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Original article

Stroop interference and development: Influence of expectation on color-naming response times

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

C. Lemercier[a,*], A. Simoës-Perlant[a], J.R. Schmidt[b], C. Boujon[c]

[a] *Toulouse university, 31000 Toulouse, France*
[b] *Department of experimental clinical and health psychology, Ghent university, 25843 Ghent, Belgium*
[c] *Angers university, 49000 Angers, France*

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ABSTRACT

Introduction/objective. – In a sample of 171 participants aged 6 to 18, the present investigation assessed the changes in the size of the Stroop effect with age, and its relationship with the development of expectancies.
Method. – Experiment 1 consisted in four separated tasks, involving naming print colors or reading color words in either a purely neutral or mixed incongruent/neutral 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 three to seven 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, as revealed by decreased response times. More surprisingly, the magnitude of the Stroop effect was similar across age groups. No reversed Stroop effects were observed (Experiment 1). Moreover, increasing the number of different colors to be named slowed color-naming, but did not impact word reading latencies (Experiment 2).
Conclusion. – A reduction of the cost associated with increasing neutral stimulus set size with age was also observed, revealing the development of expectation processes. The regression analysis linking the data of the two experiments confirmed the impact of expectancies on color-naming but not on word reading. The analysis also supported the idea that the Stroop effect is in part due to expectation.

Mots clés :
Effet Stroop
Interférence
Développement
Expectation
Habileté de lecture

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 de lecture d'items incongruents. 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 du nombre de stimuli différents à traiter conduit à une augmentation des temps de dénomination de la couleur et ne produit aucune variation des temps de lecture quel que

* Corresponding author at: CLLE-laboratoire travail et cognition, UMR CNRS 5263, 5, allée Antonio-Machado, 31058 Toulouse cedex 01, France.
E-mail address: celine.lemercier@univ-tlse2.fr (C. Lemercier).

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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 neutres 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 ce processus.

1. Introduction

Since initial work by Stroop (1935), it has been well established that it is more difficult to name the print color of an incongruent color word (e.g., saying "red" while reading the word BLUE printed in red) compare to naming the print color of a neutral string of letters (e.g., saying "red" to the string of letters "XXX" displayed in red). The increase in response time observed in the incongruent condition is commonly known as the interference or Stroop effect. To correctly name the print color, participants should ignore the word. Given that word reading is more automatic than color naming, reading the word will interfere with color naming. By investigating in the variation in size of the Stroop effect with age (based either on the comparison between blocked or intermixed incongruent and neutral items), the present study aims to stress the significant role of expectation in the variation of color naming response time from neutral to incongruent items.

Prior findings has suggest that participants' ability to resist interference increases with age (e.g., Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Carver, Livesey, & Charles, 2001; Enns & Cameron, 1987; Pennequin, Nanty, & Khomsi, 2004; Rubia et al., 2000; Tipper, Bourque, Anderson, & Brehaut, 1989). As word reading becomes increasingly automatic with age, incongruent words gradually begin to interfere with color naming (Gerstadt, Hong, & Diamond, 1994; MacLeod, 1991; Shiffrin & Schneider, 1977; Schadler & Thissen, 1981). For instance, Schiller (1966) showed, for instance, that the interference effect is minimal for children in first grade, maximal in second and third grade, and then progressively declines starting from fifth grade. When children are too young to read, word meaning does not interfere with color naming. When their reading skills increase, word meaning interferes with color naming. Further, it has also been argued that the inhibition mechanism is not yet mature at eight years old. As such, the magnitude of the interference effect is greater for young participants. With further development, suppression of the distracting word becomes more effective. This hypothesis, related to a deficit in inhibitory control, has also been advanced to explain the increase in the magnitude of the interference effect in the elderly. It has been suggested that older people have more difficulty suppressing the to-be-ignored word dimension while processing the relevant color dimension (Carter, Mintun, & Cohen, 1995; Comalli, Wapner, & Werner, 1962). However, a meta-analysis has demonstrated that the magnitude of the Stroop effect is in fact similar from young adulthood to old age when a general slow-down in processing is taken into account (Verhaeghen and Meersman, 1998). Bub, Masson, and Lalonde (2006) have also proposed a new explanation for the developmental variations in the Stroop effect starting from childhood. By studying the development of Stroop effect from ages 5 to 12, they have demonstrated that younger participants do not have more difficulty suppressing the irrelevant information, but have difficulty maintaining the colored task set. The authors have concluded that children maintain the color-naming task set inconsistently across different trials.

Current measurements of variation in the size of the Stroop effect across age groups involved comparing color naming response time in a neutral condition to an incongruent condition (Bub et al., 2006; Comalli et al., 1962; Pennequin et al., 2004; Schiller, 1966). Nevertheless, there might be two differences between these conditions rather than only one. In addition to a difference in conflict, the stimulus set size for neutral and incongruent items is typically not equated. Typically, there is one neutral item per color (e.g., 4 unique colored items in a four-choice task), while there are multiple incongruent word-color pairings (e.g., 12 combinations of color words and incongruent colors in a four-choice task). As a consequence, it seems possible that neither the inhibitory process nor task-set maintenance are the principal factors of color-naming response time increases, but rather the color-naming process itself. In particular, the increase in the number of items to be named from neutral to incongruent condition could explain a (main) part of the response time variations from these two color-naming conditions. This proposal fits with the idea 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 & Klein, 1991). This view is strengthened by prior studies showing that subjects can incidentally learn new associations during attention-demanding tasks and use them to improve their performance (Graf & Schacter, 1985; Shimamura & Squire, 1989; Schmidt, Crump, Cheesman, & Besner, 2007). The contingency hypothesis of Schmidt et al. (2007) proposes that once participants name the color of a colored word item, they incidentally learn the associations between the dimensions of the item (here, word and color) and then use them to predict the response to come, speeding responding when expectancies are met. For instance, when the item BLUE in red is presented more frequently presented (in high contingency), the association between red color and BLUE word will be incidentally learned, leading the participants to expect the "red" color response when the word "BLUE" is then 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 should be expected 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 six years old to adulthood. Thus, as other processes, expectation develops with age, partly explaining in part the variation in response times between children and adults in attentional-demanding task. The effect of the increase in colored stimulus set (regardless the type of colored stimuli: colors, incongruent colored words etc.) in a color-naming task would drive to of an increase in color-naming response time of less and less magnitude with age. This is the alternative hypothesis of the development of Stroop interference (and one that is outside the current debate[1]) that we will be tested in the present study.

In Experiment 1, the development of the interference effect from 6 (when children cannot yet read) to the 18+ age group has been studied. The procedure consisted of a neutral color-naming condition and a mixed color-naming condition that included both neutral and incongruent items. The original method of measurement of Stroop effects we used, consisted in comparing neutral and incongruent items belonging to the same rather than different lists (limiting the variation between lists due to stimulus set size). If variation in the interference effect with age is the consequence 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. That is, the magnitude of the interference effect should decrease with age.

If no variation in Stroop effect magnitude with age is observed using our method, we could conclude that the variations of the Stroop effect magnitude previously observed in the literature are better explained by the maturity of the expectation process. We also expected differences in color naming performance between neutral and mixed interference condition due to the different stimulus set sizes in these two conditions. Finally, in line with Canfield, Smith, Brezsnyak, and Snow's findings (1997), we expect that the younger the participant, the greater the effect of stimulus set size. Experiment 2 further investigates the question of the development of expectancies in attention-demanding tasks. The variation in neutral color-naming and word-reading response times with varying stimulus set sizes was assessed. Finally, we performed a step-by-step regression analysis to investigate the predictive value of expectation on incongruent color-naming response times across age groups. One hundred and seventy one individuals (aged 6 to the 18+) participated in the whole experimental protocol. To prevent any order effects between Experiments 1 and 2, half of the participants first completed Experiment 1 and then Experiment 2, while the other half first completed Experiment 2 and then Experiment 1.

2. Experiment 1

This experiment assessed changes in the standard Stroop interference effect (i.e., a mixed color-naming task containing both incongruent and neutral items) and in the reversed interference effect (mixed incongruent and neutral items in a word-reading task) with age.

2.1. Method

2.1.1. Participants

One hundred and seventy-one participants divided into six age groups participated in the study. The sample was divided as follows: students in first grade (32 children from 6.1 to 7.1 years old), second grade (29 children from 7.2 to 7.9 years old), third grade (29 children from 8.2 to 9.2 years old), fourth grade (29 children from 8.9 to 9.9 years old), fifth grade (29 children from 10 to 11.2 years old) and 18+ young adults (23 subjects from 17.4 to 26.3 years old). All were native French speakers.

2.1.2. Ethical clearance

The study was conducted in accordance with the French "Code of conduct applied to researchers in behavioral sciences" (Caverni, 1998). For under age participants, agreement of each legal representative was obtained. Every participant gave their free and informed consent and we made it clear to them that they could leave the experiment at any time. For each children, parents signed the informed consent. Before the beginning of the experiment, we reminded every child of their rights, and asked them if they agreed to participate in the study. We made sure that no one would feel upset or hurt and the objective of the study was clearly explained to participants. After the experiment, we communicated our results to all participants. Their anonymity was respected and protected throughout the process.

2.1.3. Stimuli

The items were created with MacDraw software and were presented on a black background. Words were presented in Times New Roman, 24-point font and were written in capital letters. The incongruent items were the color words BLEU (blue), ROUGE (red), JAUNE (yellow), and VERT (green) displayed in the same four colors (i.e., blue, red, yellow, and green), excluding congruent pairings (e.g., BLEU in blue). Two types of neutral items were created, one for the color naming task and another for the word reading task. The first set consisted of four strings of letters: QQQQQ displayed in yellow, XXXXX in red, WWWW in blue, and ZZZZ in green. The second set consisted of the four-color words printed in white.

2.1.4. Design

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 (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.

2.1.5. Procedure

Participants were individually tested on a Macintosh computer with a 17″ graphic color EGA monitor using Superlab software (version 1.7). Items appeared one after the other in the middle of a black screen. The delay between a given response and the next stimulus was 500 ms. A microphone was used to record the vocal response times (RTs). The experimenter monitored the accuracy of responses with a quotation grid. In the naming tasks, participants named the printed color as accurately and rapidly as possible. In the reading tasks, participants read the color words as accurately and rapidly as possible. Before each of the four conditions, a training session was conducted to ensure that the participant 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.

[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).

[2] The training phase was of particular interest. In France, children are familiarized with the words for colors from age five. 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.

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

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

2.2. Results

2.2.1. Neutral color naming and word-reading

A repeated-measures ANOVA was performed with the error rate and correct response times (neutral conditions) as dependent variables, age group as a between factor (6; 7; 8; 9; 10 and 18+ years old), and task (neutral word reading vs. neutral color naming) as a within factor.

2.2.1.1. Error rates. The ANOVA revealed a significant main effect of age, F (5, 165) = 2.56, MSe = 10.65, p < .05, indicating that the error rate decreased from the youngest to the oldest subjects (9 years old = 1.62%; 6 years old = 1.58%; 10 years old = 1.07%; 7 years old = 1.03%; 8 years old = 0.72%; 18+ years old = 0.52%, all p's < .05). There was also a main effect of task, 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 task was also significant, F (5, 165) = 9.10, MSe = 17.18, p < .001. This was primarily due to the 9-year-old group, whose error percentages were, for unknown reasons, higher than the other groups.

2.2.1.2. Response times. The ANOVA revealed a significant main effect of age, F (5, 165) = 60.67, MSe = 38988.21, p < .01, η^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) indicating a general speedup in responding across age groups. There was also a main effect of task, F (1, 165) = 116.95, MSe = 11621.81, p < .01, η^2 = .41, indicating that neutral color-naming RTs (892 ms) were longer than neutral reading RTs (769 ms). Finally, the interaction between age and task was significant, F (5, 165) = 30.16, MSe = 11621.81, p < .01, η^2 = .48 (see Table 1). 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.

2.2.2. Mixed interference word reading

2.2.2.1. Error rates. Analysis of the reading error rate in the mixed Stroop condition for 6 to 18+-year-olds revealed only a main effect of 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).

2.2.2.2. Response times. A repeated-measures ANOVA was performed with 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. Only the main effect of age was significant, F (5, 165) = 67.22, MSe = 113556.16, p < .01, η^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 main effect of item type (F < 1, ns) nor the interaction between age and item type (F < 1, ns) were significant.

2.2.3. Mixed interference color naming

2.2.3.1. Error rates. There was no main effects or interaction between the factors in the mixed interference color naming error rates (all p's > .05).

2.2.3.2. Response times. A repeated-measures ANOVA was conducted on correct color-naming RTs, with age as between factor and item type as within factor. The analysis revealed a significant main effect of age, F (5, 165) = 56.99, MSe = 71604.18, p < .01, η^2 = .63, indicating 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). There was also a main effect of item type, F (1, 165) = 71.24, MSe = 7673.77, p < .01, η^2 = .30, because mean neutral-items (1348 ms) were responded to faster than 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).

2.3. Discussion

Two main results are worth noting at this point. First, in line with prior findings in the developmental literature, 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 & Boelens, 2011). Then (and more interestingly), the interference effect is of the same magnitude from 6 to 18+ years old, clearly inconsistent with all prior investigations of the development of the Stroop effect with age. While there may be several potential explanations of this discrepancy, the most obvious one (and the a priori motivation for this study) was the use of a different way to measure the interference effect. The main difference between the current and previous protocols was the mixing of neutral and incongruent items within the same block. This made it possible to compare the response times of incongruent and neutral items recorded within the same list, rather than within separate lists.

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), contradicts not in line with the findings of previous developmental studies. The absence of variation in both normal and reversed 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 highlight by Lemercier, 2009). In this case, color naming but not word reading is faster in a neutral than in an incongruent condition. Expectation process (learning of colored stimulus set and predicting the response to the item to come on the basis of what has been already been presented) could then 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. This suggests that expectation process would only

Table 2
Mean color-naming and word-reading RTs (ms) by condition and age in Experiment 2 (standard errors in parentheses).

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

be in action when the task requires attentional control. It would be of a particular interest to further study the expectation process, its implication in the information processing system. As the expectation process in younger children is still in development, it is slower than for older participants. The cost associated to an increasing set size may therefore be greater for younger children, leading to an increase in the Stroop effect for them than for older children and young adults. In the present experiment, where the item set was composed of 16 mixed items, expectancies are based on the same unique item set for neutral and incongruent items. Under these conditions, expectancies cannot favor neutral color naming. Consequently, our developmental measure of Stroop effect magnitude was not affected by "item set size," which might explain the absence of significant differences in the Stroop effect with age.

3. Experiment 2

To investigate more precisely the influence of expectancies and the role of item set size in the development of performance in color naming, we examined the impact of neutral item set size on color naming and word reading in Experiment 2. As word reading is a controlled process in young childhood, expectancies 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 with an increase in color set size, but not in word reading. 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 with an 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 word reading is not yet automated.

3.1. Method

3.1.1. Participants

The same participants from Experiment 1 also participated in Experiment 2.

3.1.2. Stimuli

For experiment 2, color names and colored rectangles were created using MacDraw software. Color names were written in Times New Roman, 24-point font and in capital letters. 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.

3.1.3. Design

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.

3.1.4. Procedure

The procedure of Experiment 2 was identical to that for Experiment 1, with the following exceptions. Half of the participants completed 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 printed color as rapidly and accurately as possible for each of the 3 color-naming conditions, and read the color word 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.

3.2. Results

Analyses were based on the mean correct response latencies for the 3 colors or color words presented in all three conditions (i.e. the colors blue, green, and red). This precaution guaranteed that latency differences between Conditions 1–3 were due to the variation of the item set size and not to the unique items in the larger set sizes. 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. All results are presented in Table 2.

3.2.1. Color naming

3.2.1.1. Error rates. Analysis of the color-naming error rates revealed only a main effect of age, $F\ (5,\ 165) = 3.40$, $MSe = 1.28$, $p < .01$, $\eta^2 = .09$. 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.

3.2.1.2. Response times. A repeated-measures analysis of variance (ANOVA) was carried out with correct color-naming latency as the 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 ANOVA revealed a significant main effect of 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. There was also a main effect of 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 difference in response times across color-naming conditions (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 color-naming latencies decrease with age, but the differences 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 expectancies partly explains the changes in the size of the Stroop effect with age, using the classical comparison between neutral and incongruent conditions.

3.2.2. Word reading

3.2.2.1. Error rates. 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 main effect of condition ($F(2, 330) = 2.60$, ns) nor the interaction between age and condition ($F(10, 330) = 1.35$, ns) were significant.

3.2.2.2. Response times. An 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 a significant main effect of 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). There was also a main effect of 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 faster than 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), $t(31) = -2.93$, $p < .01$. Thus, variation in word-reading latency was not associated with changes in word set size, except for the youngest participants. Following the same idea as Experiment 1, this is consistent with the idea that the youngest group has not yet automatized word reading. As a result, word reading will be controlled for them, introducing expectancies into word reading. We found 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, consistent with our expectations. This result suggests that color naming, but not word reading, is a controlled process, implying an expectation mechanism. Colored stimulus set would be learnt, and then used incidentally by participants to predict the colored response to the item to come on the basis of what has been already been presented. Finally, we observed an interaction between stimulus set size and age in color-naming response times, such that the older the participants, the smaller the increase in the color-naming response time between conditions.

4. Reanalysis 1: expectation and variation in Stroop effect with age

Here, we perform regression analyses to evaluate the impact of age and expectation in Stroop effect magnitudes.

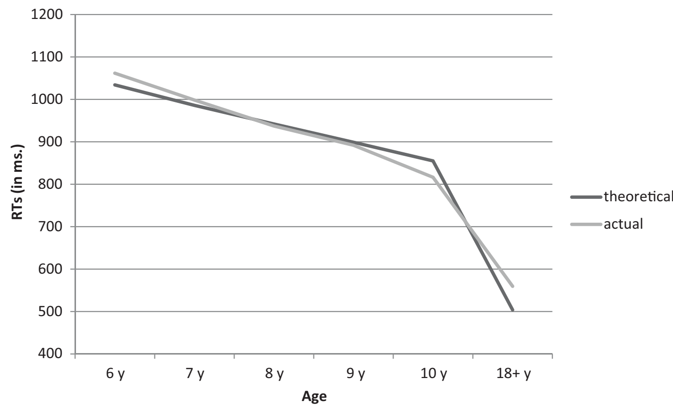

Fig. 1. Actual Experiment 1 neutral color-naming response times from 6 to 18+ years old and predicted values (based on Experiment 2 regression equation).

4.1. Method

Step-by-step regression analyses were conducted with a constant and minimum tolerance for entry into model of 0.01 to determine the effects of age and stimulus set size on the Stroop effect.

4.2. Results

The first step-by-step regression was conducted on the Experiment 2 reading RTs across the word set size (3, 5, and 7) and the age factors (6, 7, 8, 9, 10, and 18+ years old). The overall regression explained 30% of the reading RT variance, $F(1, 512) = 220.74$, $MSe = 85238.71$, $p < .01$. The model included age and a constant, but rejected the word set size variable. The regression was expressed by the following equation (1): RTs Reading = −51.87 (age) + 1264.95.

Thus, word-reading RTs did not seem to be influenced by word set size, suggesting that expectancies may play little role in word reading.

A second step-by-step regression was conducted on Experiment 2 naming RTs, including color set size (3, 5, and 7) and age as factors (6, 7, 8, 9, 10, and 18+ years old). The overall regression explained 51% of the variance in 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): RTs Naming = −43.80 (age) + 42.40 (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 Experiment 1 with the theoretical neutral naming RTs for the four items calculated from the equation (2) (see Fig. 1). Bravais-Pearson analysis revealed a correlation between these two measures of 0.77 ($R^2 = 0.60$).

Finally, we examined the association 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 ($R^2 = 0.57$), indicating a significant role of expectation in incongruent color-naming response times.

5. Discussion

The re-analysis of our data using regression confirmed the influence of expectation in color naming, but not in word reading. Finally, the correlation between the actual data from the mixed (incongruent + neutral) color naming condition (Experiment 1) and the expected data from the regression equation showed a strong link between the two measures. This suggests that expectation plays a major role in the variations in the size of the Stroop effect with age.

6. General Discussion

This study focused on both the development of Stroop effects (Experiment 1) and the role of expectancies in the magnitude 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 the interference effect is the same for participants from 6 to 18+. These data challenge previous results regarding the development of Stroop effects (Comalli et al., 1962; Schadler & Thissen, 1981; Schiller, 1966). We then 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 expectancies, seem to play a critical role in the variation in Stroop effect magnitude with age.

7. Inhibition, goal maintenance, or maturity of the expectation mechanism?

Since the very first investigation 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 typical explanation is that the inhibitory process matures progressively, becoming increasingly efficient with age. In this study, although we did not replicate the classical variation in Stroop effect with age (Experiment 1), we nonetheless showed a decrease in neutral color-naming response time with age (Experiments 1 & 2) and a decreasing sensitivity to stimulus set size with age (Experiment 2). Finally, we did observe an interference effect even for 6 years old participants. As already stressed, the main variation in the present study is linked to the protocol we used. Currently, Stroop effect development is measured by comparing data from a neutral to an incongruent condition. In the present study, Stroop effect was measured by comparing data from neutral to incongruent items belonging to the same mixed interference list. This new (in the domain of developmental studies) method of measurement allowed us to correct Stroop effect by limiting the interference of expectation process on the response times, revealing finally that incongruency has the same influence on response times from 6 years old to adulthood.

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 faster than controlled processing. The question is why a controlled process should be slower? 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 likely response to a stimulus 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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Disclosure of interest

The authors declare that they have no competing interest.

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