepts and issues (pp.191-247)..NJ: Elbraum.

Logan, G.D. (1988). Toward the instance theory of automatization. *Psychological Review, 95,* 492-527.

Lorsbach, T.C., Katz, G.A., & Cupak, A.J. (1998). Developmental differences in the ability to inhibit the initial misinterpretation of garden path passages. *Journal of Experimental Child Psychology, 71(3),* 275-296.

McGeoch, J.a. (1932). Forgetting and the law of disuse. *Psychological Review, 39,* 352-370.

Neill, W.T. (1997) Episodic retrieval in negative priming and repetition priming. Jornal of *Experimental Psychology: Learning, Memory & Cognition, 23*,1291-3105

Neill, W.T., Valdes, L.A. (1996). Facilitatory and inhibitory aspects of attention. In A.F. Kramer, M.G. Coles, & G.D. Logan (Eds.). *Converging operations in the study of visual selective attention* (pp.77-106). Washington, DC, USA: American Psychological Association.

Neill, W.T., Valdes, L.A. & Terry, K.M. (1995). Selective attention and inhibitory control of cognition. In F.N. Dempster & C.J. Brainerd. *Interference and inhibition in cognition.* NY: Academic Press, Inc.

Norman, D.A., (1968). Toward a theory of memory and attention. *Psychological Review, 75*, 522-536.

Pascual-Leone, J. (1970). A mathematical model for the transition rule in Piaget's development stages. *Acta Psychologica, 32*, 302-345.

Pascual-Leone, J. (1978). Compounds, confounds, and models in developmental information processing: A reply to Trabasso and Foellinger. *Journal of Experimental Child Psychology, 26*, 18-40.

Pascual-Leone & J, Goodman, D. (1979). Intelligence and experience: A neo-Piagetian approach. *Instructional Science, 8*, 301-367.

Pascual-Leone, J.(1983). Growing into human maturity: Toward a metasubjective theory of adulthood stages. *Life-span development and behavior, 5,* pp.117-155.

Pascual-Leone, J. (1984). Attention, dialectic and mental effort: Toward and organismic theory of life stages. In M.L. Commons, F.A. Richards, & C. Armon (Eds.), *Beyond formal operations* (pp. 182-215). NY: Plenum.

Pascual-Leone, J. (1987). Organismic processes for neo-Piagetian theories: A dialectical causal account of cognitive development. *International Journal of Psychology, 22*, 531-570.

Pascual-Leone, J. (1989) An organismic process model of Witkin's field-dependence-independence. In T. Globerson, & T. Zelniker (Eds.) *Cognitive style and cognitive development* (pp.36-70). Norwood, NJ: Ablex.

Pascual-Leone, J., Baillargeon, R., Lee, C., & Ho, G.W. (1990) *Toward standardization of mental capacity testing. Department of Psychology Report.* York University, Toronto.

Pascual-Leone, J. (1995). Learning and development as dialectical factors in cognitive growth. *Human Development, 38*, 338-348.

Pascual-Leone, J., Johnson, J., S. Baskind, & Dworsky, S. (June, 1998). *Misleading situations, active inhibition, and the fair assessment of mental capacity.* Poster presented at the meetings of the Canadian Society for Brain, Behavior, and Cognitive Science, Ottawa, Ontario.

Pascual-Leone, J., & Johnson J. (1999-a). *Development of mindfulness and mindlessness: and organismic, dialectical-constructivist viewpoint.* Unpublished manuscript, York University.

Pascual-Leone, & J., Johnson J. (1999-b). A dialectical constructivist view of representation: Role of mental attention, executives, and symbols. I.E. Sigel (Ed.) *Development of representational thought: Theories ans applications (pp. 169-201).* Mahwah, NJ: Lawrence Eribam Associates.

Pasher, H.E. (1998). *The psychology of attention.* A Bradford Book ; Cambridge; MA: MIT Press.

Piaget, J. (1921). Essay on some aspects of the development of the concept of "part" in the child. *Journal de Psychologie, 18,* 449-480.

Piaget, J. (1923). A verbal form of comparison in the child: A case of transition between predicative judgments and relational judgments. *Archives de Psychologie, 18*, 141-171.

Reber, A.S. (1985). *Dictionary of psychology*. Toronto: Penguin.

Reyna, V.F. (1995). Memory and reasoning. In F.N. Dempster, & C.J. Brainerd, (Eds), *Interference and Inhibition in cognition* (pp.29-59). New York: Academic Press.

Reyna, V.F., & Brainerd, C.J. (1991). A fuzzy-trace theory and children's acquisition of mathematical and scientific concepts. *Learning and Individual Differences, 3*, 27-59.

Rovee-Collier C., & Boller, K. (1995). Infants retroactive interference. In F.N. Dempster, & C.J. Brainerd (Eds), *Interference and Inhibition in cognition* (pp.29-59). New York: Academic Press.

Schacter, R., & Logan, G.D. (1990). Impulsivity and inhibitory control in normal development and childhood psychopathology. *Developmental Psychology, 26*, 710-720.

Shaw, M., & Shaw P. (1977) Optimal allocation of cognitive resources to spatial locations. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 201-211.

Spence, K.W. (1956). *Behaviour theory and conditioning*. New Haven: Yale University Press.

Stroop, J. (1935). Studies of interference in serial verbal reactions. Journal of *Experimental Psychology, 18,* 643-662.

Tipper, S.P. (1985). The negative priming effect: Inhibitory priming by ignored objects. Quarterly Journal of Experimental Psychology, 37A, 571-590.

Tipper, S.P., & Cranston, M. (1985). Selection attention and priming: Inhibitory and facilitatory effects of ignored primes. *Quarterly Journal of Experimental Psychology, 37A*, 591-611.

Tipper, S.P., & McLaren, J. (1990). Evidence of efficient visual selectivity in children. In J.T. Enns (Ed.), *The development of attention: Research and theory* (pp.197-210). North Holland: Elsevier science Publishers B.V.

Tipper, S.P., G. C. Baylis (1987). Individual differences in selective attention: The relation of priming and interference to cognitive failure. *Personality and Individual Differences, 8(5)*, 667-675.

Tipper, S.P., & Milliken, B. (1996). Distinguishing between inhibition-based and episodic retrieval-based accounts of negative priming. In A. Kramer, M.G. Coles, & G.D Logan (Eds). *Converging operations in the study of visual selective attention.* Washington, DC: American Psychological Association.

Townsend (1974). Issues and models concerning the processing of a finite number of inputs. In B. H. Kantowitz (Ed.), *Human information processing: Tutorials in performance and cognition* (pp. 133-168). Hillsdale, NJ: Erlbaum.

Treisman, A.(1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12*, 242-248.

Umetani, T., Kitao, S., & Katada, A. (1985). Discrimination shift learning and response inhibition of moderately and severely mentally retarded and non-retarded children. *Journal of Mental Deficiency Research, 29(3),* 219-224.

Underwood, B.J. (1957). Interference and forgetting. *Psychological Review, 64*, 49-60.

Van der Heijden, A.H.C. (1981). *Short-term visual information forgetting.* Boston: Routledge Kegan Paul.

Zeaman, D., & House, B.J. (1963). The role of attention in retardate discrimination learning. In N.R. Ellis (Ed.) *Handbook of mental deficiency* (pp.149-223). .New York: Mcgraw-Hill.

Appendix A

Sample Items from the MARS task



Figure 1

The shapes of the animals and their coding numbers to facilitate the reading of the sequences of stimuli from trial to trial (Table 1, Appendix A) for the MARS task . Corresponding letters on the keyboard are presented as well.

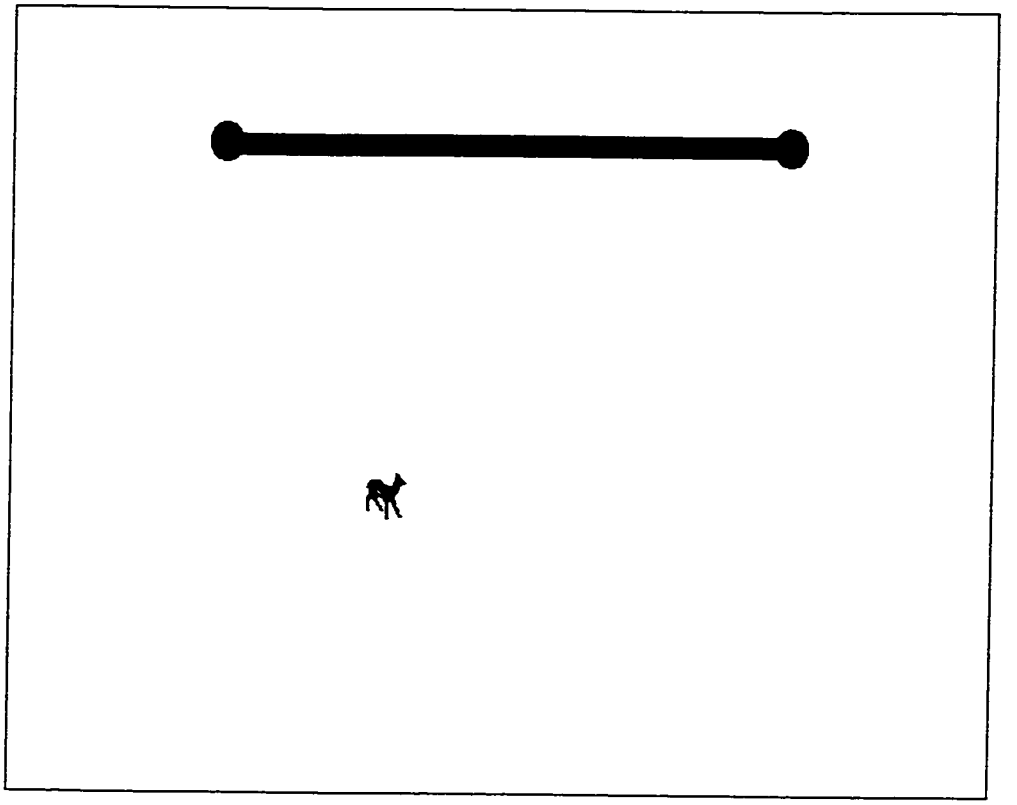


Figure 2

An example of display during training part in the MARS task.

Table 1

Sequence of trials in the MARS task.

Irrelevant and relevant items are presented using coding numbers.

Class	Condition	File	Trial	Irrelevant items	Relevant items
1	C	1/1/26	4	1	2
1	NP	1/1/27	5	7	1
1	C	1/1/22	6	9	4
1	SC	1/1/54	7	6	2
4	C	1/4/40	8	6688	1155
4	NP	1/4/41	9	3399	6688
3	C	1/3/37	10	289	467
3	NP	1/3/38	11	135	289
2	C	1/2/11	12	39	47
2	SC	1/2/41	13	79	68
2	SC	1/2/31	14	35	12
4	C	1/4/72	15	1212	5599
4	SC	1/4/73	16	7676	3344
4	SC	1/4/74	17	5858	1199
4	SC	1/4/75	18	4477	2266
1	C	1/1/61	19	3	9
1	C	1/1/43	20	6	5
2	C	1/2/43	21	18	79
2	NP	1/2/44	22	36	18
2	C	1/2/48	23	16	27
2	NP	1/2/49	24	48	16
2	C	1/2/64	25	39	27
1	C	1/1/67	26	3	7
1	NP	1/1/68	27	5	3
3	C	1/3/29	28	269	145
3	C	1/3/25	29	789	653
1	C	1/1/09	30	3	5
1	SC	1/1/37	31	4	1
1	NP	1/1/38	32	7	4
4	C	1/4/47	33	7979	3322
4	C	1/4/70	34	5566	4488
4	C	1/4/71	35	3377	1199
2	C	1/2/52	36	12	34
2	C	1/2/53	37	26	78
2	C	1/2/37	38	13	59
2	C	1/2/26	39	28	15
2	NP	1/2/27	40	46	82
3	C	1/3/09	41	347	562
3	C	1/3/10	42	449	218
3	C	1/3/33	43	999	346
3	C	1/3/26	44	789	321
3	NP	1/3/27	45	246	987
1	C	1/1/59	46	5	6
1	NP	1/1/60	47	1	5

3	C	1/3/24	48	759	246
3	C	1/3/59	49	799	831
3	NP	1/3/60	50	256	799
2	C	1/2/37	51	13	59
2	SC	1/2/03	52	24	67
2	SC	1/2/04	53	19	36
4	C	1/4/64	54	3344	5577
4	NP	1/4/65	55	8899	3344
3	C	1/3/11	56	479	536
3	NP	1/3/12	57	338	479
3	C	1/3/65	58	356	129
1	C	1/1/01	59	5	2
1	C	1/1/11	60	3	8
1	SC	1/1/02	61	4	1
1	C	1/1/08	62	5	2
4	C	1/4/01	63	2478	1359
4	C	1/4/20	64	1357	4468
2	C	1/2/54	65	26	39
2	NP	1/2/55	66	45	26
2	SC	1/2/59	67	88	39
3	C	1/3/76	68	776	388
3	SC	1/3/29	69	229	145
3	NP	1/3/30	70	348	269
4	C	1/4/66	71	5566	1177
4	SC	1/4/67	72	4466	2288
4	NP	1/4/68	73	1177	4466
1	C	1/1/29	74	9	8
1	C	1/1/42	75	5	3
2	C	1/2/29	76	46	82
2	SC	1/2/19	77	57	39
2	NP	1/2/17	78	23	57
4	C	1/4/53	79	1199	2257
4	NP	1/4/55	80	5544	1199
4	SC	1/4/56	81	6688	1133
4	SC	1/4/57	82	2255	4477
4	NP	1/4/59	83	1199	2255
3	C	1/3/01	84	734	269
3	C	1/3/75	85	551	778
3	SC	1/3/23	86	446	323
1	C	1/1/62	87	3	4
1	SC	1/1/59	88	5	6
1	SC	1/1/46	89	2	3
2	C	1/2/62	90	45	37
2	NP	1/2/56	91	26	45
3	C	1/3/02	92	388	267
3	SC	1/3/63	93	129	446
4	C	1/4/62	94	5789	2346
4	C	1/4/60	95	3368	1177
4	SC	1/4/03	96	3369	2448
4	NP	1/4/04	97	1155	3369
1	C	1/1/14	98	8	2
1	C	1/1/15	99	7	4
1	NP	1/1/16	100	6	7
3	C	1/3/44	101	125	843
3	NP	1/3/45	102	467	125
2	C	1/2/50	103	57	43

2	NP	1/2/51	104	68	57
2	SC	1/2/24	105	35	29
2	C	1/2/25	106	48	16
4	C	1/4/44	107	1668	4577
4	C	1/4/25	108	2228	1339
4	SC	1/4/29	109	6677	4455
4	C	1/4/46	110	1288	3399
3	C	1/3/56	111	149	225
3	NP	1/3/57	112	788	149
1	C	1/1/24	113	6	5
1	NP	1/1/25	114	1	6
1	SC	1/1/31	115	9	2
1	NP	1/1/61	116	3	9
2	C	1/2/72	117	79	23
2	C	1/2/73	118	14	85
2	C	1/2/74	119	36	29
1	C	1/1/57	120	9	7
1	SC	1/1/60	121	1	5
1	C	1/1/39	122	4	7
3	C	1/3/70	123	133	278
3	SC	1/3/71	124	699	455
3	SC	1/3/72	125	288	731
3	SC	1/3/73	126	666	459
3	SC	1/3/74	127	177	238
4	C	1/4/50	128	4477	6688
4	NP	1/4/51	129	2233	4477

Appendix B

Administration Procedure for the MARS task

The set of instructions was presented orally as follows:

Introduction and training.

The experimenter reads the instructions aloud to the participant as they appear on the computer screen.

- *Welcome to the game "Two Kingdoms"!*
- *There were two kingdoms: the Kingdom of Letters and the Kingdom of Animals. Press Enter to go to next page.*

The instruction to press Enter to go to next page, which is at the bottom of every display, is eventually omitted when the participant has learned this rule, although the instruction remains printed in every display. From now on the text of this instruction will be omitted, however it appears on each display.

- *The Animals lived in the forest. The Letters lived in books*
- *The Kingdom of Letters was very attractive to the Animals because the Letters had knowledge. Once the Animals decided to go to the Kingdom of Letters, and they got lost.*
- *Help the Animals get back to their Kingdom!*
- *You can return the Animals to their Kingdom by pressing magic stones. Each stone goes with only one animal. The pictures of stones are on your keyboard. Now you will learn what stone goes with what animal.*

The experimenter then points to the first set of animals on the display and then to the set of "stones" corresponding to them on the keyboard, and adds:

- *Look, the stones for these animals are located in this row.*

The same procedure is used to introduce the buttons corresponding to the other two sets of animals.

- *Now you will have practice of finding stones. Every time you make a mistake you will hear a beep, and then the computer will show you the correct stone to press. Press the correct button and then "Enter". If there is no beep, just press "Enter".*

After these words the subject has some practice with the first set of animals. The practice begins by showing the picture of all animals and the buttons that correspond to them with the first animal of the set in the middle of the display (Fig.8). Then the subject presses "Enter"to go to the next display (Fig.9). This new display shows a red animal that is beneath a red rod (or "magic wand"), and the subject is encouraged to press the appropriate button. If the subject makes a mistake a beep sounds and the display that has previously been used to introduce the animal appears. The experimenter may says:

- This time you made a mistake, so the computer made a beep sound and showed you what the correct stone is. Look again at the picture and try to remember what stone goes with this animal.

Some participants attempt to press the button while the feedback picture is shown. In this case the experimenter points to the bottom of the picture with the instruction to press "Enter", and encourages the subject to respond when the next training display appears. The same animal appears but in blue colour beneath a blue rod. The experimenter has the following dialogue with the participant:

- *Is it the same animal?*
- *Yes.*
- *That is right. It is the same animal, but different in colour. No matter what colour the animal is it goes with the same stone.*

The above procedure is repeated for each animal of the set. When the first set of animals has been introduced, practice with all three animals of the set begins. Practice continues until the subject

makes 13 consecutive correct responses. After practice with the first set of animals, the same procedure is repeated for the second and third sets. The final practice involves all nine animals and continues until the subject makes 45 consecutive correct responses. At the beginning of this practice the experimenter says:

- *From now on you will practice with all the animals. Try your best. You have to make 45 correct responses without any mistakes before you get permission from the computer to play the game.*

When this criterion is met, the experimenter reads the following instructions aloud, which are found in the computer display:

- *Congratulations! You are now the master of magic stones.*
- *From now on, there will be more than one animal on the screen. There will be animals with the colour of a wand, animals with the opposite colour and lots of blue and red letters.*
- *To help red Animals you will have a red wand. To help blue Animals you will have a blue wand. The wands look like this.*

With these words the examiner points to the red and blue thick lines (rods) on the display.

- *The colour of the wand is blue. This means that you must select only blue animals.*

The experimenter then should asks the subject to point to the animal and respond; he/she asks using these words:

- *What animal should you help now? Do you remember which stone goes with this animal?*

If the participant fails to find the correct animal the examiner says, pointing to the animal and then pressing the correct button:

- *Look, there is only one animal that has the same colour as the wand on this picture, and this animal goes with this button.*

The instructions then continue with the next display:

- *Now the colour of the wand is red. This means that you must select only red animals.*

The same procedure described above was used for the introduction of the blue wand. The instructions then continue with these words:

- *Now let's have some practice with the wands. Remember, you have to find only the animals that are the same colour as the wand.*

At the end of a short practice (five displays) the final words for the training part are said:

- *Well, you must be tired from so much practicing. You did it very well, and you are ready now to play the game. I look forward to seeing you next time. Goodbye.*

If testing is conducted immediately after the training part, as in the present research, the examiner may omit the last two sentences.

Testing

The experimenter reads all instructions aloud to the participant as they appear on the screen:

- *Welcome back to the game "Two Kingdoms"!*
- *Let's refresh your memory about which stone goes with each animal.*

After the subject pass the criterion of 13 consecutive correct responses, the examiner reminds the participant to attend to the wands:

- *Good! Now let's see if you remember about the wands.*
- *The colour of the wand is red. This means that you must select only red animals.*
- *The colour of the wand is blue. This means that you must select only blue animals.*

The procedure during responses to these two instructions is the same as in the introduction to the wands during training.

- *Good! You have learned the game rules very well. You are almost ready to play the game.*
- *Your job for each picture is to find all the animals with the colour of the wand and then press all the stones that go with these animals.*
- *Sometimes an animal will appear more than once. Be sure to press the correct stone for every animal you see. For example, if you see a correct animal two times you press the stone two times.*
- *For each picture first press all the stones for the animals you found, and then press "Enter" to go to the next page.*
- *Each picture will be shown for a short time only. You may press the stones while the picture is shown, or after it disappears.*
- *Remember, in this game two things are important: first, finding all the correct animals; second, finding them fast. However, doing it well is better than going fast.*
- *Do you have any questions? Ask them now because you will not have time to ask questions while the pictures are being shown. If everything is clear, it is time for the game. Have fun!*

Examples of some of the trials are presented in Figures 2-7. After the test, the following words appear on the screen:

- *Well done! I hope you are not so tired that you will not be able to enjoy the kingdom of your friends. That is it for now!!! Goodbye.*

Appendix C

Introduction and training sequence control file for the MARS task

*Introduction and training sequence control file for

the Mental Attention Reversal Shift Task (train.seq, first session)

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* Last revised December 9/98

TRAINING SESSION
BUTTONMAP BUTTON3.MAP
KEYBOARD

' Set end-of-trial signal source to a 5 second automatic response timer.
TRIALEND BY EXPERIMENTER
' Set response acknowledgement to both click and latched lights.
BUTTONCLICK ON
BUTTONLIGHT NONE
' Set hintlevel to sound and graphics hints.
HINTLEVEL 5
HINTDURATION 8
' Set prestimulus image.
PRESTIMULUS  NULL
POSTSTIMULUS NULL

TIMEOUT 120

' Introduction

' Welcome to the game "Two Kingdoms"!
SHOWKEY INSTR1.PCX 60
' There were two kingdoms: the Kingdom of ...and the Kingdom of Animals
SHOWKEY INSTR2.PCX 60
' The Animals lived in .... The Letters lived in books.
SHOWKEY INSTR3.PCX 60
' The Kingdom of Letters was very attractive... and they got lost.
SHOWKEY INSTR4.PCX 60
' Help the Animals to come back...
SHOWKEY INSTR5.PCX 60
' You can retern the animals ... by pressing stones.
SHOWKEY INSTR6.PCX 60
'Picture of all animals
showkey instr7.pcx 60
'Every time when you will make mistake you will hear beep...
SHOWKEY INSTR7-1.PCX 60


'introduction to the first set of animals

trial hint1.pcx 60    'introduction to the 1st animal
REVIEW TR1R.PCX 60    'practice with the 1st animal in blue and red color
review tr1b.pcx 60

trial hint2.pcx 60    'introduction to the 2nd animal (4 legs)
REVIEW TR2R.PCX 60    'practice with the 2nd animal in blue and red color
REVIEW TR2b.PCX 60

trial hint3.pcx 60
REVIEW TR3R.PCX 30
REVIEW TR3b.PCX 30

'show Set up review trial LOOP until the subject passes the criterion.

CRITERION 13 :end1
:LABEL1

Review tr1r.pcx 30
Review tr3r.pcx 30
```

```
REVIEW TR2B.PCX 30
REVIEW TR3B.PCX 30
REVIEW TR1B.PCX 30
REVIEW TR2r.PCX 30
REVIEW TR1r.PCX 30
REVIEW TR3r.PCX 30
REVIEW TR3B.PCX 30
REVIEW TR2B.PCX 30
REVIEW TR1b.PCX 30
Review tr1r.pcx 30
Review tr3r.pcx 30
REVIEW TR2B.PCX 30
REVIEW TR3B.PCX 30
REVIEW TR1B.PCX 30
REVIEW TR2r.PCX 30
REVIEW TR1r.PCX 30
REVIEW TR3r.PCX 30
REVIEW TR3B.PCX 30
REVIEW TR2B.PCX 30
REVIEW TR1b.PCX 30
GOTO :LABEL1
:end1
'introduction to the 2nd set of animals (birds)

trial hint4.pcx 60
REVIEW TR4R.PCX 60
review tr4b.pcx 60

trial hint5.pcx 60
REVIEW TR6R.PCX 60
REVIEW TR6b.PCX 60

trial hint6.pcx 60
REVIEW TR5R.PCX 30
REVIEW TR5b.PCX 30

'show Set up review trial LOOP until the subject passes the criterion.

CRITERION 13 :END2
:LABEL2
Review tr4r.pcx 30
Review tr6r.pcx 30
REVIEW TR5B.PCX 30
REVIEW TR6B.PCX 30
REVIEW TR4B.PCX 30
REVIEW TR5r.PCX 30
REVIEW TR4r.PCX 30
REVIEW TR6r.PCX 30
REVIEW TR6B.PCX 30
REVIEW TR5B.PCX 30
REVIEW TR4b.PCX 30
Review tr4r.pcx 30
Review tr6r.pcx 30
REVIEW TR5B.PCX 30
REVIEW TR6B.PCX 30
REVIEW TR4B.PCX 30
REVIEW TR5r.PCX 30
REVIEW TR4r.PCX 30
REVIEW TR6r.PCX 30
REVIEW TR6B.PCX 30
REVIEW TR5B.PCX 30
REVIEW TR4b.PCX 30
GOTO :LABEL2
:end2

'Introduction to the 3rd set of animals (fat animals)

Trial hint7.pcx 60
REVIEW TR9R.PCX 30
REVIEW TR9b.PCX 30
```

```
Trial hint7.pcx 60
REVIEW TR9R.PCX 30
REVIEW TR9b.PCX 30

Trial hint9.pcx 60
REVIEW TR7R.PCX 60
Review tr7b.pcx 60

Trial hint8.pcx 60
REVIEW TR8R.PCX 60
REVIEW TR8b.PCX 60


'Show Set up review trial LOOP until the subject passes the criterion.

CRITERION 13 :END3
:LABEL3

Review tr7r.pcx 30
Review tr9r.pcx 30
REVIEW TR8B.PCX 30
REVIEW TR9B.PCX 30
REVIEW TR7B.PCX 30
REVIEW TR8r.PCX 30
REVIEW TR7r.PCX 30
REVIEW TR9r.PCX 30
REVIEW TR9B.PCX 30
REVIEW TR8B.PCX 30
REVIEW TR7b.PCX 30
Review tr7r.pcx 30
Review tr8r.pcx 30
REVIEW TR8B.PCX 30
REVIEW TR9B.PCX 30
REVIEW TR7B.PCX 30
REVIEW TR8r.PCX 30
REVIEW TR7r.PCX 30
REVIEW TR9r.PCX 30
REVIEW TR9B.PCX 30
REVIEW TR8B.PCX 30
REVIEW TR7b.PCX 30
GOTO :LABEL3
:end3

'show Set up review trial LOOP until the subject passes the criterion.
'all animals in the loop

CRITERION 45 :END4
:LABEL4

'RANDOM ORDER OF RANDOM RED AND BLUE ANIMALS
REVIEW TR4B.PCX 30
REVIEW TR2B.PCX 30
REVIEW TR9B.PCX 30
REVIEW TR7R.PCX 30
REVIEW TR6R.PCX 30
REVIEW TR8B.PCX 30
REVIEW TR2R.PCX 30
REVIEW TR1B.PCX 30
REVIEW TR5B.PCX 30
REVIEW TR3R.PCX 30
REVIEW TR9B.PCX 30
REVIEW TR1R.PCX 30
REVIEW TR7B.PCX 30
REVIEW TR8B.PCX 30
REVIEW TR3R.PCX 30
REVIEW TR6B.PCX 30
REVIEW TR4B.PCX 30
REVIEW TR2R.PCX 30
REVIEW TR5R.PCX 30
```

```
REVIEW TR3B.PCX 30
REVIEW TR1B.PCX 30
REVIEW TR9R.PCX 30
REVIEW TR6B.PCX 30
REVIEW TR4R.PCX 30
REVIEW TR7R.PCX 30
REVIEW TR5B.PCX 30
REVIEW TR8R.PCX 30

GOTO :LABEL4
:end4

'Congratulation! You became be master of the stones
SHOWKEY INSTR8.PCX 60
'From now on there will be more than one animal
showkey 2-instr5.pcx 60
'Introduction of the wands
SHOWKEY INSTR6-1.PCX 60

'The colour of the wand is blue
Review INSTR9.PCX 60
'Now the colour of the wand is red.
Review INSTR9-1.PCX 60
'Now let's have some practice with wands
Showkey instr6-3.pcx 60
Review 1-1-26.pcx 60    'blue 2
Review 1-1-32.pcx 60    'red 4
Review 1-1-22.pcx 60    'blue 4
Review 1-1-42.pcx 60    'blue3
Review 1-1-67.pcx 60    'red 9


SHOWKEY GOODBYE1 60

' End of session.

:END
```

Appendix D

Descriptive data for the MARS task

Grade 2

Plots of latency 1 and 2 by classes and conditions. The number of classes is shown at the top bars of the plots, and the conditions are shown at the bottom of plots, where 1 is negative priming, 2 is shifting colour and 3 is control conditions.

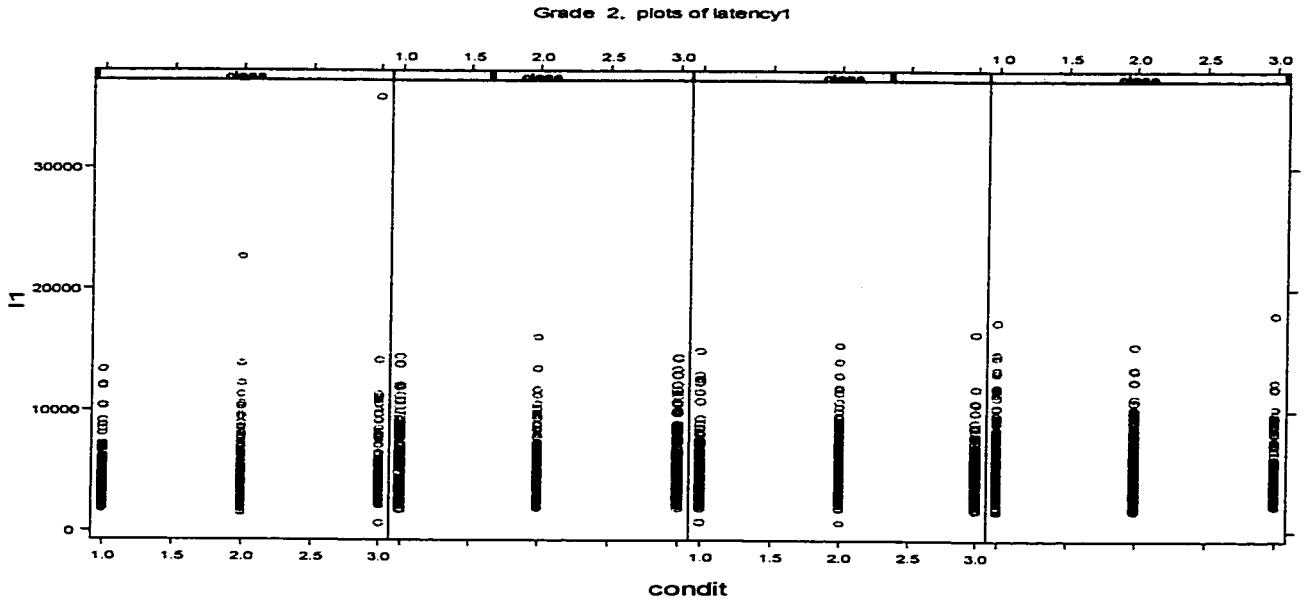


Figure 1.1

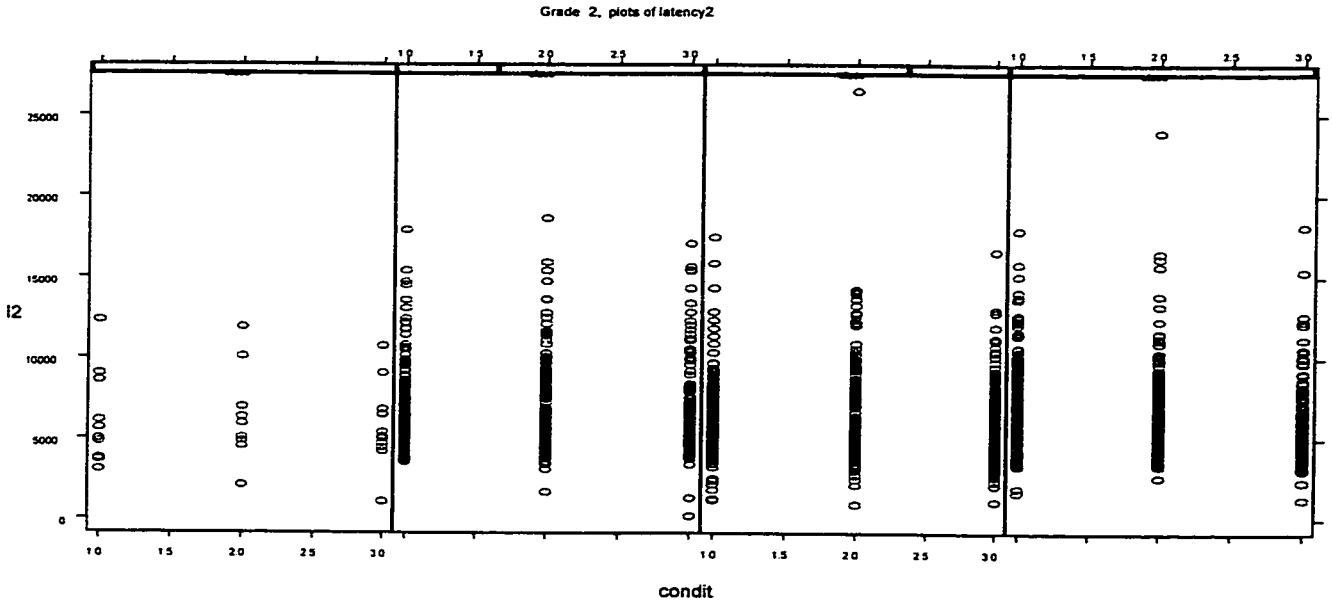


Figure 1.2

Plots of latency 3 and 4 by classes and conditions. The number of classes is shown at the top bars of the plots, and the conditions are shown at the bottom of plots, where 1 is negative priming, 2 is shifting colour and 3 is control conditions.

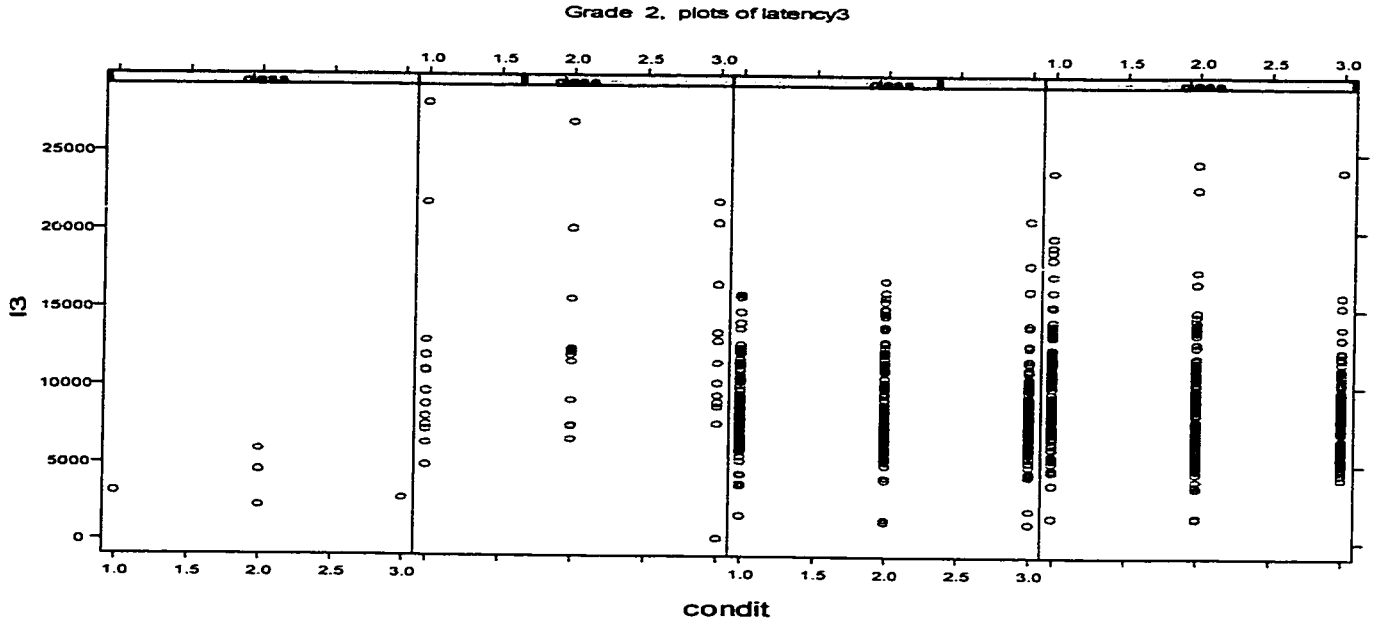


Figure 1.3

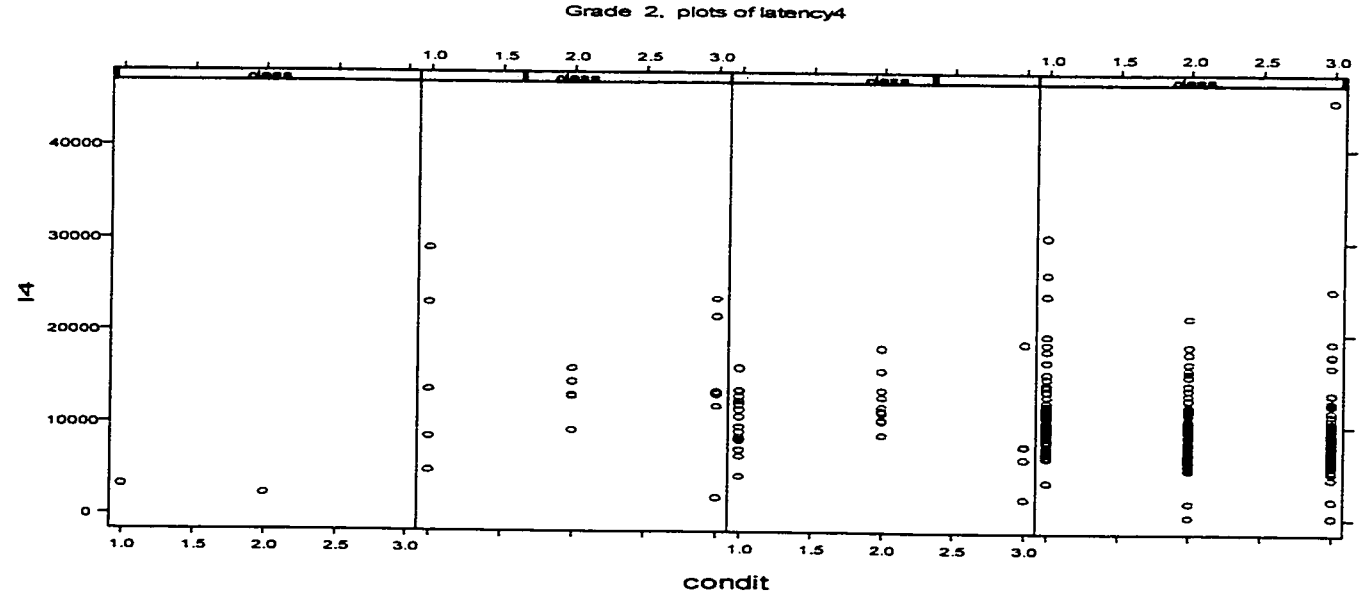


Figure 1.4

Grade 4

Plots of latency 1 and 2 by classes and conditions for grade 4. The number of classes is shown at the top bars of the plots, and the conditions are shown at the bottom of plots, where 1 is negative priming, 2 is shifting colour and 3 is control conditions.

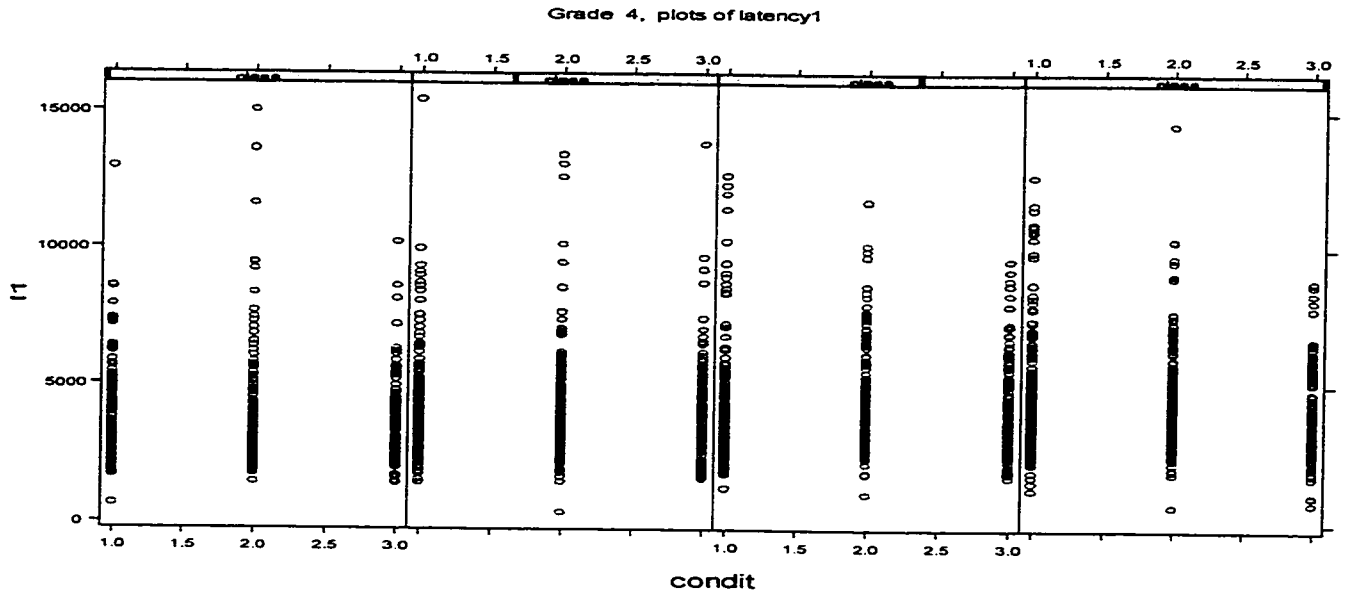


Figure 2.1

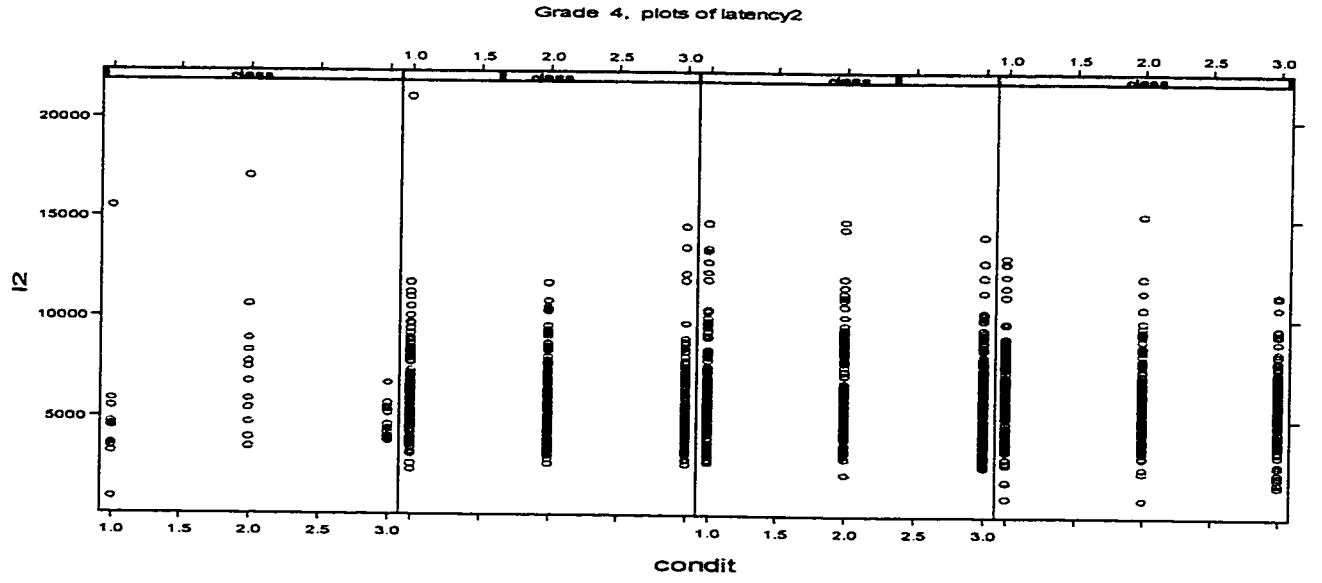


Figure 2.2

Plots of latency 3 and 4 by classes and conditions for grade 4. The number of classes is shown at the top bars of the plots, and the conditions are shown at the bottom of plots, where 1 is negative priming, 2 is shifting colour and 3 is control conditions.

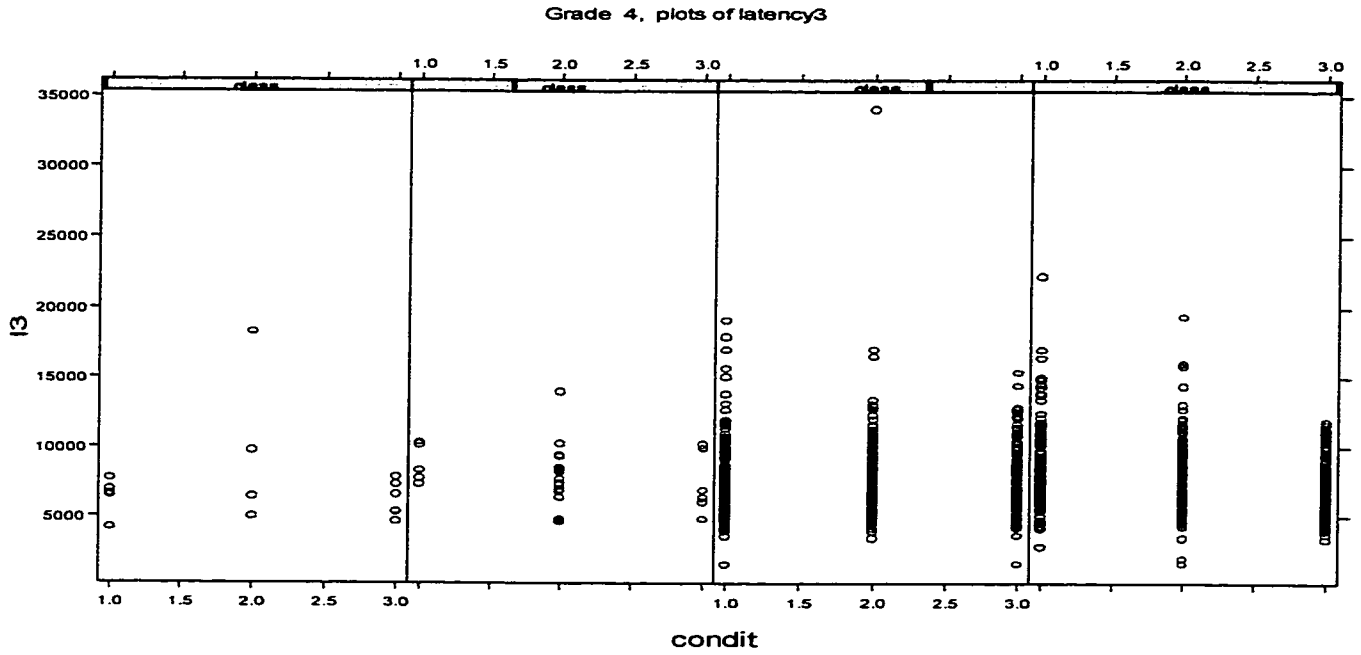


Figure 2.3

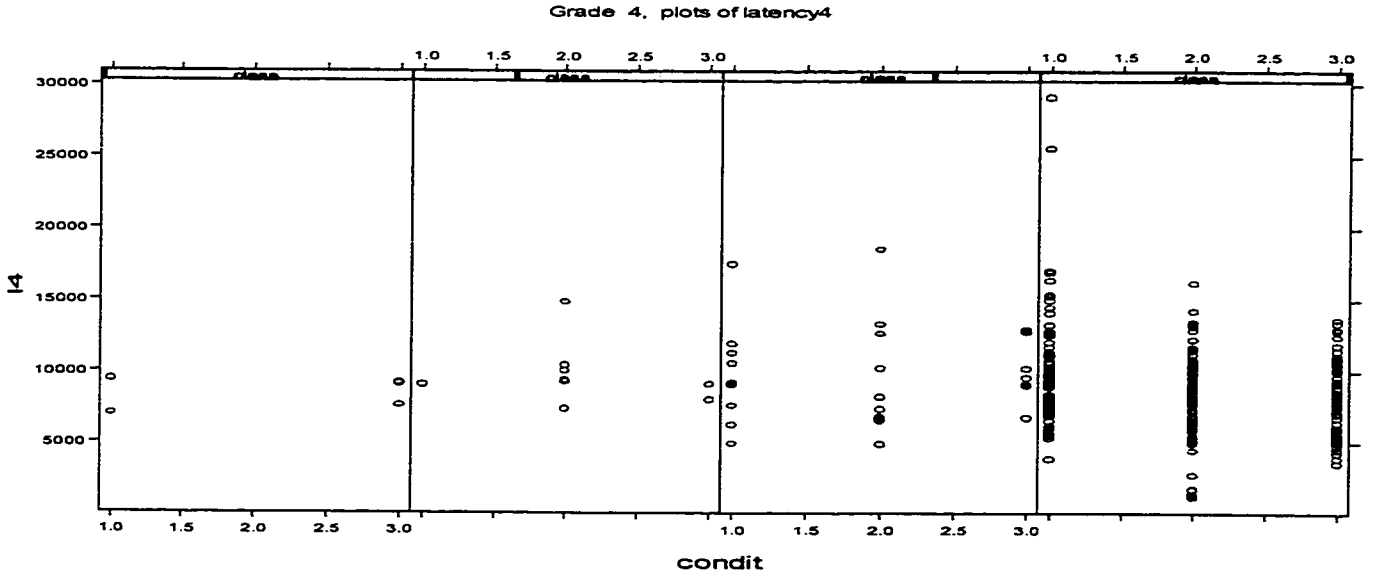


Figure 2.4

Grade 6

Plots of latency 1 and 2 by classes and conditions for grade6. The number of classes is shown at the top bars of the plots, and the conditions are shown at the bottom of plots, where 1 is negative priming, 2 is shifting colour and 3 is control conditions.

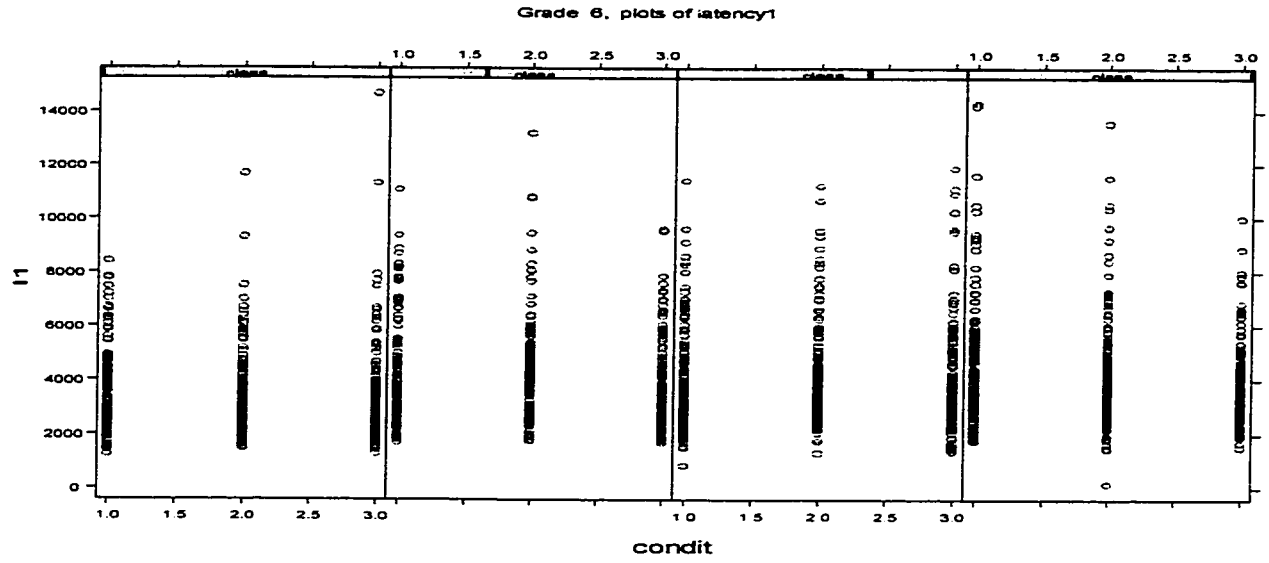


Figure 3.1

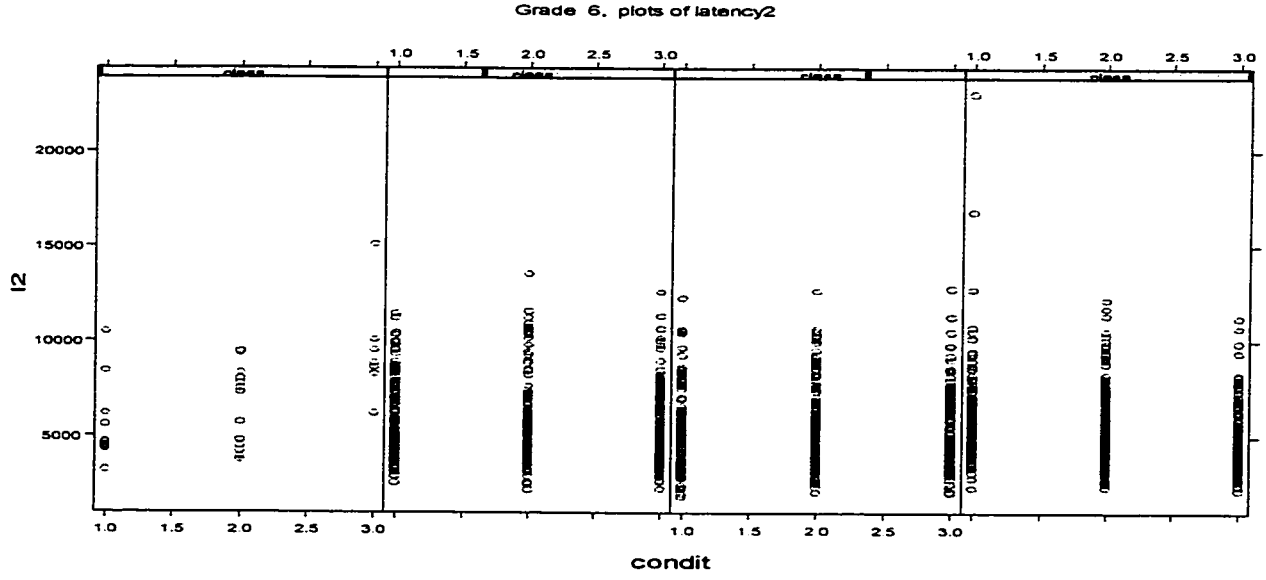


Figure 3.2

Plots of latency 3 and 4 by classes and conditions for grade6. The number of classes is shown at the top bars of the plots, and the conditions are shown at the bottom of plots, where 1 is negative priming, 2 is shifting colour and 3 is control conditions.

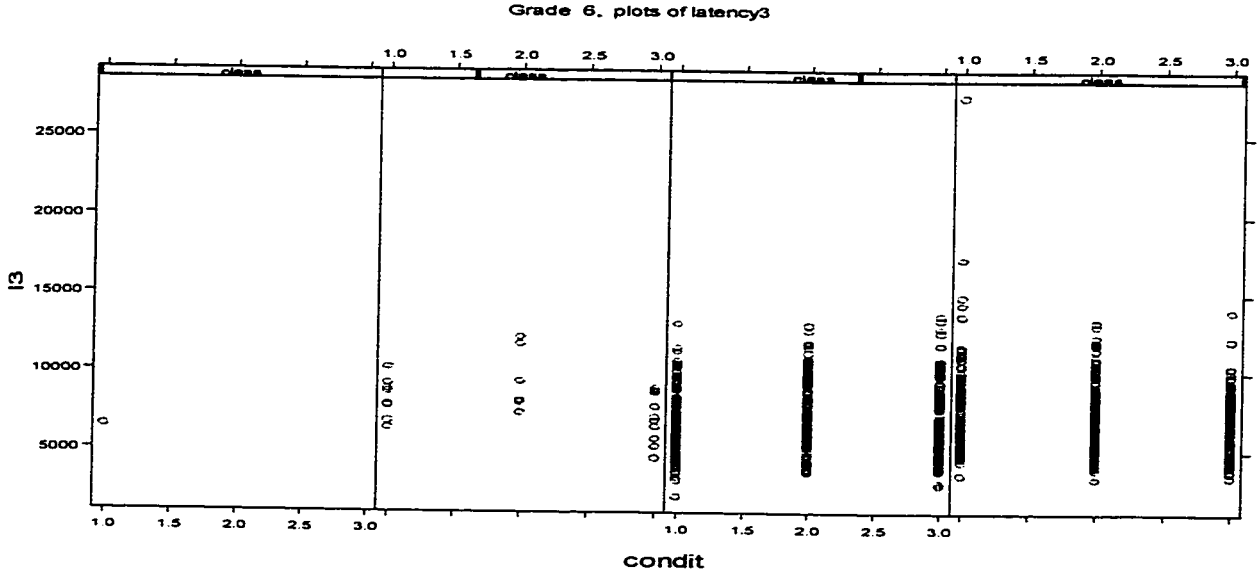


Figure 3.3

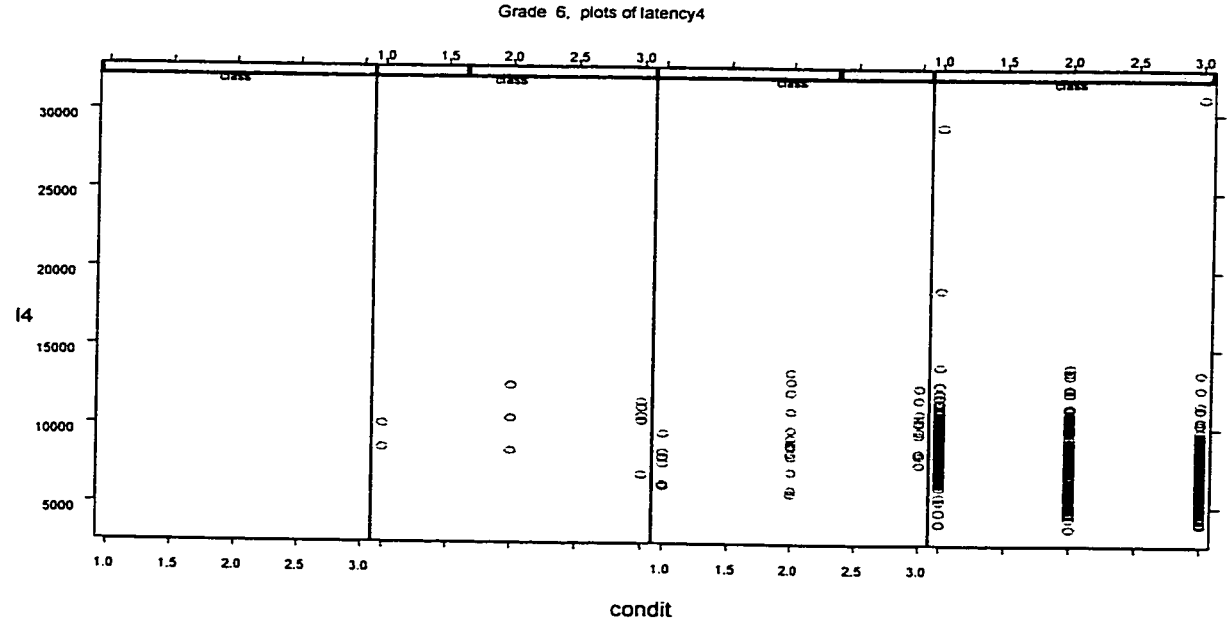


Figure 3.4

Table 1

Grade2 Subjects' Medians of Latency1 for Correct Responses and the Means and Standard Deviations of the Medians

Class	Cond	mean	St.dev.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
1	NP	**4357**	**1305.9**	3449	3378	5293	3894	3591	2751	3697	4107	5535	5949	8420	3877	4580	4260	5438	3589	4609	4340	3736	2642
1	SC	**4654**	**1508.8**	4741	3688	3735	3924	4282	2992	4079	6300	7697	6929	7501	2832	4477	5871	5239	3008	4220	4666	4322	2587
1	C	**4297**	**1030.6**	5403	4074	3571	4519	3957	3049	4061	5298	3374	6638	4513	2487	3830	6003	4909	3144	4910	4212	4522	3473
2	NP	**5015**	**1523.9**	6715	4083	5366	3280	3337	3006	6510	6373	3624	8641	5148	3448	4364	6345	6943	4165	3941	5372	5441	4208
2	SC	**5081**	**1323.8**	5184	5579	5260	4581	2843	2673	4768	6489	4685	6936	5980	4596	2840	5059	7967	4649	6144	4577	5181	5627
2	C	**5178**	**1355.7**	5548	5206	5249	4665	2569	3087	5803	5179	3660	6484	5257	4529	8187	5355	7485	4243	6550	4266	5623	4619
3	NP	**4887**	**1447.8**	5998	3778	5612	4637	2733	2436	5195	4388	4939	6713	4841	5139	4873	4208	6846	3204	8300	4193	6101	3604
3	SC	**5690**	**2069.0**	9115	3866	8201	3271	2641	2923	6952	7356	5549	8666	7693	3766	5343	5745	7113	3751	7398	5040	6287	3120
3	C	**4865**	**1306.4**	6255	4432	6542	4103	3519	2216	5186	5701	2924	6213	6978	4935	5196	4739	6599	3514	4271	3941	5733	4305
4	NP	**5622**	**1666.1**	7496	4984	6683	3571	2546	5295	7943	7643	4671	6946	6046	3937	5497	5989	7567	3526	5620	5368	7832	3277
4	SC	**5397**	**2035.3**	4673	5878	4522	9543	2707	2595	5716	8499	3032	7494	6352	4539	5938	3602	7121	3135	8136	3376	5939	5142
4	C	**5016**	**2193.8**	11802	3367	3963	3625	3579	2845	5482	7845	3700	8219	5416	3914	5541	4334	6545	3434	4929	3758	5032	2991

Table 2

Grade 4 Subjects' Medians of Latency 1 for Correct Responses and the Means and Standard Deviations of the Medians

Clas	Con	mean	St. dev.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
1	NP	**3907**	**1091**	5197	6198	3133	3292	5019	3404	4173	3549	2844	4156	5048	3390	4657	2399	3580	2395	4734	2560	5306	3117
1	SC	**3985**	**1322**	5087	2910	2562	2928	5610	2822	6385	3323	2616	5543	4239	2835	3486	2836	7092	3719	3954	3323	4171	4263
1	C	**3345**	**693.4**	3978	4506	3444	2816	4382	2539	4527	3120	2779	2500	3945	3509	2804	2330	3770	2694	3939	3069	3294	2963
2	NP	**3978**	**1418**	4153	6116	2658	3337	5145	2611	4003	3879	2926	2628	3955	3496	4854	2753	8415	4033	3806	2264	4248	4278
2	SC	**4214**	**1237**	4043	7032	4192	4611	5849	2526	5391	3295	3188	3148	4565	4976	4340	2482	6081	3151	4780	2728	3865	4046
2	C	**3884**	**940.9**	5561	5478	2998	3685	4559	2800	4523	3076	2924	4381	4248	3385	3783	2690	5026	4259	3840	2247	3500	4715
3	NP	**4180**	**1607**	3731	6325	3616	4342	5241	2043	8508	3722	3179	7385	3626	2960	3317	2721	4196	3222	3506	3074	3876	5020
3	SC	**4391**	**1197**	4968	3677	3786	4716	6749	2667	5937	3630	2499	3139	3904	4251	4595	3352	6574	5281	3771	5223	3779	5328
3	C	**4109**	**1475**	3693	4989	2610	3974	5194	3302	5930	3799	3152	3986	3515	2952	4201	2251	8654	3870	3209	3059	3710	6122
4	NP	**4401**	**1414**	4581	3484	5217	6827	6832	3297	5319	3503	3586	1464	3743	3407	5485	2894	6390	5037	4669	4086	2892	5317
4	SC	**4421**	**982.3**	5151	5694	3788	4444	4929	2645	5965	4399	3754	4834	4176	4259	4068	3203	4843	5795	3591	2798	4180	5913
4	C	**3955**	**1016**	4751	4573	2943	4655	5007	2816	5032	3493	3138	3454	4263	3388	4371	2496	5916	3847	2746	2516	4264	5433

Table 3

Grade 6 Subjects' Medians of Latency 1 for Correct Responses and the Means and Standard Deviations of the Medians

Class	Con	mean	St.dev	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
1	NP	**3239**	**763.0**	3777	2591	3809	3142	3892	1930	2430	2078	3653	2473	3453	2503	3644	3052	3641	2581	4338	4734	3782	3272
1	SC	**3642**	**1081.3**	4247	3430	4861	2821	3779	2622	2791	2659	4775	3874	2869	3533	3522	2777	4369	2585	7077	3954	3432	2866
1	C	**3221**	**876.7**	3634	3681	3989	3530	2628	1877	2215	1888	4085	4186	2775	2377	3840	3798	2731	2068	4997	3939	3188	3005
2	NP	**3935**	**1391.9**	2751	2770	4373	4462	3316	3445	2682	2232	7347	3279	3108	3495	4848	3749	3944	3486	7640	3806	3387	4587
2	SC	**4072**	**1267.8**	3709	6721	6602	2994	3151	3352	4272	2963	5812	3730	2809	2764	4426	2827	3523	2985	5784	4780	3851	4392
2	C	**3707**	**1000.9**	2983	2937	4996	3629	3710	2506	3688	2450	5939	3796	2696	3353	4533	2669	3554	2929	5699	3840	3679	4552
3	NP	**3990**	**1426.5**	4103	5437	6711	2957	3683	2518	2201	2186	6620	3734	2669	3909	3981	3543	3841	2977	6547	3506	3245	5426
3	SC	**4726**	**1645.2**	4892	8908	6263	3880	5860	3351	2703	2767	6093	4979	3379	2610	6549	5455	4257	3669	6883	3771	4222	4026
3	C	**3747**	**1299.0**	4057	4124	5645	2922	4258	2250	2960	2721	5196	4070	2583	1850	3397	3302	3792	3044	7361	3369	3012	5031
4	NP	**4344**	**1173.1**	3215	3541	5684	4007	3159	3608	3264	3068	5095	4539	6156	3168	5047	4030	3850	3711	7350	4235	4397	5767
4	SC	**4636**	**1469.2**	3494	7918	6515	3378	6065	4129	2395	3165	7062	5978	5020	3413	4013	3983	4401	3726	5400	3298	3998	5365
4	C	**3928**	**1244.5**	3572	4179	6086	3549	4167	3649	3172	2257	4446	3736	3191	3495	4221	4436	3259	2921	7865	2746	3041	4572

Table 4
Subjects' Overall Accuracy

		Class 1			Class 2			Class 3			Class 4		
Grade	Subj	Cl1, C	Cl1, NP	Cl1, SC	Cl2, C	Cl2, NP	Cl2, SC	Cl3, C	Cl3, NP	Cl3, SC	Cl4, C	Cl4, NP	Cl4, SC
2	1	57	43	29	29	29	36	14	33	76	21	43	13
2	2	71	57	57	71	50	64	86	67	19	67	54	34
2	3	86	100	86	86	93	86	86	95	90	92	57	63
2	4	100	86	100	100	64	86	71	71	71	58	75	34
2	5	100	100	86	93	93	86	81	81	67	83	93	59
2	6	57	100	86	86	79	71	38	52	62	75	61	56
2	7	100	100	100	100	100	100	100	95	95	92	82	91
2	8	100	86	71	93	100	86	95	90	71	92	71	75
2	9	71	57	43	79	71	43	76	67	33	67	43	28
2	10	86	100	100	86	71	71	95	86	81	75	75	50
2	11	100	71	86	86	100	86	57	52	57	58	25	41
2	12	100	86	100	100	93	86	100	95	90	57	82	66
2	13	86	86	86	79	71	57	81	67	62	67	43	41
2	14	100	86	86	86	79	93	76	81	67	83	68	44
2	15	100	100	100	79	86	100	90	76	76	75	75	88
2	16	100	100	86	100	93	100	95	100	67	92	86	72
2	17	86	71	43	64	93	79	48	62	48	21	43	31
2	18	71	86	71	93	100	79	86	71	76	38	50	59
2	19	100	100	100	100	93	100	100	100	90	83	79	94
2	20	86	29	57	100	64	43	52	100	76	75	82	41
4	1	100	100	86	100	79	93	100	100	71	67	64	63
4	2	43	43	71	86	57	50	86	81	57	58	36	66
4	3	86	86	100	86	93	57	86	81	71	38	68	75
4	4	57	71	86	100	100	100	100	100	100	71	64	69
4	5	100	100	100	93	86	93	86	90	93	79	79	63
4	6	86	100	86	50	50	64	57	38	36	25	29	28
4	7	71	86	71	93	86	93	71	67	64	83	64	50
4	8	86	71	86	100	57	79	86	76	64	33	75	44
4	9	86	86	71	100	86	93	100	71	64	58	79	81
4	10	71	71	29	29	36	36	29	10	36	4	4	16
4	11	71	86	57	93	86	79	71	67	93	88	75	69
4	12	100	100	71	100	100	79	93	86	93	92	82	59
4	13	71	100	71	100	100	86	93	95	86	88	79	69
4	14	100	100	100	93	86	71	93	100	71	58	75	66
4	15	100	86	57	64	100	57	93	95	86	75	93	91
4	16	100	86	57	100	86	86	64	90	86	83	75	78
4	17	100	100	100	100	93	86	93	95	93	63	71	66
4	18	100	100	100	86	100	93	93	100	86	33	57	59
4	19	100	57	71	93	86	100	93	100	100	67	86	81
4	20	86	100	71	93	79	79	64	86	79	88	75	66
6	1	100	86	86	79	100	86	57	71	67	54	46	41
6	2	86	57	57	14	29	79	38	52	33	38	36	25
6	3	100	100	86	100	100	86	86	86	67	71	75	59
6	4	100	86	100	92	100	93	95	95	89	63	75	72
6	5	71	57	57	71	57	57	76	38	52	42	71	47
6	6	86	71	86	93	93	86	86	86	81	58	82	50
6	7	100	100	86	79	100	100	95	100	62	67	75	59
6	8	100	100	100	86	93	100	90	100	90	58	66	53
6	9	100	71	29	64	79	57	76	52	33	46	64	19
6	10	57	71	43	79	71	57	62	71	57	54	54	25

6	11	86	86	71	100	71	43	100	86	67	50	50	50
6	12	86	71	71	86	71	64	67	62	57	54	68	47
6	13	100	71	86	100	100	71	100	100	43	67	71	59
6	14	71	71	71	86	93	50	100	100	52	63	79	56
6	15	100	100	86	100	100	86	100	86	90	63	79	66
6	16	100	100	100	93	100	57	95	90	95	67	64	47
6	17	100	86	86	100	100	93	86	100	62	58	71	44
6	18	100	100	100	100	93	86	100	95	95	46	71	50
6	19	100	100	86	100	93	100	100	100	95	67	75	59
6	20	100	71	57	100	86	86	95	95	81	58	75	47

Table 5
Sample Statistics for the MARS Task

	N	Mean	Std. Dev
Overall latency	60	4334	1117
Overall accuracy	60	76.24	13.94
Overall accuracy 1	60	82.69	13.39
Accuracy 1, NP	60	85.62	14.21
Accuracy 1, SC	60	76.47	15.33
Accuracy 1, C	60	85.99	14.15
Ratio of NP/C	60	1.0636	0.1166
Ratio of SC/C	60	1.1272	0.1539
Ratio of NP/C, class4	60	1.1578	0.3095
Ratio of SC/C, class4	60	1.1692	0.3413

Table 6
Correlation Analysis for the MARS task

n = 60	Grade	L1 NP	L1 SC	L1 C	L1 NP/C	L1SC/C	L1 NP/C, cl. 4	L1 SC/C, cl. 4
Accuracy , *r*	0.033	-0.069	-0.148	-0.129	0.099	-0.087	0.343	-0.195
p	0.797	0.598	0.257	0.325	0.447	0.505	0.0071*	0.134
Accuracy, NP; *r*	0.113	-0.047	-0.177	-0.124	0.131	-0.158	0.35	-0.228
p	0.388	0.717	0.175	0.345	0.315	0.227	0.006*	0.078
Accuracy, SC, *r*	-0.05	0.02	-0.135	-0.064	0.14	-0.183	0.322	-0.205
p	0.699	0.879	0.303	0.626	0.283	0.16	0.011*	0.115
Accuracy, C; *r*	0.013	0.043	-0.09	-0.053	0.157	-0.145	0.297	-0.112
p	0.917	0.743	0.493	0.683	0.23	0.267	0.02*	0.39

Appendix E

Results of mixed model analysis of latency 1

Estimation Method: RML

Grade 2

Class 1

```
> fit1.1 <- lme(fixed = logllmodcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = grade2$class == 1, data = grade2, na.action = na.omit)
Restricted Loglikelihood: -170.56
Restricted AIC: 351.1199
Restricted BIC: 370.4096

Cluster Residual Variance: 0.1358245

Fixed Effects Estimate(s):
                   Value Approx. Std.Error   z ratio(C)
(Intercept)  8.39340761        0.05643445  148.7284331
     NP vs. C -0.01104878        0.04793869   -0.2304774
     SC vs. C  0.05553026        0.04832786    1.1490320

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.4058464
SC vs. C -0.4018930   0.4789222

Standardized Population-Average Residuals:
       Min         Q1          Med        Q3      Max
 -2.465987 -0.6344741 -0.09251707 0.4948175 5.038608

Number of Observations: 350
Number of Clusters: 20
```

Class 2

```
> fit1.2 <- lme(fixed = logllmodcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = grade2$class == 2, data = grade2, na.action = na.omit)
Restricted Loglikelihood: -170.547
Restricted AIC: 351.0941
Restricted BIC: 370.5246

Cluster Residual Variance: 0.1304638

Fixed Effects Estimate(s):
                   Value Approx. Std.Error   z ratio(C)
(Intercept)  8.523160459        0.06217881  137.0749977
     NP vs. C -0.005781644        0.04610061   -0.1254136
     SC vs. C -0.008048824        0.04704182   -0.1710993

Standardized Population-Average Residuals:
       Min         Q1          Med         Q3      Max
 -3.121091 -0.6192839 -0.09463642 0.5980319 2.535812

Number of Observations: 360
Number of Clusters: 20
```

Class 3

```
> fit1.3 <- lme(fixed = logllmodcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = grade2$class == 3, data = grade2, na.action = na.omit)
Restricted Loglikelihood: -149.0916
Restricted AIC: 308.1833
Restricted BIC: 327.2985

Cluster Residual Variance: 0.1194417

Fixed Effects Estimate(s):
                   Value Approx. Std.Error   z ratio(C)
(Intercept)  8.47594401        0.06810626  124.4517681
     NP vs. C -0.01069147        0.04507812   -0.2371765
     SC vs. C  0.12203592        0.04755040    2.5664544*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
```

```
NP vs. C -0.3381359
SC vs. C -0.3238330   0.4850010

Standardized Population-Average Residuals:
       Min         Q1         Med        Q3       Max
 -2.739314 -0.6180176 -0.04630477 0.6041218 3.050748

Number of Observations: 338
Number of Clusters: 20
```

Class 4

```
> fit1.4 <- lme(fixed = logl1modcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = grade2$class == 4, data = grade2, na.action = na.omit)
Restricted Loglikelihood: -169.4083
Restricted AIC: 348.8167
Restricted BIC: 367.7512

 Cluster Residual Variance: 0.1397765

Fixed Effects Estimate(s):
                Value Approx. Std.Error z ratio(C)
(Intercept) 8.45971645        0.07402645 114.279644
     NP vs. C 0.11951328         0.05161147   2.315634*
     SC vs. C 0.07565238         0.05264546   1.437016

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.3946923
SC vs. C -0.3823552   0.5489429

Standardized Population-Average Residuals:
       Min         Q1         Med        Q3       Max
 -2.763988 -0.6645272 -0.1087728 0.6468709 3.871019

Number of Observations: 326
Number of Clusters: 20
```

Grade 4

Class 1

```
> fit1.1 <- lme(fixed = logl1modcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = g4$class == 1, data = g4, na.action = na.omit)

Restricted Loglikelihood: -141.3395
Restricted AIC: 292.6791
Restricted BIC: 311.9545

Cluster Residual Variance: 0.1145367

Fixed Effects Estimate(s):
                Value Approx. Std.Error z ratio(C)
(Intercept) 8.0844601        0.05361419 150.789558
     NP vs. C 0.1294359         0.04369901   2.961988*
     SC vs. C 0.1377163         0.04512041   3.052194*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.4093631
SC vs. C -0.3977677   0.4867802


Standardized Population-Average Residuals:
       Min         Q1         Med        Q3       Max
 -2.253765 -0.6885394 -0.04306647 0.6241724 2.730064

Number of Observations: 349
Number of Clusters: 20
```

Class 2

```
> fit1.2 <- lme(fixed = logl1modcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = g4$class == 2, data = g4, na.action = na.omit)

Cluster Residual Variance: 0.1223508

Fixed Effects Estimate(s):
                  Value Approx. Std.Error z ratio(C)
(Intercept) 8.18827281        0.06033622 135.710746
     NP vs. C 0.05378231         0.04390644   1.224930
     SC vs. C 0.09595505         0.04458155   2.152349*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.3566209
SC vs. C -0.3509703   0.4826411


Standardized Population-Average Residuals:
      Min         Q1          Med         Q3      Max
 -2.47944 -0.5632038 -0.02994454 0.5817003 3.86168

Number of Observations: 373
Number of Clusters: 20
```

Class 3

```
> fit1.3 <- lme(fixed = logl1modcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = g4$class == 3, data = g4, na.action = na.omit)

Restricted Loglikelihood: -148.9627
Restricted AIC: 307.9254
Restricted BIC: 327.286

Cluster Residual Variance: 0.1165239

Fixed Effects Estimate(s):
                  Value Approx. Std.Error  z ratio(C)
(Intercept) 8.26509048        0.05983296 138.1360874
     NP vs. C 0.01053027         0.04394427   0.2396279
     SC vs. C 0.13684864         0.04513364   3.0320763*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.3736117
SC vs. C -0.3651972   0.4958817

Standardized Population-Average Residuals:
      Min         Q1          Med         Q3      Max
 -2.414971 -0.6627449 -0.04032402 0.5957206 3.318692

Number of Observations: 355
Number of Clusters: 20
```

Class 4

```
> fit1.4 <- lme(fixed = logl1modcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
   subset = g4$class == 4, data = g4, na.action = na.omit)
Restricted Loglikelihood: -146.5088
Restricted AIC: 303.0176
Restricted BIC: 322.118

Cluster Residual Variance: 0.1216798

Fixed Effects Estimate(s):
                  Value Approx. Std.Error   z ratio(C)
(Intercept) 8.2607350        0.05705335    144.789667
     NP vs. C 0.1356992         0.04861901   2.791072*
     SC vs. C 0.1062636         0.04799097   2.214241*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
```

```
NP vs. C -0.4756993
SC vs. C -0.4885242   0.5656411

Standardized Population-Average Residuals:
       Min         Q1          Med        Q3      Max
 -2.677758 -0.7370727 -0.05988541 0.6141746 2.997934

Number of Observations: 337
Number of Clusters: 20
```

Grade 6

Class 1

```
> fit1.1 <- lme(fixed = logllmodcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = g6$class == 1, data = g6, na.action = na.omit)

Restricted Loglikelihood: -147.1757
Restricted AIC: 304.3514
Restricted BIC: 323.6554

Standard Deviation(s) of Random Effect(s)
 (Intercept)
     0.22862

 Cluster Residual Variance: 0.1162846

Fixed Effects Estimate(s):
                  Value Approx. Std.Error z ratio(C)
(Intercept) 8.03832508        0.05939863 135.328469
     NP vs. C 0.05662987         0.04379234   1.293146
     SC vs. C 0.13110935         0.04483883   2.924014*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.3499184
SC vs. C -0.3413908   0.4657647


Standardized Population-Average Residuals:
       Min         Q1         Med        Q3      Max
 -2.470081 -0.6484398 -0.0490691 0.6479575 4.394747

Number of Observations: 351
Number of Clusters: 20
```

Class2

```
> fit1.2 <- lme(fixed = logllmodcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = g6$class == 2, data = g6, na.action = na.omit)

Restricted Loglikelihood: -143.1369
Restricted AIC: 296.2738
Restricted BIC: 315.6344

Standard Deviation(s) of Random Effect(s)
 (Intercept)
   0.2227841

 Cluster Residual Variance: 0.1128469

Fixed Effects Estimate(s):
                  Value Approx. Std.Error  z ratio(C)
(Intercept) 8.19990989        0.05843914 140.3153647
     NP vs. C 0.03272092         0.04297324   0.7614255
     SC vs. C 0.10610855         0.04456778   2.3808354*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.3637189
SC vs. C -0.3591412   0.4809569
```

```
Standardized Population-Average Residuals:
       Min         Q1        Med       Q3      Max
 -2.298896 -0.6738491 0.04242202 0.666691 2.936941

Number of Observations: 355
Number of Clusters: 20
```

Class 3

```
> fitl.3 <- lme(fixed = logllmodcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = g6$class == 3, data = g6, na.action = na.omit)

Restricted Loglikelihood: -135.4958
Restricted AIC: 280.9916
Restricted BIC: 300.1068

Standard Deviation(s) of Random Effect(s)
 (Intercept)
   0.2816279

 Cluster Residual Variance: 0.1089488

Fixed Effects Estimate(s):
                   Value Approx. Std.Error z ratio(C)
(Intercept) 8.207769481        0.06977066 117.639269
     NP vs. C 0.007709749         0.04264219   0.180801
     SC vs. C 0.146402975         0.04516605   3.241439*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.2999030
SC vs. C -0.2837833   0.4663272

Standardized Population-Average Residuals:
       Min         Q1          Med        Q3      Max
 -2.644445 -0.6386728 -0.08527775 0.5746232 3.463509

Number of Observations: 338
Number of Clusters: 20
```

Class 4

```
> fitl.4 <- lme(fixed = logllmodcorresp ~ cond, random =  ~ 1, cluster =  ~ Subj,
    subset = g6$class == 4, data = g6, na.action = na.omit)
Restricted Loglikelihood: -137.4274
Restricted AIC: 284.8548
Restricted BIC: 304.0142

Standard Deviation(s) of Random Effect(s)
 (Intercept)
   0.2142751

 Cluster Residual Variance: 0.1127753

Fixed Effects Estimate(s):
                  Value Approx. Std.Error z ratio(C)
(Intercept) 8.25938388        0.05873255 140.627033
     NP vs. C 0.09585814         0.04517365   2.121992*
     SC vs. C 0.12721007         0.04613240   2.757499*

 Conditional Correlation(s) of Fixed Effects Estimates
       (Intercept)     NP vs. C
NP vs. C -0.4321602
SC vs. C -0.4219850   0.5483749

Standardized Population-Average Residuals:
       Min         Q1        Med        Q3      Max
 -2.972712 -0.6840199 0.03794057 0.6075223 2.983064

Number of Observations: 341
Number of Clusters: 20
```