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Abstract: Introduction/objective: The variation of the Stroop effect with age, and its relationship with the development of expectation was investigated in a sample of 171 participants from 6 to 18+ years old.
Method: The first experiment consisted in naming the color and reading the names of colors in a neutral and then a mixed incongruent condition. Experiment 2 examined changes in the effect of expectation on color naming and word reading processes with age. We manipulated the stimulus set size (from 3 to 7 different neutral stimuli to name or read per condition) in a neutral word-reading and a neutral color-naming task.
Results: As expected, color naming and word reading develop with age, such that response times are reduced. More surprisingly, the magnitude of the Stroop effect was similar, and no reversed Stroop effect was found irrespective of age group. Finally, the increase in the number of different colors to be named increased the color-naming latency but did not impact the reading latency. Besides, the increase of the stimulus set size led to an increase of the color naming times and produces no variation of word reading whatever the age. Finally, analysis revealed a reduction of the temporal cost associated with the increase of the neutral stimulus set size with age, revealing the development of expectation process.
Conclusion: A further analysis linking the data of the two experiments confirmed the implication of the expectation mechanism in the color-naming process but not in word reading. It also supported the idea that the Stroop effect is in part due to expectation.

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# Interference and development: Influence of expectation process on color-naming response times.

# Interférence et développement: Influence du processus d'expectation sur les temps de dénomination de la couleur.

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## Abstract

Introduction/objective: The variation of the Stroop effect with age, and its relationship with the development of expectation was investigated in a sample of 171 participants from 6 to 18+ years old.

Method: The first experiment consisted in naming the color and reading the names of colors in a neutral and then a mixed incongruent condition.  Experiment 2 examined changes in the effect of expectation on color naming and word reading processes with age. We manipulated the stimulus set size (from 3 to 7 different neutral stimuli to name or read per condition) in a neutral word-reading and a neutral color-naming task.

Results: As expected, color naming and word reading develop with age, such that response times are reduced. More surprisingly, the magnitude of the Stroop effect was similar, and no reversed Stroop effect was found irrespective of age group. Finally, the increase in the number of different colors to be named increased the color-naming latency but did not impact the reading latency. Besides, the increase of the stimulus set size led to an increase of the color naming times and produces no variation of word reading whatever the age. Finally, analysis revealed a reduction of the temporal cost associated with the increase of the neutral stimulus set size with age, revealing the development of expectation process.

Conclusion: A further analysis linking the data of the two experiments confirmed the implication of the expectation process in the color-naming process but not in word reading. It also supported the idea that the Stroop effect is in part due to expectation.


Keywords: Stroop effect; Interference; Development; Expectation

**Résumé**

Introduction/objectif : La variation de l'effet Stroop avec l'avancée en âge et sa relation avec celle de l'expectation ont été étudiées à partir d'un échantillon de 171 participants âgés de 6 à 18 ans et plus.

Méthode : La première expérience est composée de trois conditions : deux conditions neutres de dénomination de couleur et de lecture de noms de couleur, et une condition mixte (intégrant des items neutres et incongruents) de dénomination et lecture de couleur. L'expérience 2 examine l'évolution de l'effet d'expectation avec l'âge en lecture neutre et en dénomination neutre, en fonction de la taille de l'ensemble des stimuli à traiter (de 3 à 7).

Résultats : Comme attendu, les temps de dénomination et de lecture neutres s'accélèrent avec l'avancée en âge. De façon plus surprenante, aucun effet de l'âge n'est observé sur l'effet Stroop et sur l'effet Stroop inversé. Par ailleurs, l'augmentation de la taille de l'ensemble des stimuli à traiter conduit à une augmentation des temps de dénomination de la couleur et ne produit aucune variation des temps de lecture quel que soit l'âge des individus. L'analyse révèle enfin une réduction du coût temporel associé à l'augmentation de la taille de l'ensemble des stimuli neutre avec l'avancée en âge, révélant le développement du processus d'expectation.

Conclusion : Une analyse complémentaire liant les données des deux expériences confirme l'implication du processus d'expectation dans le processus de dénomination de la couleur. Il supporte également l'idée que l'effet Stroop est en partie expliqué par de processus.

Keywords: Effet Stroop; Interference; Development; Expectation ; habileté de lecture

## Introduction

Since 1935, it has been well established that it is more difficult to state the color of a word representing the name of a different, or incongruent, color (for instance, the word blue printed in red – participant has to say “RED”) than to state the color of a neutral string of letters (for instance, a string of letters “XXX” displayed in red – participant has to say “RED”). The increase in response time observed is more commonly known as the interference or Stroop effect. As already demonstrated, subjects' ability to resist interference increases with age (e.g.,Enns and Cameron, 1987; Tipper et al., 1989; Rubia et al., 2000; Carver et al., 2001; Bunge et al., 2002; Pennequin et al., 2004).

As word reading becomes increasingly automatic with age, it gradually interferes with incongruent color-naming processing (Shiffrin and Schneider, 1977; Schadler and Thissen, 1981; MacLeod, 1991; Gerstadt et al., 1994). Schiller (1966) showed for instance that interference effect is minimal for children in 1$^{st}$ grade, maximal in 2$^{nd}$ and 3$^{rd}$ grade and then progressively declines starting from 5$^{th}$ grade. When children are too young to read, word meaning does not interfere with color-naming. When her/his reading skills increase, word meaning interferes with color-naming processing. As the inhibition mechanism is not yet mature at age 8, the magnitude of the interference effect is greater for young participants. This hypothesis, related to a deficit in inhibitory control, has also been advanced to explain the increase in the magnitude of the interference effect with age. It has been suggested that older people have more difficulty suppressing the to-be-ignored word dimension while they process the relevant color dimension (Comalli et al., 1962; Carter et al., 1995). However, a meta-analysis demonstrated that Stroop effect magnitude is in fact similar from young adulthood to old age when a general slow-down in processing is taken into account (Verhaeghen and De Meermans, 1998). Bub et al. (2006) also developed a new explanation for the developmental variations in the Stroop effect starting from childhood. By studying the development of the Stroop- and the reverse Stroop-effect from 5 to 12, they demonstrated that younger participants do not have more difficulty suppressing the irrelevant information, but rather have difficulty maintaining the colored task set. The authors concluded that children accomplish the color-naming task set inconsistently across different trials.

Current measurements of variation in the Stroop effect with age consist in comparing color naming response time under a neutral condition to the time under an incongruent condition, considering that the only difference is the kind of item (i.e. neutral vs. incongruent). We consider there are two differences between these two conditions rather than only one: the first is the kind of item (neutral vs. incongruent), the second is the stimulus set size (4 different colored items vs. 12 from neutral to incongruent conditions). As a consequence, it seems possible that neither the inhibitory process nor task-set maintenance are the principal factors, but rather the color-naming process itself. This proposal fits with the idea (Logan, 1980) that during the controlled task, participants learn the “stimulus set”, which enables them to predict the response to the item to come, on the basis of what has been already been presented (Bruner, 1951; Logan, 1980; Kingstone and Klein, 1991). This view is strengthened by other studies showing that subjects can incidentally learn new associations during attention-demanding tasks and use them to improve their performance (Graf and Schacter, 1985; Shimamura and Squire, 1989; Schmidt et al., 2007). The contingency hypothesis of Schmidt et al. (2007) considers that once participants name the color of a colored word item, they incidentally learn the associations between the item’s dimensions (here, word and color) and then use them to predict the response to come, favoring an acceleration in their processing. For instance, when the item BLUE in red is presented more frequently (in high contingency), then the association between red color and BLUE word would be incidentally learned, driving the participants to expect the "red" color response when the word "BLUE" is presented. These studies state that the item set is encoded and/or incidentally learnt during attention-demanding tasks, enabling participants to predict or expect the response to come on the basis of what has already been presented. Since the expectation process is based on the item set, it is predictable that the greater the number of items in a set, the longer the expectation process will take.

If expectation has been observed in adulthood, the chances are high that it is also present from childhood. One of the characteristics of the development of these processes with age is their acceleration. For instance, reading times become faster and faster, as the process automates from 6 years old to adulthood. We can therefore consider that, like other processes, expectation develops with age, explaining in part the variation in response times between children and adults. This is the alternative hypothesis on the development of Stroop interference (and one that is outside the current debate[1]) that we will test in the present study.

## Overview

In Experiment 1, we studied the development of the interference effect from 6 (when children cannot yet read) to the 18+ age group. The procedure consisted in showing participants a neutral color-naming condition and a mixed color-naming condition that included neutral and incongruent items. Stroop effects were measured by comparing neutral and incongruent items that belonged to the same rather than different conditions, limiting the variation between conditions due to stimulus set size. If variation in interference effect with age is the consequence

[1] It is outside the debate in the sense that it explores the question of the variation in color-naming response times with age (the focus is rather on the process), while the other hypotheses focus on the variation in incongruent response time from childhood to adulthood (the focus is rather on the stimuli processing).

of either the maturity of the inhibitory process or of greater difficulty in managing the colored task set, then we should replicate the results of the literature regarding the development of the Stroop effect, i.e. with a decrease in the magnitude of the interference effect with age. If, on the other hand, it is due to the maturity of expectation with age, there should be no variation in Stroop effect magnitude in our mixed interference condition. We also expected variations in color naming performance from neutral to mixed interference condition due to the different stimulus set sizes in these two conditions. Finally, according to Canfield et al. (1997), we should expect that the younger the participant, the greater the effect of stimulus set size. Experiment 2 further investigates the question of the development with age of expectation in attention-demanding tasks. We considered the variation in neutral color-naming and word-reading response times regarding the size of the stimulus set. Finally, we made a step-by-step regression analysis to investigate the predictive value of expectation in the incongruent color-naming response time regarding age. 171 individuals (from 6 to the 18+ age group) participated in the whole experimental protocol. To prevent any order effect between Experiments 1 and 2, half of the participants first did Experiment 1 and then Experiment 2, while the other half first did Experiment 2 and then Experiment 1.

## Experiment 1

This experiment was planned to analyze any changes in the interference effect (mixed interference color-naming task containing both incongruent and neutral items) and in the reversed interference effect (mixed interference word-reading task) with age.

### Method

#### Participants

One hundred and seventy-one subjects divided into 6 age groups participated in the study. The sample was broken down as follows: students in 1st grade (32 children from 6.1 to 7.1 years old), 2nd grade (29 children from 7.2 to 7.11 years old), 3rd grade (29 children from 8.2 to 9.2 years old), 4th grade (29 children from 8.11 to 9.11 years old), 5th grade (29 children from 10 to 11.2 years old) and young adults, the "18+" group (23 subjects from 17.5 to 26.3 years old). All were native French speakers.

**Ethical clearance**

We made sure to respect the French "Code of conduct applied to researchers in behavioral sciences" (Caverni, 1998). For minors, we obtained the agreement of each legal representative. Every participant gave their free and informed consent and we made it clear to them that they could leave the scientific process at any time. Our material was designed in such a way as to leave no misunderstanding on any matter at all. We made sure that no one would feel upset or hurt and the objective of the study was clearly explained to participants. We communicated our results to all the participants. Their anonymity was respected and protected throughout the process.

**Stimuli and Apparatus**

*Items*. The items were created with MacDraw software. They were written in capital letters (Times New Roman, 24). The incongruent items included four colored words: BLEU (blue), ROUGE (red), JAUNE (yellow) and VERT (green) displayed in different colors (e.g. BLEU (blue) was written in red). Two types of neutral items were created: (a) for the color-naming tasks, four strings of letters: QQQQQ displayed in yellow, XXXXX in red, WWWW in blue, and ZZZZ in green, (b) for the reading tasks, four color names BLEU (blue), ROUGE (red), JAUNE (yellow) and VERT (green) printed in white on a black background.

*Conditions.* Neutral and mixed interference conditions were created for each task (reading and naming). The neutral color-naming condition contained 60 colored neutral strings of letters (4 items, each repeated 15 times), the neutral word-reading condition contained 60 names of colors printed in white on black (4 items, each repeated 15 times) and the mixed interference conditions contained 80 trials including 60 incongruent trials (12 incongruent items, each repeated 5 times) and 20 neutral trials (4 items, each repeated 5 times), all randomly presented.

**Procedure**

Subjects were tested individually on a Macintosh computer with Superlab software (version 1.7). All experimental conditions were computerized. Items appeared one after the other in the middle of a black screen (on a 17" graphic color EGA monitor). The trial presentation was self-paced. The delay between a given response and the next stimulus (Response-Stimulus Interval: RSI) was 500 ms. A microphone was used to record the vocal Response Times (RTs). The experimenter monitored the accuracy of subjects' responses with a quotation grid. In naming tasks, subjects had to name the printed color as accurately and rapidly as possible. In reading tasks, subjects had to read the color names as accurately and rapidly as possible. Before each of the four conditions, a training session was conducted to ensure the subject understood the instructions. A word identification training session was also carried out before the beginning of the experimental session to insure that all participants knew the name of the colors[2]. Once it was established that the children knew the names of the four colors, the experimental session began. The four conditions were presented randomly. The experiment lasted for 10-15 minutes for the youngest subjects and 5-7 minutes for the oldest.

[2] The training phase was of particular interest. In France, children are familiarized with the words for colors from age 5. Reading is taught in schools using the "whole language" approach. The youngest participants in the present study had therefore learnt to read all the words by the "whole language" method.

## Results

**Analysis of the neutral color naming and word-reading conditions**. A repeated-measures ANOVA was performed with the error rate and response times (neutral conditions) as dependent variable, Age as a between factor (6; 7; 8; 9; 10 and 18+ years old) and Processing type (neutral reading vs. neutral naming) as a within factor.

*Error rate analysis*. Two main effects emerged from the results: (a) Age [$F$ (5, 165) = 2.56, $MSe$ = 10.65, $p$ < .05], indicating that the error rate decreased from the youngest to the oldest subjects (6 years old = 1.58%; 7 years old = 1.03%; 8 years old = 0.72%; 9 years old = 1.62%; 10 years old = 1.07%; 18+ years old = 0.52%, all *p's <.05*); (b) the Processing type [$F$ (1, 165) = 65.08, $MSe$ = 122.85, $p$ < .0001), indicating that the neutral color-naming error rate (2.19%) was higher than the neutral reading error rate (1.38%). Finally, the interaction between age and processing type was also found to be significant [$F$ (5, 165) = 9.10, $MSe$ = 17.18, $p$ < .001].

The interaction effect is due to the 9 years old group, whose percentage of error is higher than for the other groups. We do not have any explanation for this result.

*Analysis of RTs for neutral color naming and word-reading.* The analysis revealed two main effects: (a) Age [$F$ (5, 165) = 60.67, $MSe$ = 38988.21, $p$ < .01, $\eta^2$ = .65) (respectively from 6 to 18+ years old: 1141 ms; 7 years old = 901 ms; 8 years old = 828 ms; 9 years old = 768 ms; 10 years old = 730 ms; 18+ years old = 515 ms; all *p's <.05*); (b) the Processing type ($F$ (1, 165) = 116.95, $MSe$ = 11621.81, $p$ < .01, $\eta^2$ = .41), indicating that neutral color-naming RTs (892 ms) were longer than neutral reading RTs (769 ms). Finally, the interaction between Age and Processing type was found to be significant ($F$ (5, 165) = 30.16, $MSe$ = 11621.81, $p$ < .01, $\eta^2$ = .48; see Table I). The neutral reading RTs were longer than the neutral naming RTs ($t$ (31) = 3.38, $p$ < .01) for 6 year-olds. The neutral naming RTs were longer than the neutral reading RTs (all *p's < .05*) for participants from 7 to 18+ years old. In accordance with previous developmental studies, the 6 year-olds' neutral color-naming latency was longer than their neutral word-reading latency.

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Insert Table I

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**Analysis of the mixed interference word reading condition**

*Analysis of error rate.* Analysis of the reading error rate in the mixed Stroop condition for 6 to 18+ year-olds showed that the only factor to have a main effect was Age ($F$ (5, 165) = 16.51, $MSe$ = 36.49, $p$ < .01), indicating a linear decrease in error rate with age (3.23% at 6; 1.12% at 7; 0.34% at 8; 0.43% at 9; 0.65% at 10; 0.27% at 18+, respectively).

*Analysis of correct word-reading latency* A repeated-measures ANOVA was performed with the correct word-reading latency as dependent variable: Age (6; 7; 8; 9; 10 and 18+ years old) as a between factor and Item type (incongruent vs. neutral) as a within factor. The analysis showed that age was the only factor to have a main effect ($F$ (5, 165) = 67.22, $MSe$ = 113556.16, $p$ < .01, $\eta^2$ = .67 with a linear decrease in reading latency from the youngest to the oldest participants (1515 ms at 6; 857 ms at 7; 769 ms at 8; 698 ms at 9; 673 ms at 10; 480 ms at 18+, respectively). Neither the Item type ($F$ < 1, ns.) not the interaction between Age and Item type ($F$ < 1, ns.) revealed any significant difference.

**Analysis of the mixed interference color-naming condition**

*Analysis of the error rate.* Analysis revealed no main effect of Age ($F$ (5, 165) = 2.06, $MSe$ = 27.26, ns.) on error rate.

*Analysis of correct color-naming latency.* A repeated-measures ANOVA was conducted on correct-naming latency as a dependent variable, with Age as between factor and Item type as within factor. The analysis revealed two main effects: (a) Age ($F$ (5, 165) = 56.99, $MSe$ = 71604.18, $p < .01$, $\eta^2 = .63$) with a linear decrease in response time from the youngest to the oldest participants (1637 ms at 6; 1508 ms at 7; 1497 ms at 8; 1449 ms at 9; 1255 ms at 10; 842 ms at 18+, respectively); (b) Item type ($F$ (1, 165) = 71.24, $MSe$ = 7673.77, $p < .01$, $\eta^2 = .30$) mean Neutral-items latency (1348 ms) was shorter than for the incongruent items (1428 ms). Finally, the interaction between Age and Item type was not significant ($F$ = 1.12, ns.).

It is also worth mentioning at this stage of the analysis that the neutral color-naming response times increased considerably, by 51% from the neutral condition (892 ms) to the mixed interference condition (1348 ms) irrespective of age group, while the difference in neutral word-reading latency was only 8% between the neutral (769 ms) and the mixed condition (832 ms). The only difference between these conditions is the number of different items used (four in the neutral condition vs. 16 in the mixed interference condition).

**Discussion**

As previously demonstrated, neutral word reading and color naming processes develop with age, such that word reading is slower than color naming at 6 years old and becomes faster than color naming at 7 years old (Comalli et al., 1962; La Heij and Boelens, 2011).

The main difference between previous protocols and the one used in the present study consisted in including neutral and incongruent items in the same condition. This made it possible to compare the response times of incongruent and neutral items recorded under the same condition rather than the RTs under incongruent color-naming condition and neutral color-naming condition. As repeatedly shown since Stroop's original study (1935), a Stroop effect was observed but not a reversed Stroop effect. However, we did not observe any variation in the magnitude of the interference effect (nor in the reversed interference effect) with age (from 6 to 18+ years old), which contradicts the findings of previous developmental studies. The absence of variation in both reversed and interference effects with age suggests that the variation in the measure we used is critical. There are currently four different items to be named or read in neutral conditions, while there are 12 different items to name in an incongruent condition (as previously pointed out by Lemercier, 2009). In this case, color naming but not word reading is faster in a neutral than in an incongruent condition. Without minimizing the effect of the type of items (neutral vs. incongruent), we can also consider that it is easier and consequently faster to predict the color response from among 4 than 12. This expectation process could be in action during color naming, explaining in part the increase in color naming response time from neutral to incongruent items, but not in word reading (suggesting that it is only in action when the task requires attentional control). As the expectation process in younger children is still in development, it is slower than for older participants. The cost associated with the increase in size of the item set may therefore be greater for them, leading to a "due-to-item-set-size" increase in the Stroop effect for them than for older children and young adults. In the present experiment, where the item set is composed of 16 mixed items, the expectation process is based on the same unique item set for neutral and incongruent items.

Under these conditions, the expectation process cannot favor neutral color naming. Consequently, the developmental measure of Stroop effect magnitude is not affected by "item set size", explaining the absence of significant differences in the Stroop effect with age. To investigate more precisely the influence of the expectation process and the role of item set size in the development of performance in color naming, we then examined the impact of the increase in neutral item set size on color naming and word reading. As word reading is a controlled process in young childhood, expectation can be expected to contribute to response times; the greater the number of different words to be read, the longer the word-reading response time. After that critical period, an improvement in neutral color naming is expected, but not in word reading with the increase in color set size.

## Experiment 2

To evaluate this hypothesis, we investigated the impact of stimulus set size on neutral color-naming and word-reading latencies. We expected an increase in color-naming latencies to coincide with the increase in stimulus set size. Lastly, we predicted an expectation effect in word reading only for the youngest participants in the study; that is, those for whom the word reading process is not yet automated.

### Method

**Participants.** Same participants as Experiment 1.

**Material**.

*Items*. For experiment 2, color names and colored rectangles were created using MacDraw software. Color names were written in capital letters (Times New Roman, 24). The colored rectangles had an average length of 2.5 cm and width of 1 cm. Seven colors were used in the color naming task:  “red”, “blue”, “green”, “yellow”, “gray”, “brown” and “purple”. In the reading task, the corresponding seven French color names were used: ROUGE (red), BLEU (blue), VERT (green), JAUNE (yellow), GRIS (gray), BRUN (brown), and VIOLET (violet). All the colors and color names were randomly presented.

*Conditions*. Three equivalent conditions of 50 neutral word-reading and 50 neutral color-naming items were created. In Condition 1, the three items BLEU (blue), VERT (green) and ROUGE (red) were randomly presented. In Condition 2, the five items BLEU (blue), BRUN (brown), VERT (green), ROUGE (red) and JAUNE (yellow) were presented. Finally, in Condition 3, the seven items BLEU (blue), BRUN (brown), VERT (green), GRIS (gray), VIOLET (violet), ROUGE (red) and JAUNE (yellow) were presented. Subjects were individually tested on a Macintosh® computer with Superlab software version 1.7. All experimental conditions were computerized. Items appeared one after the other in the middle of a black screen (on a 17" graphic color EGA monitor). Trial presentation was self-paced. The RSI was 500 ms. A microphone was used to record the vocal RTs. The experimenter monitored the accuracy of the subjects' responses with a quotation grid.

**Procedure.** Half of the participants went through the three conditions from Condition 1 to Condition 3 and the other half in reverse order. One subgroup began with the word-reading task and ended with the color-naming task, the second in reverse order in each condition. Participants had to name the color in which the name of a color was displayed as rapidly and accurately as possible for each of the 3 color-naming conditions. Participants had to read the names of colors as rapidly and accurately as possible for each of the 3 word-reading conditions. Practice sessions were held before each condition was tested. The experiment lasted approximately 30 minutes for the youngest participants and 15 minutes for the oldest.

**Results**

Analyses were based on the mean correct-response latency time for the 3 colors or color names presented from Condition 1 to Condition 3 (i.e. the colors blue, green and red). This precaution guaranteed that latency differences between Conditions 1 and 3 were due to the variation of the item set size[3]. All results are presented in Table II.

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[3] We also performed an analysis on the response time of all the items from each condition, and did not find significant differences from those presented in the paper.

Insert Table II

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**Analysis of the color-naming task**

*Error rate analysis.* Analysis of the color-naming error rate showed that Age was the only factor to have a major effect ($F$ (5, 165) = 3.40, $MSe$ = 1.28, $p$ < .01, $\eta^2$ = .09). The color-naming error rate was the same for participants aged from 6 to 10 years old and was higher than the error rate of 18+ year-old participants. The color-naming error rates were respectively 0.77%, 0.60%, 0.93%, 0.93%, 0.86% and 0.32% for 6, 7, 8, 9, 10 and 18+ year old participants. No main effect of Condition ($F$ < 1, ns.) and no significant interaction between Age and Condition ($F$ < 1, ns.) were found.

*Correct color-naming latency analysis.* The repeated-measures analysis of variance (ANOVA) was carried out with correct color-naming latency as dependent variable, Age (6, 7, 8, 9, 10, 18+) as a between factor, and Condition (Condition 1 = 3 colors, Condition 2 = 5 colors, Condition 3 = 7 colors) as a within factor.

Analysis revealed two significant main effects: (a) Age ($F$ (5, 165) = 49.61, $MSe$ = 60263.47, $p$ < .01, $\eta^2$ = .60) indicating that there was a linear decrease in color-naming time, respectively from 6 to 18+ years old: 1157 ms, 1054 ms, 944 ms, 889 ms, 832 ms and 596 ms; and (b) Condition ($F$ (2, 330) = 113.9, $MSe$ = 10231.64, $p$ < .01, $\eta^2$ = .41) showing a linear increase in color-naming latency from Condition 1 (840 ms) to Condition 2 (932 ms, $t$ (170) = -10.85, $p$ < .01) and from Condition 2 to Condition 3 (1009 ms, $t$ (170) = -6.30, $p$ < .01). Finally, the interaction between Age and Condition was significant ($F$ (10, 330) = 2.81, $MSe$ = 10231.64, $p$ < .01, $\eta^2$ = .08). The gap between response times of color-naming conditions (from Condition 1 through Condition 3) showed a linear decrease with age ($F$ (5, 165) = 4.65, $MSe$ = 12258.53, $p$ < .01, $\eta^2$ = .12).

Not only did the color-naming latencies decrease with age but the variation from Condition 1 to Condition 3 also diminished with age. Latency increased more with the increase in stimulus set size in the color-naming condition for the youngest participants in our study than it did for the oldest. This result is in line with our hypothesis that greater maturity of expectation with age would partly explain the variation in Stroop effect magnitude with age, using the classical comparison between neutral and incongruent conditions.

**Analysis of the word-reading task**

*The analysis of the reading-error rate.* The word-reading error rate analysis revealed a significant effect of Age ($F$ (5, 165) = 15.19, $MSe$ = .77, $p$ < .01, $\eta^2$ = .32; 1.02% at 6 years old, .22% at 7 years old, .16% at 8 years old, .23% at 9 years old, .13% at 10 years old and .05% at 18+ years old). Finally, neither the Condition ($F$ (2, 330) = 2.60, ns.) nor the interaction between Age and Condition ($F$ (10, 330) = 1.35, ns.) were found to be significant.

*The correct word-reading RTs.* The repeated-measures analysis of variance (ANOVA) was carried out with correct-reading latency as a dependent variable, Age (6, 7, 8, 9, 10, 18+) as a between factor, and Condition (Condition 1 = 3 colors, Condition 2 = 5 colors, Condition 3 = 7 colors) as a within factor.

The analysis revealed two significant main effects; (a) Age ($F$ (5, 165) = 50.77, $MSe$ = 143379.21, $p$ < .01, $\eta^2$ = .61) respectively from 6 to 18+ years old: 1303 ms, 810 ms, 711 ms, 639 ms, 637 ms and 481 ms; (b) Condition ($F$ (2, 330) = 4.53, $MSe$ = 6415.95, $p$ < .01, $\eta^2$ = .27). Word-reading latencies were not significantly different between Condition 1 (779 ms) and Condition 2 (773 ms, $t$ <1) but the former were shorter than for Condition 3 (799 ms, $t$ (170) = -3.75, $p$ < .01). Finally, the interaction between Age and Condition was significant ($F$ (10, 330) = 2.07, $MSe$ = 6415.95, $p$ < .03, $\eta^2$ = .06). Further analyses showed that only the 6 year-old group demonstrated significant variation in their response times between Conditions 2 (1281 ms) and 3 (1363 ms, $t$ (31) = -2.93, $p$ < .01).

The variation in word-reading latency was not associated with the increase in word set size, except for the youngest participants. This suggests that during word-reading tasks, skilled or "to-be-skilled" readers do not expect the response to the item to come on the basis of the stimulus set, whereas it seems that "lower-skilled" readers do use expectation when they perform a word-reading task.

## Expectation and variation in Stroop effect with age

An increase in color-naming response times but not in word-reading response times with the increase in stimulus set size starting from 7 years old was found, in accordance with our expectation. This result suggests that color naming but not word reading is a controlled process implying an expectation mechanism. Finally, an interaction between stimulus set size and Age in color-naming response time was revealed, such that the older the participants, the smaller the increase in the color-naming response time between conditions. Further regression analyses were performed to evaluate the impact of age and expectation in the explanation of the variation in Stroop effect.

**Step-by-step regression analyses.** Step-by-step regression analyses (with minimum tolerance for entry into model = 0.01 and including a constant) were then conducted to determine the relative implication of Age and stimulus set size in the Stroop effect.

The first analysis made a step-by-step regression of the reading RTs on the word set size (3, 5 and 7) and the age (6, 7, 8, 9, 10 and 18+ years old) in the second experiment. The overall regression explained 30% of the reading RTs variance ($F$ (1, 512) = 220.74, MSe = 85238.71, $p$ < .01). It included the Age and a constant and rejected the word set size for the reading task. The regression was expressed by the following equation (1):

$$\text{RTs Reading} = -51.87 \times \text{Age} + 1264.95$$

Second, the "word set size" factor was excluded by the regression analysis. Only Age was kept. Word-reading RTs were not influenced by word set size. We could therefore consider that word reading does not involve an expectation mechanism.

The second analysis made a step-by-step regression of the naming RTs on color set size (3, 5 and 7) and age (6, 7, 8, 9, 10 and 18+ years old) in the second experiment. The overall regression explained 51% of the variance of color-naming RTs ($F$ (2, 512) = 263.41, MSe = 29895.36, $p <$ .01). It included Age, color set size and a constant. The regression was expressed by the following equation (2):

$$\text{RTs Naming} = -43.80 \times \text{Age} + 42.40 \times \text{color set size} + 1123.25$$

To assess the accuracy of this last equation, we compared the average neutral naming RTs from the neutral condition of the first experiment with the theoretical neutral naming RTs for 4 items calculated from the equation (2) (see Figure 1). Bravais-Pearson analysis revealed a correlation between these two measures of 0.77 ($R^2 = 0.60$). Lastly, we examined the link between expectation and incongruent color naming by comparing actual incongruent color-naming response times from Experiment 1 and a theoretical condition with 16 different stimuli for presentation. Bravais-Pearson analysis revealed a correlation between these two measures of 0.76 ($R^2 = 0.57$), stressing the significant role of expectation in incongruent color-naming response times.

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Insert Figure 1. Actual (from Experiment 1 neutral color-naming condition) and theoretical (from Experiment 2 equation of regression of color-naming latency) neutral color-naming response times from 6 to 18+ years old.

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**Discussion**

This study focused on both the development of Stroop effects (Experiment 1) and the implication of an expectation process in the variation of interference with age (Experiment 2).

First, no reversed Stroop effect was observed for 6 year old participants or unskilled readers. Second, the magnitude of interference effect is the same for participants from 6 to 18. These data challenge previous results about the development of Stroop effects (Comalli et al., 1962; Schiller, 1966; Schadler and Thissen, 1981) and call into question the significance of the contribution of stimulus set size in current explanations for variations in the Stroop effect with age. Considering that controlled but not automatic processes imply expectation, we conducted a second experiment in which the neutral stimulus set size (ranging from 3 to 7) was manipulated in word-reading and color-naming conditions. As expected, an increase in color-naming response time was observed as a function of the increase in the neutral color set size. The stimulus set size had no impact on the word-reading response times except in the case of 6 year old participants (for whom word reading was not yet a skilled process). Finally, the comparison between simulated data based on the regression analysis for 16 “neutral” colored items and those from Experiment 1 (mixed interference condition) showed a strong correlation. Stimulus set size and therefore expectation each seem to play a critical role in the variation in Stroop effect magnitude with age.

**Inhibition, goal maintenance, or maturity of the expectation mechanism?**

Since the very first study of Stroop tasks and development (Comalli et al., 1962), it has been repeatedly shown that the interference effect decreases with age starting from 7 years old. The current explanation is that the inhibitory process matures progressively, becoming increasingly efficient with age. In this study, although we did not replicate classical variation in Stroop effect with age (Experiment 1), we nonetheless showed a decrease in neutral color-naming response time with age (Experiment 1 & 2) and a decreasing sensitivity to stimulus set size with age (Experiment 2). Finally, we did observe an interference effect starting from 6 years old.

Our purpose in the present study was not to enter the debate on the explanation of the interference effect. Participants showed a significant increase in color-naming latency from neutral to incongruent colored items irrespective of age. Our purpose was rather to examine which processing characteristics of color naming could partially explain the previously demonstrated developmental variations in response latencies.

According to Schneider and Shiffrin (1977), automatic processing is usually much faster than controlled processing. The question is why a controlled process should be longer? What could explain the increase in response latency? Both recent and earlier studies (Bruner, 1951; Schmidt et al., 2007) suggested that controlled but not automatic processes activate an expectation mechanism that predicts the response to the item to come on the basis of the items already presented. This mechanism is thought to develop with age, explaining in part variations in response latency from childhood to adulthood. Further studies could determine whether the variation of expectation with age could also explain in part the increase in interference effect in elderly adults.

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Table 1. Neutral naming and reading RTs (ms) from 6 to 18+ years old in Experiment 1

Table 1: Temps de dénomination et de lecture neutres de 6 à 18 ans et +, dans l'expérience 1.

| Age group | Neutral word reading | Neutral color naming |
|---|---|---|
| 6 years | 1141 (1.79) | 1035 (1.38) |
| 7 years | 804 (0.35) | 998 (1.72) |
| 8 years | 718 (0.21) | 937 (1.24) |
| 9 years | 645 (0.14) | 891 (3.10) |
| 10 years | 643 (0.34) | 816 (1.79) |
| 18+ years | 472 (0.087) | 559 (0.96) |

Table 2. Mean color-naming and word-reading RTs (ms) by Condition and Age in Experiment 2

Table 2. Temps moyen de dénomination de couleur et de lecture par condition et par âge, dans l'expérience 2.

| | NEUTRAL COLOR NAMING | | | NEUTRAL WORD READING | | |
|---|---|---|---|---|---|---|
| Age group | Condition 1 | Condition 2 | Condition 3 | Condition 1 | Condition 2 | Condition 3 |
| 6 years | 992 (38.42) | 1129 (45.25) | 1233 (60.88) | 1176 (60.96) | 1160 (59.54) | 1239 (60.16) |
| 7 years | 953 (19.19) | 1054 (28.33) | 1153 (40.13) | 805 (29.40) | 801 (26.82) | 821 (30.17) |
| 8 years | 880 (14.79) | 947 (16.97) | 1003 (24.51) | 723 (14.51) | 699 (15.69) | 710 (18.15) |
| 9 years | 801 (22.48) | 897 (21.51) | 968 (24.47) | 638 (17.06) | 633 (16.53) | 645 (16.45) |
| 10 years | 771 (20.12) | 840 (18.16) | 884 (21.93) | 635 (13.67) | 631 (12.59) | 644 (15.56) |
| 18+ years | 529 (11.72) | 605 (10.03) | 654 (12.41) | 481 (8.44) | 476 (7.26) | 484 (10.25) |

Figure

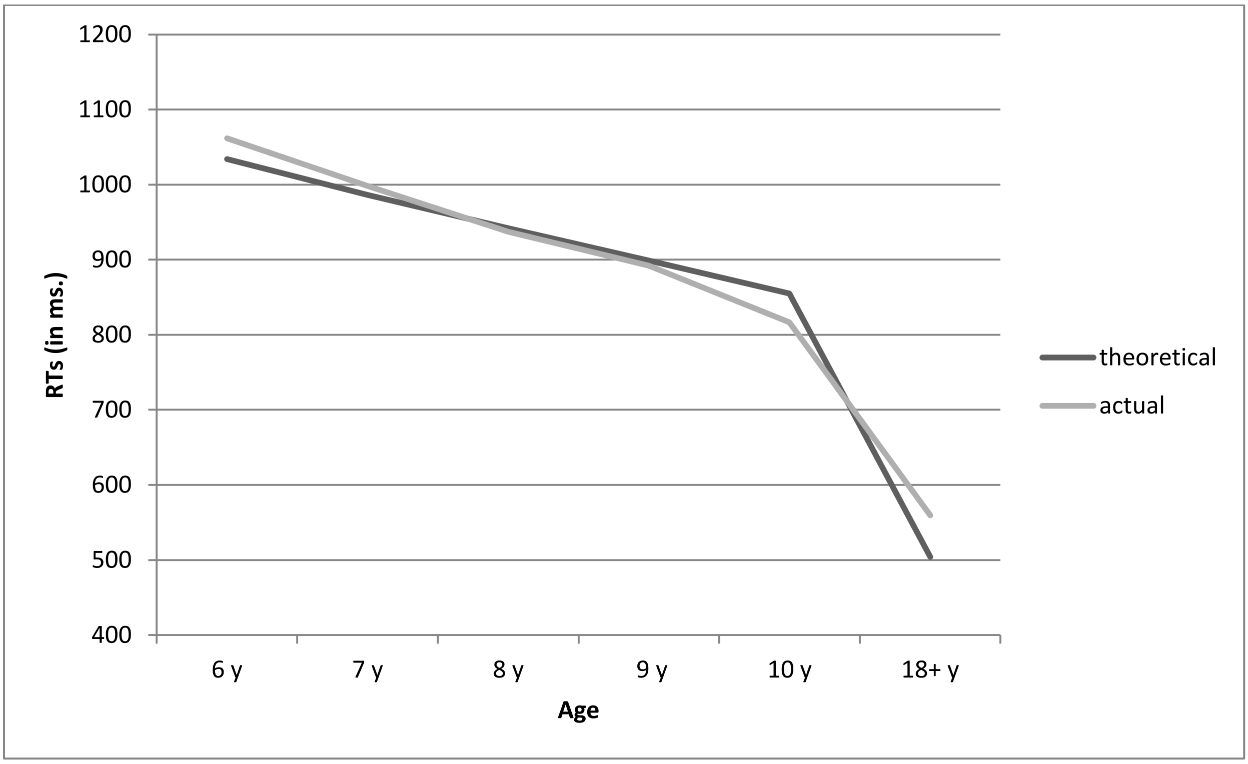


Figure 1. Actual (from Experiment 1 neutral color-naming condition) and theoretical (from Experiment 2 equation of regression of color-naming latency) neutral color-naming response times from 6 to 18+ years old.

Figure 1. Temps de dénomination neutre de la couleur de 6 ans à 18 ans et + réels (latence de dénomination de la couleur neutre dans l’Expérience 1) et théoriques (basés sur l’équation de régression de la latence de dénomination de la couleur dans l’expérience).