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Authors

Rudling, Philip J.
Mareschal, Denis

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A Connectionist Investigation of Developmental Effects in Stroop Interference

Philip. J. Rudling (`p.j.rudling`@exeter.ac.uk)
Department of Psychology, University of Exeter,
Perry Rd, Exeter, EX4 4QG, UK.

Denis Mareschal (d.mareschal@exeter.ac.uk)[1]
Department of Psychology, University of Exeter,
Perry Rd, Exeter, EX4 4QG, UK.

Abstract

When naming the ink color of color words, adults and children show Stroop interference (Stroop 1935). Cohen, Dunbar and McClelland (1990) produced a connectionist model that accounted for many of the Stroop phenomena within adults. This paper shows how the paradigm can be extended to show the development of the interference in children as they learn to read. We train a network taking into account the amount of reading practice and attentional skills that would befit a young child to give a prediction of the development of the Stroop effect. These predictions are then tested using a picture-naming Stroop study with two groups of 8 year olds of differing reading ability. The results support the model, suggesting children initially show reverse Stroop interference that with practice becomes normal Stroop interference.

Introduction

This paper explores whether a connectionist model can account for developmental phenomena in the classic Stroop interference task (Stroop 1935). Cohen, Dunbar and McClelland (1990) describe a connectionist model that accounts for much of the Stroop related phenomena. This includes the emergence of interference as a result of learning. A behavior that required attentional control becomes more automatic through learning and interferes with less well learned tasks. Although the model accounts for many aspects of reading/color naming interference in adults, it is not clear that it adequately models the development of Stroop interference during childhood (i.e., as the child learns to read) because it does not take into account changes in information processing capacity that occur during childhood.

One can make a distinction between learning and development (e.g., Liben, 1987; Boden, 1989). Development involves a change in processing capacity of a cognitive system. This may include an increase in representational capacity or simply a change in the efficiency of the information processing system. It is generally believed to be maturationally controlled or at least strongly dependent on internal processes. At a biological level, the initial burst of synaptogenesis between 0 and 2 years of age marks a developmental or "experience-expectant" process (Greenough, Black, & Wallace, 1987). This is a maturational controlled process by which new structures (new connections) are being put in place to enable complex learning to take place. At a behavioral level in children, this might manifest itself in terms of increases in processing speed, better control of attention, or better control of memory (Weinert and Schneider, 1995).

Learning involves tuning existing structures in response to idiosyncratic environmental pressures. This may involve developing new internal representations of a problem or building associative links in memory. At a biological level, the tuning of synapses in response to neural activity marks a learning or "experience-dependant" process (Greenough, Black, & Wallace, 1987). It is a process that is predominantly dependent on the environment and will vary from individual to individual depending on experience. At a behavioral level in children this might manifest itself in terms of differences in factual knowledge of color names or reading ability.

The picture of Stroop interference painted by MacLeod and Dunbar (1988) is consistent with a learning account. They report on experiments showing the continuous nature of automaticity and its dependency on the learning experience. This account forms the basis of the Cohen *et al* model. However, during early childhood much more is going on. While simple tasks like reading or color naming are being learned, the child is developing along a whole host of dimensions that may affect the performance of reading and color naming. Such dimensions include the ability to suppress erroneous responses (inhibition of response) or the ability to attend to a task for longer periods of time (focussed attention).

The purpose of this paper is to adapt the Cohen el al. model by incorporating some developmental changes in

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[1] Now at the Department of Psychology, Birkbeck College, Universoty of London. Malet St. London, WC1E 7HX, Uk.

Gerstadt, Hong, and Diamond (1994) used a simple counterfactual picture task to test Stroop interference in very young children. They found that children under the age of 6 could remember the counterfactual rules of the task but failed to inhibit the wrong response during testing. This was accounted for by appealing to the development of focussed and sustained attention during childhood. A purely learning model of the Stroop effect would be valid for adults or possibly older children as the processes underlying the acquisition of new skills are relatively stable. In contrast, a developmental model must take account of other changes that are occurring in children.

This aspect of development was modeled by blurring the activation on the task node in a graded fashion on the testing trials; i.e. simulating task confusion in early networks. As with Gerstadt *et al*'s younger children, the network is capable of completing the tasks in control conditions (i.e. the training set) but finds it difficult to carry out the response in the testing phase. The network was trained without adding noise to the inputs but tested with the addition of noise. The following testing regime was devised to capture the development of focussed and sustained attention: at 10 epochs 50% random noise was added (values ranging between 0.75 to 1.25), after 25 epochs test with 10% noise (0.95 to 1.05) and at 40 epochs no noise was added.

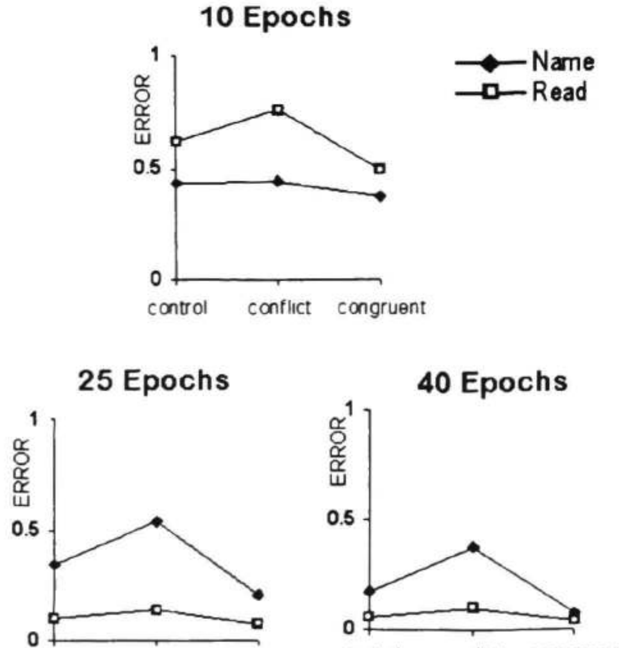

Figure 3: The developing network results

Figure 3 shows the performance of the new model (averaged over n=10 different networks). These networks were run with the same learning rate, momentum, and initial weight range as the replication models above. These simulations show a progression from a reverse Stroop effect pattern to the more usual Stroop profile. That is, there is an initial period in which reading is slower than naming (i.e., error for reading is higher than error for naming) and naming interferes with reading. Although at 10 epochs there is a large amount of error in both task responses, there is a slight amount of interference in the conflict conditions and positive interference on congruent trials. (This interference can be increased if less noise is added to the task demand nodes). By 25 epochs the classic Stroop profile is apparent. Further training just brings both error curves lower while preserving the shape of the interaction.

The model makes a strong prediction. It suggests that, in children, the development of Stroop interference will first pass through a phase of reverse interference before shifting to the classic interference curve as children's reading becomes more automated with practice. The reverse interference should be found in poor readers of a younger age (i.e., whose information processing capacity may be lagging behind that of older children).

Testing the Model's Predictions

The following picture naming Stroop study was carried out to test the model's predictions. A picture naming rather than a color naming task was used in order to increase the range of stimuli that could be presented. This ensured that the younger children would maintain their attention on the task longer

Participants: Forty-five normal healthy children were tested (15 male, 30 female). They came from two primary schools in Exeter, UK. The children were separated into two groups according to their reading abilities (median split). Those with a British Ability Reading Scale (BARS) score less than 120 (22 children) and those scoring more than 122 (22 children). Group 1 (poorer readers) had a mean age of 7.8 years and reading score 82 (standard deviation of 18), group 2 (better readers) had mean ages and reading scores of 8.5 and 158 (standard deviation 21) respectively. One child was unable to read well enough to complete the exercise. Note that the two groups differed in age by about 1 year ($t_{42}=3.403$ $p<.01$) providing scope for changes in selective attention and not just reading ability.

Materials: The experiment was carried out using A4 cards with stimuli printed on them. These were held in a ring-bound folder. Each sheet held six stimuli (3 by 2 landscape orientation) containing pictures and labels. There were 108 stimulus picture/words (and a further 6 practice items). The words were taken from a popular British child's book "My first 1000 words in English". The objects came from 6 broad categories, and each card contained an item from each of these categories; farm animals, food, household objects, zoo animals, transport and children's objects. Each item selected had a simple phonetic name under eight letters long and a prototypical color picture taken from a information processing. The adapted model is then tested against children's performance on a Stroop interference task. The result of this paper unfolds as follows. First, the Stroop literature is briefly reviewed with an eye on developmental effects. Next the Cohen et al. model is described and the results replicated. This model is then adapted to take account of information processing changes in childhood. The new model makes an explicit prediction of reversed Stroop interference in early childhood. The prediction is tested and the implications of the new model for understanding connectionist models of development are discussed.

Stroop Interference in Children

The Stroop effect concerns the non-symmetrical interference of an automatic process on a controlled process. For example, if the instruction given is to name the ink color (red) and the word spells "green", naming that ink color can take significantly longer than a control color naming condition. This interference is not present when reading a word in an incongruent ink color (although Stroop did acknowledge the existence of such interference in special circumstances; this is known as the reverse Stroop effect). There have been many other Stroop type interference phenomena (for example Picture-Word interference by Dyer, 1973) that can all be described by this automatic/controlled process explanation. (See MacLeod 1990 for a detailed review of the Stroop literature).

Within the empirical literature, the developmental aspects of the Stroop effect have been reasonably well documented. The main finding is that this interference is apparent from an early age and quickly reaches a maximum after two or three years schooling. This level of interference then falls slightly, though remains highly significant throughout adult life until old age when interference increases again (MacLeod 1990, Ehri and Wilce 1979). The same pattern is true of the picture naming Stroop analogue (Ehri 1976). It has also been noticed that poor (i.e. younger) readers show little interference although early on in their development, and suggested that children may pass though a "reverse" Stroop effect phase when presented with a simplified Stroop type task (Arochova 1971). Given that the more automatic (practised) process interferes with the controlled process and the fact that children can color name quite accurately before they learn to read, it seems reasonable to suggest that, when a child first learns to read, color naming is the more automatic process and therefore gives rise to a reverse Stroop effect. Finally, Corbitt (1978) showed that the amount of interference was related to the reading ability and not just the chronological age *per se*.

The Cohen, Dunbar and McClelland Model

The model employed by Cohen *et al* consisted of interconnected nodes in three layers. The input layer contained nodes representing the color of word and content of the word (i.e. red and green) and two task nodes that informed the network of the task to be carried out (read the word or name the color). The output layer contained two nodes, one for the output "red", the other "green". Between the input and output nodes there is a hidden layer of nodes organized as two task pathways (color naming and word reading) for the colors red and green. The architecture is shown in Figure 1. Note that this network could be employed for any two conflicting tasks, for example the picture-word Stroop task. The network was then trained on reading and color naming tasks at a ratio of 10:1 (reflecting the fact that we read more often than we name colors).

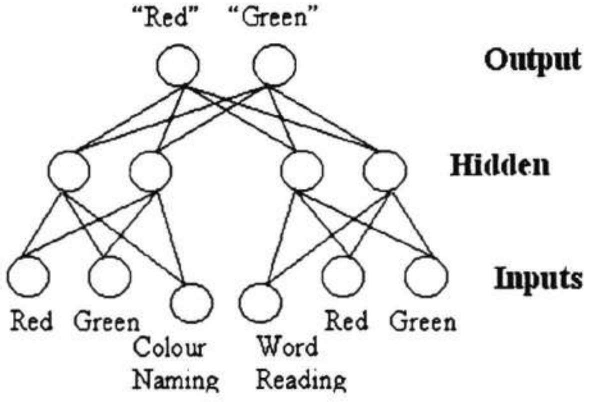

Figure 1: The Network Architecture

The model makes a number of simplifications. Two of these are architectural assumptions. First of all, this is a feed-forward backpropagation model; information flows one way (from input to output). It may be more realistic to look at a recurrent type architecture where the output may influence the response of following decisions. Secondly, it is assumed the output of such a model can be translated into reaction time data comparable to that in empirical studies. To convert these output activations into reaction times, Cohen *et al* use a method of adding small amounts of stochastic noise to the actual outputs to drive them towards a target output. The number of cycles required to do this is mapped onto reaction times.

Two further assumptions that reflect the authors' beliefs about the nature of the task are built into the network. First, the weights from the "task" units to the hidden layer weights are fixed. The idea is to ensure that the task demands remain clear; i.e. only the task that is being demanded (reading or color naming) has any impact on the hidden units, and that impact is always constant. Secondly, although the weights are initially randomized, the weights between the input units and the hidden layer are set deliberately larger than the weights from the hidden layer to output units. This captures the assumption that when children learn to read and first encounter the Stroop type situations, they have long since acquired some representation of the stimuli (e.g., a color or a word) and are primarily learning the response task (embodied in the hidden unit to output layer weights).

The aims within the next two sections are to: (1) replicate the Cohen et al. Model, (2) adapt the model by providing a training set with an increasing vocabulary, and (3) adapt the model to capture changes in focussed attention and inhibition of response during childhood.

Replicating the Cohen *et al.* Model

The network (Figure 1) was initially set up exactly as stated in the Cohen *et al* paper; including the initial randomising of weights (with hidden to output weights weaker than input to hidden weights), and with the task selection weights fixed. The network was then trained with the ratio of reading items to naming items at 10:1. After training for 1000 epochs (learning rate=0.3, momentum=0.3), the network was tested with 12 items for both the reading and naming tasks in the control, conflicting and congruent conditions.

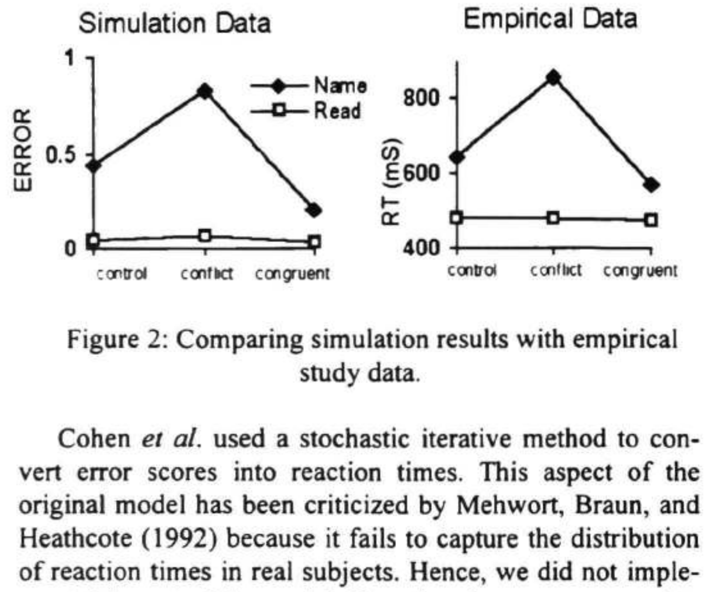

Figure 2: Comparing simulation results with empirical study data.

Cohen *et al.* used a stochastic iterative method to convert error scores into reaction times. This aspect of the original model has been criticized by Mehwort, Braun, and Heathcote (1992) because it fails to capture the distribution of reaction times in real subjects. Hence, we did not implement this part of the model. Reaction times are assumed to be linearly related to error scores (cf. Seidenburg and McClelland, 1989; for a similar assumption). In models with two output units (such as this one), a winner take all constraint satisfaction mechanisms that adds a constant amount to each output unit per cycle would take a number of cycles proportional to the absolute error to reach equilibrium (Feldman and Ballard, 1982). In the results below, we report the absolute error of the network (the absolute value of the difference between the target and output) and show that there is a qualitative fit with the human reaction time data.

Figure 2 shows the results of the model replication. As reported by Cohen *et al*, we find a clear qualitative fit between the performance of the model and the results of the empirical study reported in Dunbar and MacLeod (1984). This confirms that the model -- including its fixed and confined weights assumptions -- captures the shape of the effect found in the empirical studies.

Modelling the Effect of Development on Stroop Interference

The Cohen *et al* model focussed on the development of the Stroop effect as the result of two skills learned simultaneously, but needing some kind of initial weight constraint to achieve a good fit to empirical data. This can be interpreted as the acquisition of the Stroop interference in adults (see especially simulation 6 in Cohen *et al* 1990). However, children usually learn to name colors by the age of three and start learning to read words a couple of years later. Hence, learning to name colors is well underway before learning to read even begins.

To address this issue, the next set of simulations remove the assumptions that color and word representations were better developed than response abilities, and varies the ratios of reading to naming during training. This network was initially seeded with completely random weights, unlike Cohen *et al*'s constraint of larger initial weights from the inputs to the hidden units. To simulate the growth in vocabulary and the increase in reading practice as the child gets older, the naming/reading training set ratios were increased over time.

The two new parameters introduced here are the ratio of naming/reading, and the rate of increasing that ratio. Cohen *et al* state that ratios between 5:1 and 20:1 give the same Stroop like profile and settled on 10:1 as a reasonable value. They point out that the whole model works under the assumption that word reading is a more frequent task in adults than color naming, although admittedly there is no evidence to put a number on it. For these simulations, the training regime ratios were: 0:1 (reading to color naming) from epochs 1-5 , 1:1 from epochs 6-10 at, 10:1, from epochs 11-25, and 50:1 from epochs 26-40. Each epoch consists of 100 training presentations of a randomly selected example from the training set.

A further point is that it cannot be assumed that the ability to encode the task requirements or the ability to maintain a representation of the task requirement has fully developed by the time reading and naming interference begin to appear. As discussed above, many components of information processing continue to develop during childhood (see Weinent and Scheider 1996 for a review). For example, CorelDraw3 clipart collection. The items within each group were ranked according to word length and distributed across each card accordingly to ensure all cards contained words of the same overall difficulty.

Task completion times were measured with a hand-held digital chronometer. A number of children were video taped to provide cross-validation of recorded times.

Procedure: The experiment took place in a small, well-lit room within the children's school and each child tested on their own. Each child was seated at a desk and given a very general introduction to put them at ease. The participants were then required to read from the BARS index to locate their reading abilities.

There are two main tasks: word reading and picture naming. These tasks were kept separate so the child did not get confused over what was done. Each task has three conditions: control (either word or picture on own), conflicting (word presented with semantically related picture, or vice versa), and congruent (matching word and picture). Each condition was carried out twice for both tasks. The test consisted of 108 trials in total. The number of trails was kept low to prevent boredom or fatigue, especially with younger children. Clear instructions including a practice were given when the task changed from reading to naming (or vice versa).

The basic instruction was to "name the picture (or word) as quickly as possible without making a mistake; try to think before you speak. If you cannot read or name a word, go onto the next one". Each subject was given 6 practice items. If the subject was not able to complete the task they were given the option to repeat the practice until they were performing satisfactorily. Before the experimental trails each subject was asked if they where ready to proceed.

The experimenter supervised each trial, operated the digital chronometer and made a note of every error made by the participants. The trials on which the children made errors on more than two words were excluded from further analysis.

Experimental Results

The mean reaction times for each group are shown in Figure 4. These results confirm the model prediction that the poorer (younger) readers display the reverse Stroop effect and the better (older) readers display the standard Stroop interference.

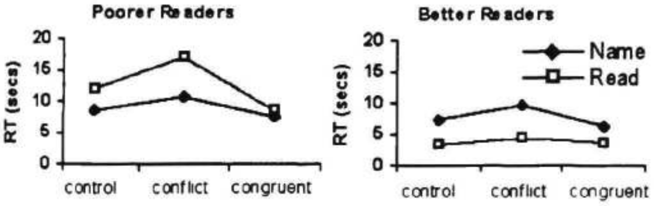

Figure 4: Mean response times for the picture naming task

To confirm this, the data were analyzed using a repeated measures ANOVA with three factors (Condition, Task, and reading Group). The ANOVA revealed a significant three way interaction of Condition, Task and Group $F_{2,84}$=16.93 p<.001. To explore this interaction, a two-way ANOVA was carried out within each group. A significant interaction of Condition by Task was found for both the reader groups ($F_{2,42}$=8.55 p<.001 and $F_{2,42}$=13.96 p<.001 for the poorer and better readers respectively). Both groups were experiencing some kind of task/condition interference.

There was a significant effect for Task within each Group ($F_{1,21}$=15.28 p<.001 and $F_{1,21}$=252.31 p<.001 for group 1 and 2 respectively) confirming that the poorer readers in group 1 took longer to read than to name the pictures, and the better readers in group 2 took longer to name the pictures than to read. Collapsing across tasks, we see that there is a significant difference in reading response times ($F_{1,42}$=130.36 p<.001) between the poor and good readers (as would be expected) but that there are also significant naming response times ($F_{1,42}$=5.76 p<.05) demonstrating a small increase in processing speed associated with the age differences between the two groups.

Further paired T-tests showed a longer response time for the conflicting reading words (compared with the mean of the control and congruent conditions) within the poorer reading group (t_{21}=6.75 p<.001). A similar test showed that the better reading group were significantly slower with naming the conflicting pictures (t_{21}=7.14 p<.001).

Conclusion

The results of the empirical study confirm the predictions made by the connectionist model; namely, that there is a reverse Stroop interference giving way to the classic Stroop during the development of Stroop effects. These results are consistent with the findings of Arochova (1971) who suggested there may be reverse Stroop interference with pre-school children with letter naming type tasks and the Ehri and Wilce's (1979) demonstration that Stroop interference becomes very pronounced after a couple of years of schooling.

One clear distinction between the model and the empirical study is that the network is based on a two color Stroop task and the empirical results are based on a multiple picture naming task. However, it would be straight forward to extend the developmental model to include multiple responses, as was done by Cohen et al.

This work suggests that more attention should be paid to the distinction between learning and development. While learning is an integral part of what happens during childhood, many maturational and developmental processes are also present during childhood. Fine grained models of child development should incorporate changes in information processing as well as changes in knowledge.

One shortcoming of this model is its failure to capture the decline in the Stroop effect after reaching optimum interference. There are two possible explanations for this. Firstly (and probably the most likely), by the age of 11 children have mastered other skills that affect their performance on Stroop tasks such as the ability to monitor and consciously change their response.

One way to overcome this problem within the model is to change the ratio of reading to naming in the training set. If the ratio of reading to naming is allowed to progress so that reading does not massively exceed naming (i.e. kept at a maximum of 10:1), the network is able to make better progress in learning the naming task. The result of this is that the error (and so predicted reaction time) for the color naming time is reduced, lessening the Stroop effect. Conversely, if the ratio is allowed to creep up to 1000:1, there will be large amounts of error in the color task as the network becomes optimized to carrying out the reading task. Hence, the final amount of Stroop interference in these models can be adjusted by adapting the training ratio.

In summary, this paper has (1) replicated the results of a published model of Stroop interference, (2) extended the model to embody constraints from cognitive development, and (3) tested and confirmed the predictions of the extended model on young children. This project continues to argue for the validity of connectionist methods as a serious means of addressing cognitive development in children.

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