Psicológica (2015), 36, 37-67.

Practice and colour-word integration in Stroop interference

Amara Gul[1] and Glyn W. Humphreys[2]

[1]*The University of Birmingham, UK.*

[2]*Oxford University, UK.*

Congruency effects were examined using a manual response version of the Stroop task in which the relationship between the colour word and its hue on incongruent trials was either kept constant or varied randomly across different pairings within the stimulus set. Congruency effects were increased in the condition where the incongruent hue-word relations were maintained. This effect was observed even when only a single letter was coloured rather than the whole word. The data suggest that the Stroop interference effect can increase when words and hues become bound by learning, which can make it more difficult to ignore the word when responding to the hue. The implications for understanding Stroop interference are discussed.

Stroop colour naming is one of the most widely studied paradigms for examining human selective attention (Stroop, 1935; see MacLeod, 1991, for a review). In the classic version of the test, participants are asked to name the colour of the ink in which a word is written while ignoring the word. Typically, reaction times (RTs) to name the ink colour are slower when word‘s name is incongruent (word RED in blue ink) relative to when it is congruent with the colour name (RED in red ink). In contrast, at least for naming tasks, the effects of color congruence on word naming are small (White, 1969). This interference effect from the word on naming its colour demonstrates that we have problems in attending selectively to one component of a multidimensional stimulus and ignoring a highly over

---

[1] Acknowledgement: Preparation of this article was supported by the IUB-FDP scholarship to the first author. Corresponding author: Amara Gul. School of Psychology. The University of Birmingham. Edgbaston. Birmingham. B 15 2TT. UK. Tel: +92 (0) 307 504 7077. Email: amara_psychology@hotmail.com

learned response to another. The data on Stroop interference are typically attributed to an alternative response competing with the required response when the stimuli are incongruent relative to when they are congruent (Sichel & Chandler, 1969; Regan, 1979; Dunbar & MacLeod, 1984). For naming, word reading is the dominant response and so there is more competition from the word's name for colour naming than from the colour's name for word reading. However, as there is not a dominant manual response to words or colors, this asymmetric interference effect disappears. Consistent with this argument, the asymmetry between word and colour naming decreases when participants make manual responses, when congruency effects are more equitable for colour and word naming (McClain, 1983 a,b).

Learning and the Stroop effect

The differential effects of interference on colour and word naming suggest that Stroop effects can be modulated by the amount of practice people have on tasks. There is evidence that practice on the Stroop task itself changes the magnitude of interference effects. With practice, people gain in attentional control as shown in a classic Stroop experiment (1935), when subjects were presented conflicting word stimuli (incongruent words-RED written in green ink) to color name the words. After eight days of practice (200 trials per day), interference was reduced for conflicting words. Similarly, Ellis et al. (1989) instructed their subjects to practice the Stroop colour-naming task over three or four daily sessions. The results showed a significant decrease in interference over practice trials. Similarly, Ellis and Dulaney (1991) instructed normal adults to read Stroop words, followed by practice in colour naming with Stroop words, then reading Stroop words. The results demonstrated reduced Stroop interference after practice. MacLeod (1998) also had participants practice on both word and colour naming with Stroop stimuli across 5 consecutive days and reported that interference on colour naming decreased by 49%.

Colour and Word Integration in Stroop interference

According to tectonic theory of the Stroop interference effect, attention is modulated by correlated aspects of the environment and most salient stimulus dimensions regardless of the explicit task goal. The selection of stimulus dimensions is controlled by memory based structures such as dimensional imbalance/uncertainty which buildup of excitation to targets and inhibition to distractors and to memories related to previous stimuli (Melara & Algom, 2003).

Prior studies have also shown that Stroop interference is greater when colours are perceptually integrated with colour words, compared with when the stimuli are presented in a non-integrated fashion. Stroop interference is larger for words which display frequently in congruent colours and is smaller for words which appeared most of the time in incongruent colors (Schmidt & Besner, 2008). Contingency between word and colour speeds up performance which is learned via simple storage and retrieval of episodic memories (Schmidt, 2013). With an extensive practice to a small set of consistently mapped incongruent items, Musen and Squire (1993) found a reduction in reaction times to incongruent items. During attention demanding task, new associations are incidentally learned (Lemercier, 2009) which is related with working memory capacity to process two-dimensional stimulus (Kane, Bleckley, Conway, & Engle, 2001; Unsworth & Spillers, 2010). Schmidt and Besner (2008) argue that the speed up of performance should be the same for congruent and incongruent trials whereas Schmidt (2013) withdraws this claim.

Besner and Stolz (1999) for example, presented stimuli where, instead of the whole word, only one of the letters was coloured. Stroop interference decreased in the single-letter-colored condition compared to when al1 the letters were coloured. Risko, Stolz, and Besner (2005, Experiment 1) similarly presented displays of either colour words (i.e., *green*, *red*, *blue*, and *yellow*) or color-neutral words (e.g., *house*) in 16 different locations for visual search. In the integrated condition, the target colour and the colored word were spatially integrated together while in the separated condition, the target color and the coloured word were spatially separated. Participants were instructed to classify the color of the target item among the four different display colours. When the target color and the colour word were *integrated*, the participants responded more quickly on congruent than incongruent trials. When the target colour and the coloured word were spatially separated, responses on congruent and incongruent trials were equivalent.

The present study

In the present study, we combined the effects of learning and of perceptual integration within a manual version of the classic Stroop paradigm. There is much evidence that learning can influence perceptual integration. For example, through learning participants can learn to integrate letters in a new perceptual object, a word. The presence of the word can then modulate perception of the components – as found in studies of the word-superiority effect (Reicher, 1969; Wheeler, 1970). In some cases the effects of integrated perception are dependent on letters having the same case to form a familiar visual unit. For example, in neuropsychological cases of simultanagnosia, patients may only read letters when they form such a familiar, same-case group (Hall, Humphreys & Cooper, 2001; Kumada & Humphreys, 2001) and the difficulties in reading mixed-case words can be made worse when the same-case letters group into another word (e.g., it is difficult to read the whole string 'sPrInG' due to the presence of the same-case PIG; Humphreys, Mayall & Cooper, 2003). The perceptual integration of color and form is also affected by learning. Rappaport, Humphreys & Riddoch (2013) reported efficient visual search for conjunctions of coloured objects carrying their learned colours (e.g., detecting yellow corn amongst yellow lemons, purple aubergines and orange carrots) but not when the colors were inter-changed and had weaker learned relationships to the shapes (purple corn amongst purple lemons, orange aubergines and purple carrots). Such data suggest that learned color-shape relations attract attention to the integrated representation of the target object. Rappaport, Riddoch and Humphreys (2011) further report that color-shape learning could also disrupt performance when the task was to select one but not the other dimension of the stimulus. On the majority of trials in their experiment participants had to name objects, however if the object was colored red, then they had to name the color ('red'). Colour naming was disrupted if the object had a learned relationship with the colour (e.g., a red strawberry) compared with then the object was not usually that colour (a red lemon). This disruption did not occur when the color and shape were not perceptually integrated and the colour appeared in the background surrounding the shape. Rappaport et al. (2011) propose that it is difficult to attend to the colour of an object when the colour and the shape form an integrated perceptual unit.

In the present study we examined whether learning between a color and a word would modulate performance in the Stroop task, if particular colours and words were consistently paired together. In particular we manipulated whether participants saw consistent or inconsistent color-word pairings on incongruent trials as they carried out word or colour identification tasks. In Experiment 1 we kept the incongruent colour-word pairs constant and found that the magnitude of Stroop interference increased across blocks of trials – in contrast to the previously reported effects of practice on Stroop interference (Ellis et al., 1989; Stroop, 1935). In Experiment 2 we directly contrasted performance when the incongruent colour-word relations were constant across trial blocks and then they varied. Stroop interference was greater in trial blocks with consistent incongruent color-word pairs, and practice reduced Stroop interference only with inconsistent colour-word pairings. The congruity effects will then increase with practice in the experiment. In Experiment 3 we tested the generality of these effects by examining the effects of consistent and inconsistent colour-word pairings when only a single letter was colored in the words. Having only a single letter coloured may make it more difficult to learn the relations between an incongruent color word and its hue (Besner, Stolz & Boutilier, 1997), reducing the tendency for greater practice to increase Stroop interference when the inconsistent color-word pairings are consistent across the experiment.

EXPERIMENT 1

Effects of practice with consistent, incongruent colour-word pairs

Participants performed manual word and colour identification tasks to congruent and incongruent colour words. A manual identification task was used here to equate colour-on-word and word-on-colour interference, so that we could maximize interference effects across both tasks as the trial blocks varied. On incongruent trials, the colour and the word were consistent across the trial blocks, giving opportunity for the learning of integrated colour-word representations.

METHOD

Participants. 14 postgraduate students (ages 20-27 years, mean 23 years) with self-reported normal colour vision took part in the study.

Word/Colour Identification task stimuli. The stimuli consisted of eight coloured words either depicted in the colour corresponding to the coloured word for four stimuli: ‘Blue’, ‘Green’, ‘Red’, and ‘Yellow’ (*congruent*) or one specific mismatch for each word on incongruent trials (e.g., the word ‘Red’ was always presented in blue). The RGB breakdowns for the stimuli were: blue= 0,0,255, green= 128,255,128, red= 255,0,0, and yellow= 255,255,128. The words were written in courier new font, 38 point, bold.

All stimuli were same for the two tasks except they were presented against a pink or aqua colour background to signal either word or color identification task. Tasks were counter-balanced across participants. For half of the participants, the experiment started with the presentation of the word identification task. This was counterbalanced across participants; for the other half of the participants, the colour identification task was carried out first.

Apparatus and display. The experiment was designed in E-prime software (Schneider, Eschman, & Zuccolotto, 2002, version 1.2) and was presented on 14 inch laptop screen. Participants responded by pressing different keys set on a keyboard. Each trial began with presentation of a central fixation (+) cross for 1,000 ms, followed by a blank screen for 1,000 ms, then the word appeared on the screen until the response was made (Figure 1).

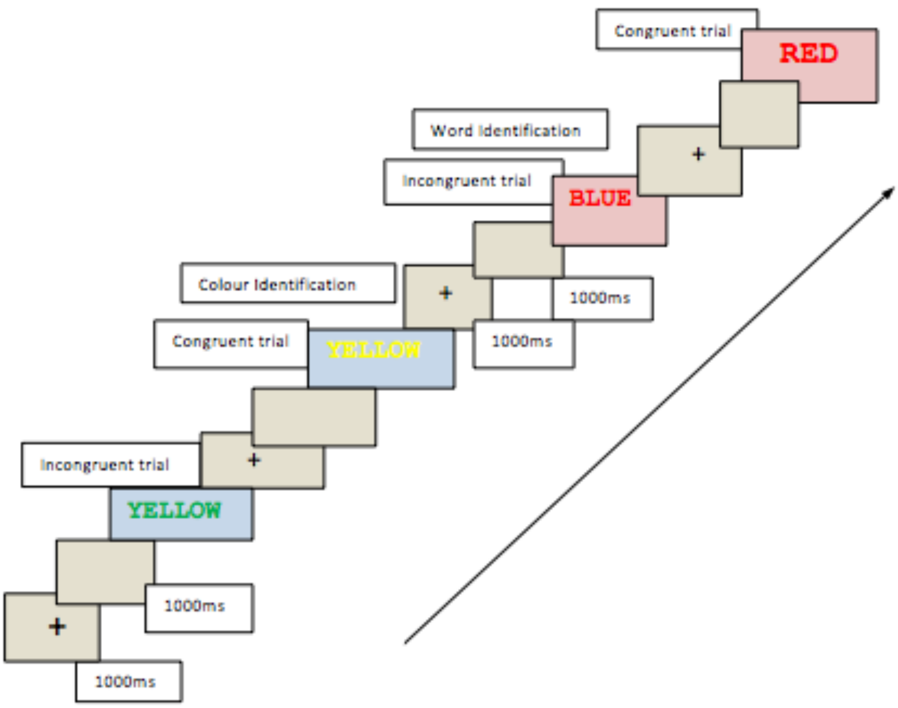

Figure 1. Example of Word / Colour Identification tasks with the congruent and incongruent word stimuli in alternate run.

Block structure. Participants were presented with eight alternating blocks of the word and colour identification tasks. Each block carried 16 trials (8 blocks with 16 trials each=128 experimental trials). Within 16 trials per block, congruent stimulus was presented twice (4 congruent words x 2= 8 trials) and incongruent stimulus twice per block (4 incongruent words x 2= 8 trials). First 4 trials within each block were discarded in order to minimize effects of task switching from one trial block to another.

Design and procedure. The study received approval from research ethics committee. The experiment was conducted in a single session and was performed in a dark room. Participants were given an informed consent form and a description of the experiment. They were told that this was a reaction time experiment, and that they must respond by pressing the fixed keys on the keyboard as quickly as possible without sacrificing accuracy. The participants were instructed to "*identify the word"* in the word identification task and "*identify the colour in which the word is printed*" in the color identification task. They were told that the response keys were: 1=blue, 2=green, 3=red, 4=yellow and any questions were answered. Participants completed 128 experimental trials of the word/colour identification task. Following this, they were debriefed and thanked for their participation.

RESULTS

Mean RTs on post switch trials (5-16 in each block) were taken to examine the basic Stroop effect during a stable period of task performance (when the task was repeated across trials). After removing the outliers (RTs were excluded above 2.5 standard deviations from each participants' mean) and RTs on the incorrect trials, mean RTs were submitted to a repeated measures analysis of variance (ANOVA) with task (*word* vs. *colour identification*), block (1 *vs*. 2 vs. 3 vs. 4) and congruency (*congruent* vs. *incongruent*) as within subject factors. The main effect of congruency was significant $F(1,13) = 55.22$, $p < 0.001$, $MSE = 40766.11$, $\eta p2 = .80$ such that RTs were faster on congruent (M= 1036 ms) than incongruent (M=1236 ms) stimuli. The main effects of block ($F < 2$) and task ($F < 1$) failed to reach significance. There was one significant higher order interaction which was between task, block, and congruency $F(3,13) = 4.01$, $p < 0.01$, $MSE = 77605.06$, $\eta p2 = .23$. This was decomposed by analysing the data in separated repeated measure ANOVAs for the word and colour identification tasks with block and congruency as within subject factors.

For the colour identification task, there was no effect of block $F < 1$. There was a main effect of congruency $F(1,13) = 37.46$, $p < .001$, MSE = 32150.49, ηp2 = .74, and there was a significant interaction between block and congruency $F(3,13) = 4.87$, $p < .01$, MSE = 135166.04, ηp2 = .27. The magnitude of the congruency effect (incongruent minus congruent trials) increased from block 1 to 4 $F(3,13) = 4.87$, $p< .01$, MSE = 270331.10, ηp2 = .27. RTs speeded up on congruent trials with progressive blocks $F(3,13)$ = 17.01, $p < .001$, MSE = 62410.76, ηp2 = .56 while there was no effect of block on incongruent trials $F < 1$.

For the word identification task, there was no effect of block (F<1). There was a significant main effect of congruency $F(1,13) = 48.00$, $p < .001$, MSE = 21955.25, ηp2 = .78. The interaction between block and congruency was significant $F(1,13) = 6.10$, $p < .01$, MSE = 75263.76, ηp2 = .31. RTs on congruent trials decreased from block 1 to 4 $F(1,13) = 3.69$, $p < .05$, MSE = 93282.54, ηp2 = .22 while no effect of block was observed on incongruent trials $F(1,13) = 1.24$, $p = .30$, $MS\ E$= 175637.11, ηp2 = .08. The congruency effect differed across blocks $F(3,13) = 6.10$, $p < .01$, MSE = 150527.94, ηp2 = .31. Pairwise comparisons showed a reliable increase in the congruency effect from block 1 to 2 $t(13) = 3.40$, $p < .01$ only, while the congruency effect was stable from blocks 2 to 3 $t(13) = 2.04$, $p = .06$ and blocks 3 to 4 $t(13) = 0.69$, $p = .05$ (Figure 2).

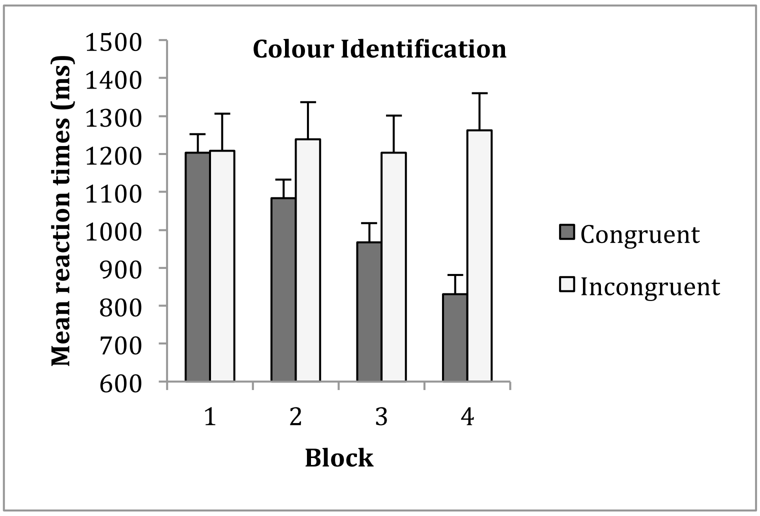

Fig 2a. Mean reaction times (ms) in the colour identification task on congruent and incongruent trials.

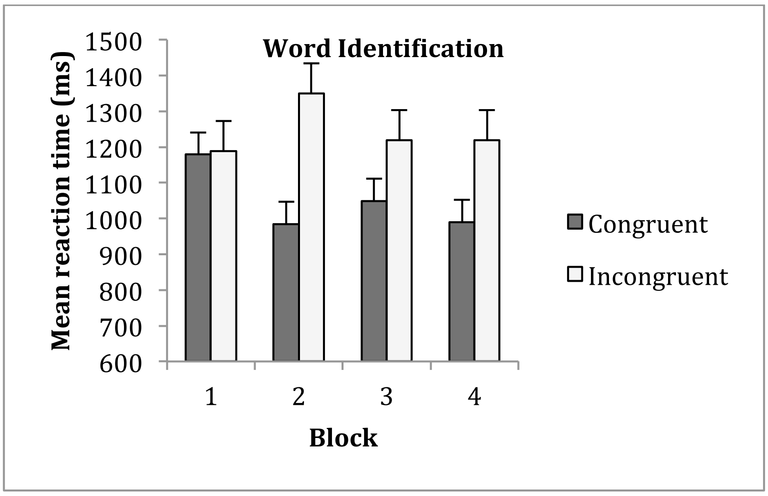

Figure 2b. Mean reaction times (ms) in the word identification task on congruent and incongruent trials.

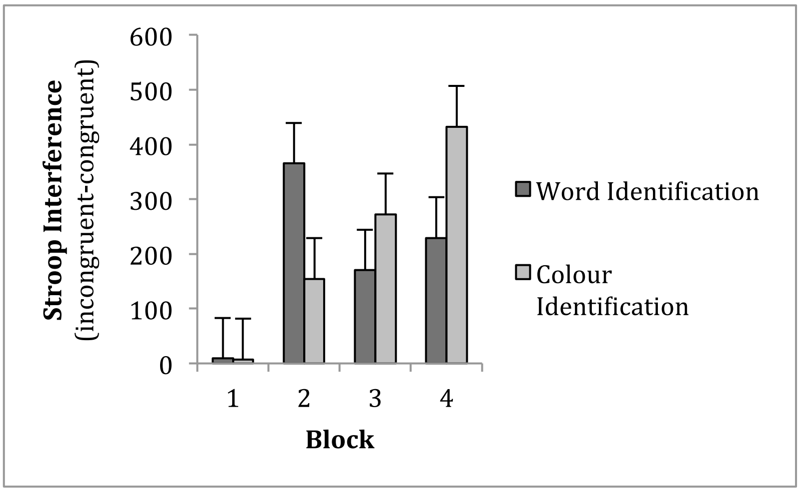

Figure 3. Stroop Interference (ms) in blocks the for word and colour identification task.

The error rate was low and there was no speed-accuracy trade-off. The mean error rates are presented in Table 1.

Table 1. Mean percentage errors (PE) and standard deviations (SD) of errors on congruent and incongruent trials in experiment 1.

Word Identification	**Congruent** PE (*SD*)	**Incongruent** PE (*SD*)
Block 1	2.5 (.02)	3 (.02)
Block 2	3 (.02)	4 (.02)
Block 3	3 (.03)	3.5 (.02)
Block 4	2.5 (.01)	2.5 (.03)
Colour Identification		
Block 1	2 (.02)	2 (.01)
Block 2	2.5 (.02)	2.5 (.03)
Block 3	2 (.03)	2 (.01)
Block 4	1 (.01)	2 (.02)

DISCUSSION

Overall, there was an equal congruency effect for both the word and colour identification tasks. This fits with prior studies using manual responses (e.g., Keele, 1972; Pritchatt, 1968). More importantly, congruency interacted with block and task. For the colour identification task, there was a differential effect of congruency across the blocks as RTs on congruent trials decreased while on incongruent trials RTs tended to increase – the net result being that the congruency effect increased across the trial blocks (see Figure 3). In the word identification task there was also an increase in the congruency effect across the trial blocks, but in this case the greatest change was from block 1 to block 2, after which the larger congruency effect was maintained. The pattern of these results go against prior findings on the effects of practice on Stroop interference – where it has been found that interference decreases as participants become more practiced (Ellis et al., 1989; Stroop, 1935). Even if a decrease in interference was not apparent, we would expect practice to have a benefit of at least equal magnitude on incongruent and congruent trials. This was not the case. An alternative account can be proposed based on the idea of colour and word binding. Risko, Stolz, and Besner (2005), for example, reported faster RTs on congruent trials and slower RTs on incongruent trials relative to neutral trials when the colour word and the colour target were integral. With a small set of colours and words, and with certain words always paired with the same colour here, then integrated word-colour representations may be formed. For such integrated representations it may be more difficult for participants to attend to either the colour or the shape without processing the other dimension. It follows that responses to congruent trials (based on either dimension) will be facilitated while incongruent trials may be disrupted – though the slowing on incongruent trials may be balanced against a general speeding of RTs through practice at the task.

In Experiment 2 we tested this idea of learned colour-word bindings further. We directly contrasted performance when the bindings were kept constant (on incongruent trials one word was assigned to one colour) with performance when the bindings varied (where participants received all colour-word pairings, so one word was not consistently paired with one colour). Did congruency effects increase with practice for the constant colour-word condition, while decreasing when the bindings were varied?

EXPERIMENT 2

Contrasting effects of constant vs. varied colour-shape relations

METHOD

Participants. 24 postgraduate students (8 females and 16 male, ages 21-24 years, mean 22.87 years) with self-reported normal colour vision participated in the study. Participants were divided in three groups (8 participants per group) and they performed constant and varied colour-word conditions with an interval of 1 week between, and the order of these two conditions was counterbalanced across participants.

Stimuli and displays. The stimuli and displays were same as in Experiment 1, but with varied block presentation for 128 trials as described below.

Block Presentations for Constant Colour-Word Pairings. In this condition each group of participants was administered the same congruent words along with a varied presentation of incongruent words, which remained constant in all four blocks of the experiment. Participants saw the colour words RED, YELLOW, BLUE and GREEN in the congruent colours. For one subgroup of participants, incongruent trials were formed by writing the word RED in blue, YELLOW in green, BLUE in yellow and GREEN in red colour. For second subgroup of participants, incongruent trials were formed by the words written as RED in yellow, YELLOW in red, BLUE in green, and GREEN in blue colour. For another subgroup, incongruent words were presented as RED in green, YELLOW in blue, BLUE in red, and GREEN in yellow colour.

Blocked Presentation with Varied Colour-Word Pairings. The words were the same as in the constant colour-word condition, but incongruent words alternated across progressive blocks (i.e., there was one colour-word assignment for incongruent words on block 1 and 2, another for block 3 and a third for block 4). For subgroup 1, the words RED, BLUE, YELLOW and GREEN were assigned the colours blue, yellow, green, and red on block 1 and 2; the colours on block 3 were yellow, green, red, and blue, and the colors in block 4 were green, red, blue, and yellow.

For subgroup 2, the words RED, BLUE, YELLOW and GREEN were assigned the colours yellow, green, red and blue on block 1 and 2; green, red, blue, and yellow on block 3 and blue, yellow, green, and red on block 4.

For subgroup 3, the words RED, BLUE, YELLOW and GREEN were assigned the colours blue, yellow, green, and red on block 1 and 2; yellow, green, red and blue on block 3, and green, red, blue, and yellow on block 4

Apparatus and Procedure. Apparatus and procedure was same as in Experiment 1.

RESULTS

As for Experiment 1, the effects of congruency were examined, with the data averaged across post switch trials (moving from colour to word identification or vice versa). As before, this second analysis examined the basic Stroop effect during a stable period of task performance (when the task was repeated across trials). Outliers were removed and response times (RTs) were excluded above 2.5 standard deviations from each participants' mean. RTs for incorrect trials were also removed. Subsequently, mean RTs on post switch trials were calculated. Similar to the analysis for experiment 1, this was done in order to accumulate stable numbers of post switch trials.

Mean RTs on post switch trials (5-16) were submitted to a repeated measures analysis of variance (ANOVA) with task (*word identification* vs. *colour identification*), block (*first* vs. *second* vs. *third* vs. *fourth*), congruency (*congruent* vs. *incongruent*), and colour-word (*constant* vs. *varied*) as within subject factors. There was a significant main effect of congruency $F(1, 23) = 30.00$, $p < 0.001$, $MSE = 155777.78$, ηp2 = .56. RTs on congruent trials were faster than on incongruent trials (940 vs. 1096 ms, respectively). There was a significant main effect of block $F(3, 23) = 20.00$, $p < 0.001$, $MSE = 170964.43$, ηp2 = .46. RTs decreased from block 1 to 4 (block 1 = 1114 ms vs. block 2 = 1039 ms vs. block 3 = 982 ms vs. block 4= 937 ms). There was also a significant main effect of color-word, $F(1, 23) = 12.00$, $p < 0.01$, $MSE = 1821035.24$, ηp2 = .34. RTs were faster in the alternating colour-word (M=850) than the constant colour-word condition (M=1186). There was no significant main effect of task $F(1,23) = 3.00$, $p = .10$, $MSE = 32250.90$, ηp2 = .11.There was a significant higher order interaction between task, congruency, block, and colour-word $F(3,23) = 7.83$, $p < 0.001$, $MSE = 43624.00$, ηp2 =.25.

Task, Congruency, Block and Colour-word

The 4-way interaction was decomposed by submitting RTs to separate repeated measure ANOVAs for the constant and varied color-word conditions with task, block, and congruency as within-subject factors. For the constant colour-word condition, there was a significant interaction between task, block and congruency $F(3,23) = 3.00$, $p < 0.05$, $MSE = 74395.00$, ηp2 = .11. This interaction was further analyzed by submitting RTs to separate repeated measure ANOVAs for word identification and colour identification with congruency and block as within subject factors. For word identification, there was a significant interaction between congruency and block $F(3,23) = 4.00$, $p < 0.05$, $MSE = 113528.00$, ηp2 = .14. There was an effect of block on congruent trials $F(3,23) = 7.00$, $p < 0.001$, $MSE = 225840.44$, ηp2 = .23 while no significant effect was found for incongruent trials $F(3,23) = 2.00$, $p = .18$, $MSE = 137804.58$, ηp2 = .06. The congruency effect increased from block 1 to 4 $F(3,23) = 4.00$, $p < 0.01$, $MSE = 227055.49$, ηp2 = .05. For colour identification, the interaction between block and congruency was also significant $F(3,23) = 14.15$, $p < 0.001$, $MSE = 98669.46$, ηp2 =.38. There was an effect of block on both congruent $F(3,23) = 39.00$, $p < 0.001$, $MSE = 151675.00$, ηp2 = .62 and incongruent trials $F(3,23) = 6.32$, $p < 0.001$, $MSE = 98080.00$, ηp2 = .21. The interaction between block and congruency occurred because the effect of block was greater on congruent than incongruent trials, so that the congruency effect increases across trial blocks (Figure 4). For the varied colour-word condition, there was no significant interaction between task, block and congruency $F(3,23) = 0.94$, $p = .42$, $MSE = 9283.00$, ηp2 = .03 (Figure 5). The interaction between block x congruency was reliable $F(3,23) = 3.00$, $p < 0.05$, $MSE = 5629.00$, ηp2 = .10 (Stroop interference block 1= 54 ms, block 2= 44 ms, block 3= 67 ms, block 4= 79 ms) . The 4-way interaction was due to block, congruency and task affecting performance when the colour-word relations were constant.

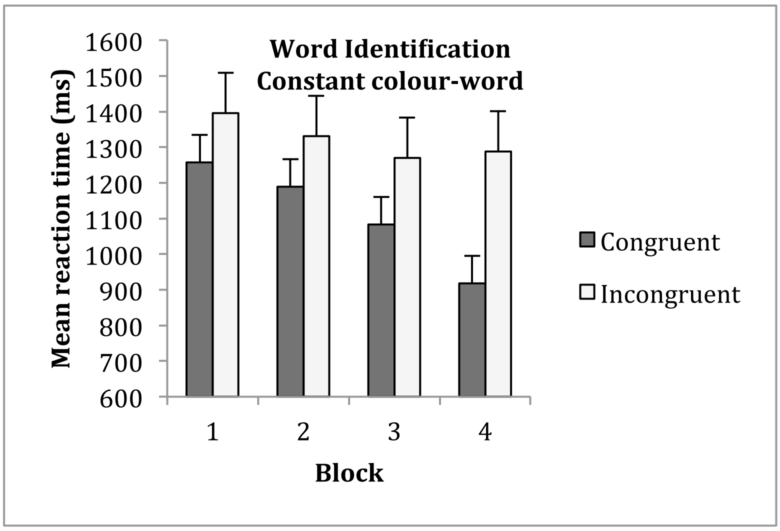

Figure 4a. Mean reaction times on word identification task in constant colour-word condition.

Error Data

Unlike Experiment 1 there was some evidence that the error data varied across the conditions. The mean errors on post switch trials (5-16) were submitted to a repeated measures analysis of variance (ANOVA) with task (*word identification* vs. *colour identification*), block (*first* vs. *second* vs. *third* vs. *fourth*), congruency (*congruent* vs. *incongruent*), and colour-word (*constant* vs. *varied*) as within-subject factors. There was a significant

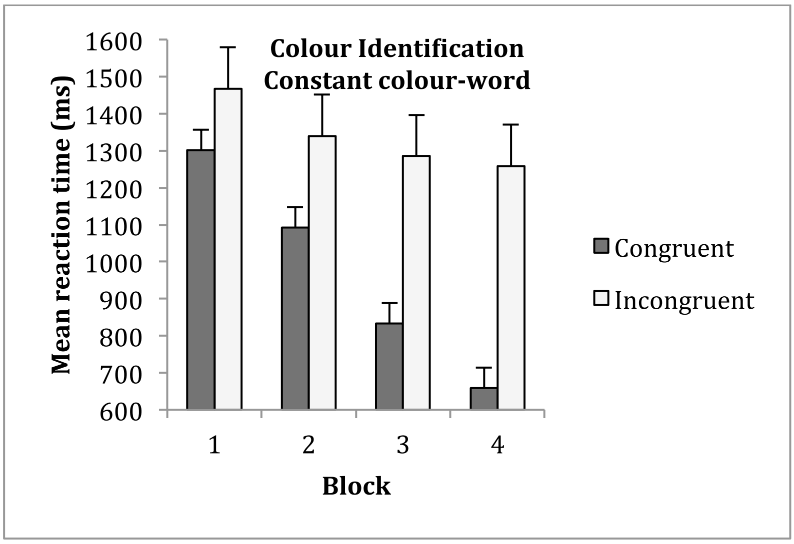

Figure 4b. Mean reaction times on colour identification task in constant colour-word condition.

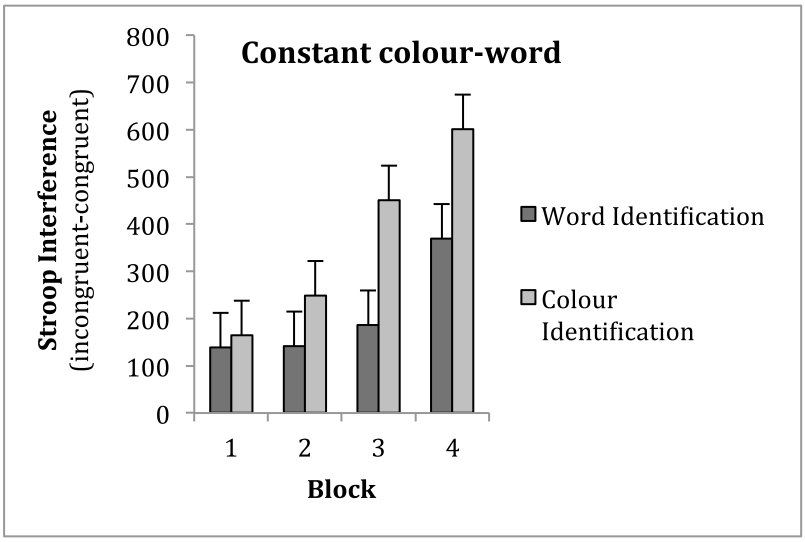

Figure 4c. Stroop Interference (ms) on word/colour identification task in constant colour-word condition.

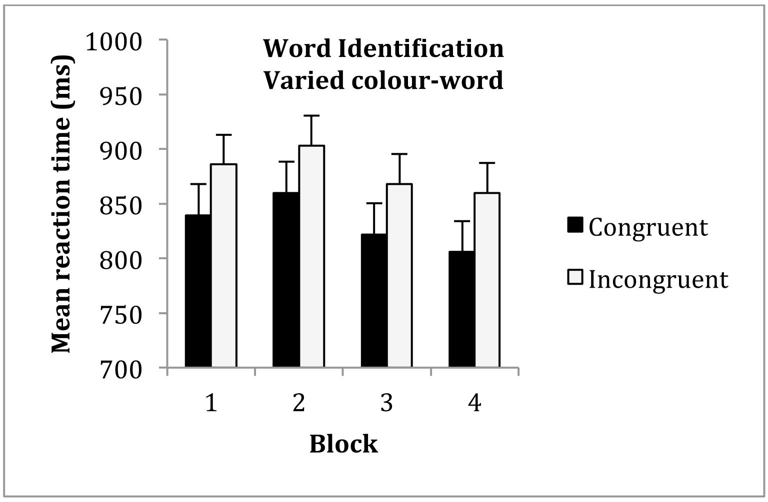

Figure 5a. Mean reaction times on the word identification task in the varied colour-word condition.

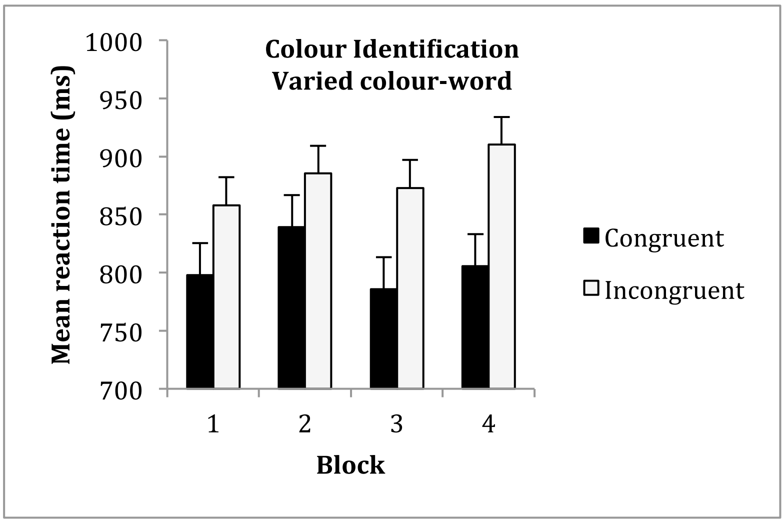

Figure 5b. Mean reaction times on the colour identification task in varied colour-word condition.

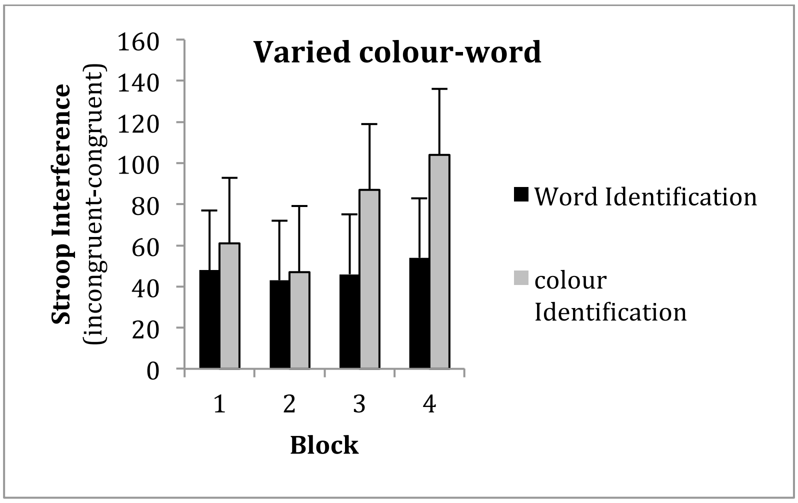

Figure 5c. Stroop Interference on the word/colour identification task in varied colour-word condition.

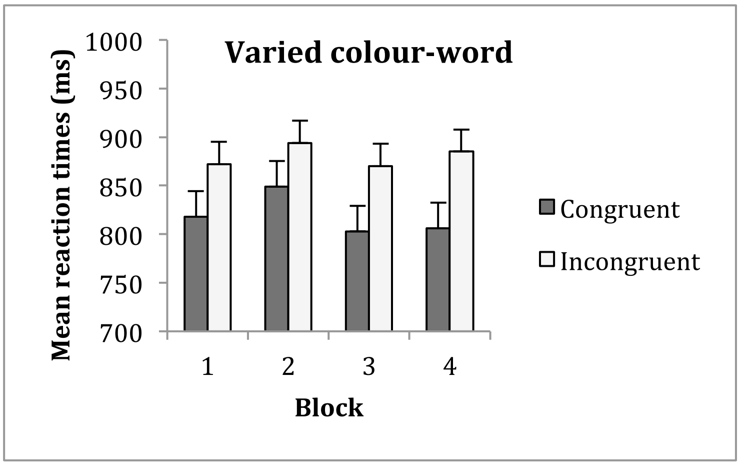

Figure 5d. Mean reaction times (ms) in blocks for varied colour-word condition.

main effect of congruency $F(1, 23) = 40.00$, $p < 0.001$, $MSE = .01$, ηp2 = .63, congruent $M = .01$, incongruent M=. 06. There were reliable main effects of: (i) task $F(1,23) = 2.00$, p= .19, $MSE = .00$, ηp2 = .07, Word identification $M = .03$, colour identification $M = .04$; (ii) block $F(3,23) = 2.00$, $p = .35$, $MSE = .01$, ηp2 = .04, block 1 $M = .03$, block 2 M= .03, block 3 $M = .03$, block 4 $M = .05$; and (iii) colour-word $F(1,23) = 1.08$, $p = .30$, $MSE = .01$, ηp2 = .04, constant colour-word $M = .04$, alternate color-word $M = .03$. There was a significant higher order interaction between task, congruency, block, and colour-word $F(3,23) = 5.00$, $p < 0.01$, $MSE = .04$, ηp2= .08. This interaction was decomposed by submitting errors to separate repeated measures ANOVAs for the constant and varied colour-word conditions with task, block, and congruency as within-subject factors. For the constant colour-word condition, there was a significant interaction between task, block and congruency $F(3,23) = 6.00$, $p < 0.01$, $MSE = .04$, ηp2= .16. This interaction was further analyzed by submitting the mean errors to separate repeated measure ANOVAs for word identification and colour identification with congruency and block as within-subject factors. The interaction between congruency and block was only reliable for colour identification $F(3,23) = 11.35$, $p < 0.001$, $MSE = .00$, ηp2 = .33 [word identification $F(3,23) = 2.15$, $p = .10$, ηp2 = .08]. The data are shown in Table 2. For the varied colour-word condition, the interaction between task, block x congruency was also reliable $F(3,23) = 3.45$, $p < 0.05$, $MSE = .03$, ηp2 = .13. However, the interaction between block x congruency was not reliable for both tasks: Word identification $F(3,23) = 3.00$, $p = .08$, $MSE = .04$, ηp2 = .09, colour identification $F(3, 23) = 1.40$, $p = .24$, $MSE = .01$, ηp2 = .05 (see Table 2).

DISCUSSION

Experiment 2 compared colour-word interference under conditions in which the color-word relations were either constant or varied across the trial blocks. When the color-word relations on incongruent trials were constant across the blocks, the data replicated Experiment 1 – congruency effects increased across the trial blocks (in this case because RTs on congruent trials decreased whilst RTs on incongruent trials did not). For word identification, the magnitude of the congruency effect peaked at trial block 2. For colour identification, the congruency increased across the trial blocks, This again replicates the pattern from Experiment 1. In contrast, when the colour-word relations on incongruent trials varied across blocks, there was no evidence for any increase in the congruency effects. These RT results were replicated in the error data.

Table 2. Error data on Word/Colour identification in Constant and Varied Colour-word conditions.

	Word Identification			
	Constant colour-word		Varied colour-word	
	Congruent	Incongruent	Congruent	Incongruent
	M (SE)	*M* (SE)	*M* (SE)	*M* (SE)
1	0 (.00)	.01 (.01)	0 (.00)	0 (.00)
2	0 (.00)	.01 (.01)	0 (.00)	0.14 (.06)
3	0 (.00)	.08 (.03)	.03 (.01)	.06 (.04)
4	0 (.00)	.08 (.02)	.02 (.01)	.06 (.01)
	Colour Identification			
	Constant colour-word		Varied colour-word	
	Congruent	Incongruent	Congruent	Incongruent
	M (SE)	*M* (SE)	*M* (SE)	*M* (SE)
1	0 (.00)	0.18 (.03)	0 (.00)	0.01 (.01)
2	0 (.00)	0.05 (.01)	0.01 (.01)	.04 (.01)
3	0 (.00)	0.01 (.01)	0 (.00)	0.09 (.04)
4	0 (.00)	0.19 (.04)	0 (.00)	.04 (.01)

The data with varied colour-word pairings did not lead to a decrease in interference, though prior results have reported this (Ellis et al., 1989; Stroop, 1935). However there was more extended practice in these experiments than here, and this is likely critical to more task control being exerted over interference. Nevertheless the critical point is that there was no evidence for interference increasing, as was found for the constant colour-word condition.

In Experiment 3 we generalized these results by assessing performance when only one letter was coloured in each word. Risko et al. (2005) reported that Stroop interference decreased in this condition, compared with the case when all the letters were assigned a common hue, consistent with participants being better able to focus attention on the colour without also processing the words. Here we tested whether the effects of having constant or varied colour-word relations on incongruent trials decreased when participants could attend to just one colored letter. An alternative is that colour-word bindings might still be formed when the incongruent colour-word relations are constant, and this does generate increasing congruency effects across the trial blocks. In contrast, there may be minimal interference with varied colour-word mappings, as full integration of the colour and word does not take place, even after practice.

EXPERIMENT 3

Effects with single coloured letters

METHOD

Unless otherwise mentioned the Method was the same as in Experiment 2.

Participants. 48 postgraduate students (17 females and 31 male, ages 21-26 years, mean 24.31 years) took part in the study. All had self-reported normal colour vision. Participants were divided into three groups (16 participants per group) and they performed the constant colour-word and varied colour-word conditions with an interval of 1 week between, and the order of these two conditions was counterbalanced across participants.

Stimuli and displays. The stimuli were same as in Experiment 2, except that the words only had a single letter coloured. while the other letters in the words were written in black.

Block Presentation for Constant Colour-Word Pairings. Each group of participants was administered the same congruent words along with a varied presentation of incongruent words, which remained constant in all four blocks of the experiment for a given individual. Participants saw the colour words RED, YELLOW, BLUE and GREEN with a single colored letter. The position of the coloured letter varied across words – the letter R in RED, O in YELLOW, L in BLUE, central E in GREEN. For one subgroup of participants, incongruent trials were formed by writing the letter R in blue, O in green, L in red and E in yellow color. For a second subgroup of participants, incongruent trials were formed by the words written as letter R in yellow, O in blue, L in green, and E in red colour. For a third subgroup, incongruent words were presented as letter R in green, O in red, L in yellow, and E in blue color.

Blocked Presentation with Varied Colour-Word Pairings. The words were the same as in the constant colour-word condition, but incongruent words varied across progressive blocks (i.e., there was one colour-word assignment of each single letter for incongruent words in each block). For subgroup 1, the letters R, L, O, and E for the words RED, BLUE, YELLOW and GREEN respectively were assigned the colors blue, red, green, and yellow on block 1; the colours on block 2 were yellow, green, blue, and red; the colours on block 3 were green, yellow, red, and blue; and the colours in block 4 were blue, red, green, and yellow.

For subgroup 2, the letters R, L, O, and E for the words RED, BLUE, YELLOW and GREEN respectively were assigned the colors yellow, green, red, and blue on block 1; the colors on block 2 were green, red, blue, and yellow; the colours on block 3 were blue, yellow, green, and red; and the colours in block 4 were yellow, green, red, and blue.

For subgroup 3, the letters R, L, O, and E for the words RED, BLUE, YELLOW and GREEN respectively were assigned the colours green, yellow, blue, and red on block 1; the colors on block 2 were blue, red, green, and yellow; the colors on block 3 were yellow, green, red, and blue; and the colours in block 4 were green, yellow, blue, and red.

Procedure. The procedure was same as the Experiment 2 except subjects were presented with four blocks of the colour identification task only with 64 trials in each block (half of them were incongruent). Participants performed 256 trials and responded by pressing different keys set on the keyboard (i.e., 1= red, 2= blue, 3= green, and 4= yellow).

RESULTS

As for Experiment 2, outliers were removed with RTs excluded if they were above 2.5 standard deviations from each participants' mean. The mean RTs were then submitted to a repeated measures analysis of variance (ANOVA) with block (*first* vs. *second* vs. *third* vs. *fourth*), congruency (*congruent* vs. *incongruent*), and colour-word (*constant* vs. *alternating*) as within subject factors. The main effect of block was significant $F(3,47)$ =

77.26, $p < 0.001$, $MSE = 50605.00$, ηp2 = .62. RTs decreased from block 1 to 4 (block 1 = 1117 ms vs. block 2 = 1005 ms vs. block 3 = 952 ms vs. block 4= 934 ms). There was a significant main effect of congruency $F(1,47) = 127.00$, $p < 0.001$, $MSE = 78268.00$, ηp2 = .73. RTs on congruent trials were faster than on incongruent trials (888 vs. 1116 ms, respectively). The main effect of colour-word failed to reach significance level $F(1,47) = 0.39$, $p = .53$, $MSE = 82734.70$, ηp2 = .00. There was a significant higher order interaction between block, congruency, and colour-word $F(3,47) = 13.00$, $p < 0.001$, $MSE = 11703.52$, ηp2 = .21. This interaction was decomposed by testing the effect of block on congruent and incongruent trials separately for each condition (constant and varied colour-word pairings). For the constant colour-word condition, there were main effects of block $F(3,47) = 95.36$, $p < 0.001$, $MSE = 89882.00$, ηp2 = .67 and congruency $F(1,47) = 70.51$, $p < 0.001$, $MSE = 47831.05$, ηp2 = .60 and a significant interaction between block and congruency $F(3,47) = 50.00$, $p < 0.001$, $MSE = 13450.36$, ηp2 = .51. A significant effect of block was observed for both congruent and incongruent trials [congruent $F(3,47) = 157.49$, $p < 0.001$, $MS E= 42802.00$, ηp2 = .77 incongruent $F(3,47) = 41.30$, $p < 0.001$, $MSE = 60530.34$, ηp2 = .46, Figure 6]. Pairwise comparisons also confirmed a progressive decrease in RTs on congruent trials with practice (1 and 2 $t(47) = 9.68$, $p < 0.001$; 2 and 3 $t(47) = 9.06$, $p < 0.001$; 3 and 4 $t(47) = 5.96$, $p<0.001$). For incongruent trials, RTs decreased only from block 1 to 3 then turned stabilized (block 1 to 2 $t(47) = 9.50$, $p < 0.001$; 2 and 3 $t(47) = 3.16$, $p < 0.01$; 3 and 4 $t(47) = 0.93$, $p=.35$). The decrease in RTs on congruent trials was greater than that on incongruent trials so that the effect of congruency increased with practice (see Figure 6). For the varied colour-word condition there was a significant main effect of congruency $F(1,47) = 135.18$, $p < 0.001$, $MSE = 50850.00$, ηp2 = .72, while the effect of block was not reliable $F(3,47) = 1.16$, $p = 0.32$, $MSE = 23216.00$, ηp2 =.02. There was a significant interaction between block and congruency [$F(3,47) = 25.40$, $p < 0.001$, $MSE = 8978.00$, ηp2 = .35, Figure 6]. The RTs on congruent trials differed across blocks $F(3,47) = 4.46$, $p < 0.01$, $MSE = 12283.00$, ηp2 = .08; however pairwise comparisons of RTs revealed no difference on congruent trials between blocks 1 and 2 $t(47) = 1.95$, $p = .056$; 2 and 3 $t(47) = 1.51$, $p = .13$; or 3 and 4 $t(47) = .09$, $p = .92$). For incongruent trials, RTs differed across blocks [$F(3,47) = 10.05$, $p < 0.001$, $MSE = 19911.00$, ηp2 = .17]. Pair wise comparisons showed an increase in RTs only from block 1 to 2 $t(47) = 3.90$, $p < 0.001$ (block 2 to 3 $t(47) = 1.85$, $p = .07$; 3 to 4 $t(47) = 1.49$, $p = .14$).

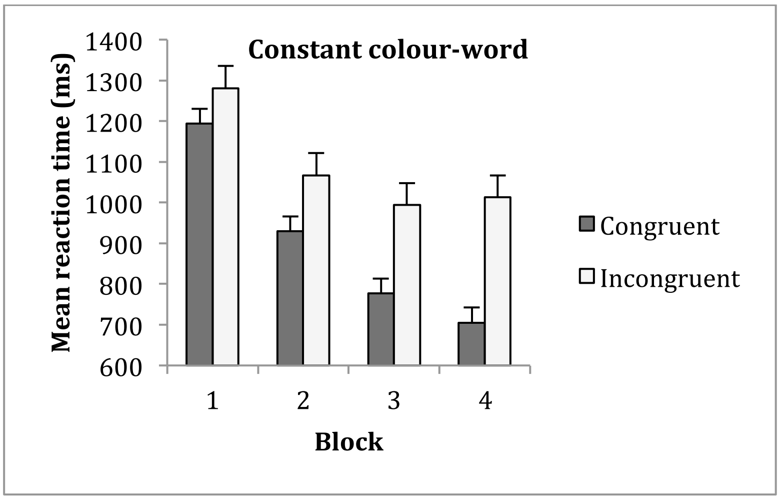

Figure 6a. Mean reaction times (ms) on congruent and incongruent trials across blocks in the constant colour-word condition.

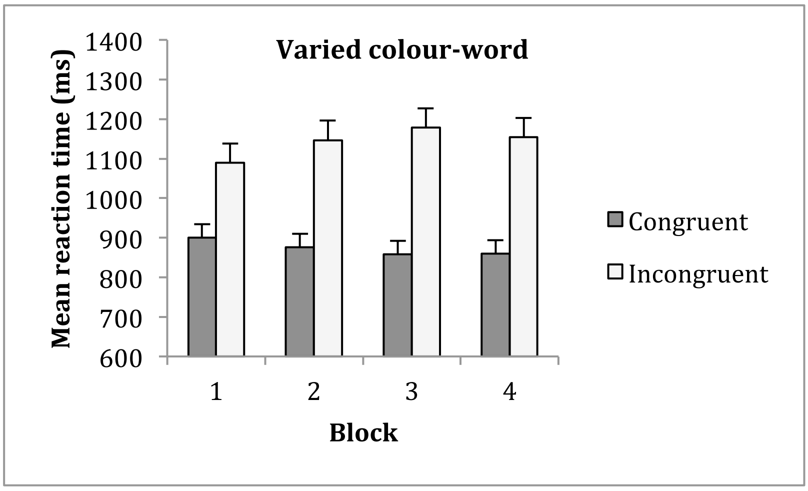

Figure 6b. Mean reaction times (ms) on congruent and incongruent trials across blocks in varied colour-word condition.

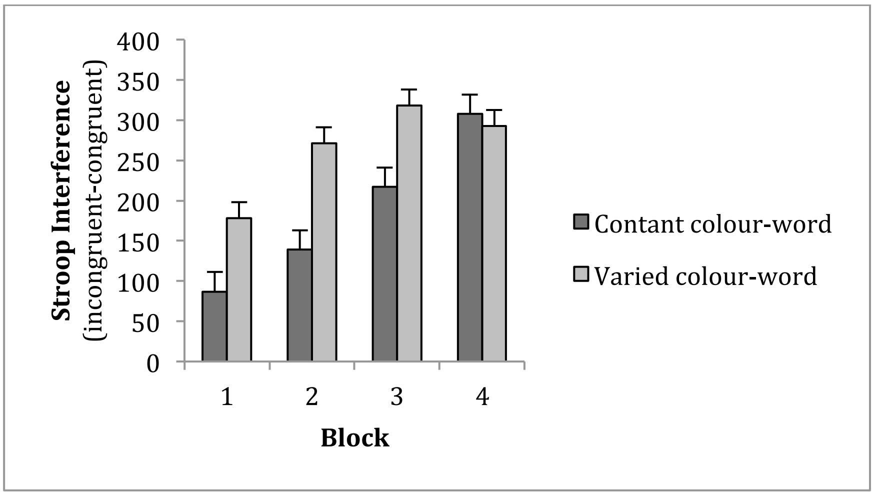

Figure 6c. Stroop Interference (ms) in the constant and varied colour-word conditions.

Error data

The mean errors were submitted to a repeated measures analysis of variance (ANOVA) with block (*first* vs. *second* vs. *third* vs. *fourth*), congruency (*congruent* vs. *incongruent*), and colour-word (*constant* vs. *alternating*) as within-subject factors. The main effect of block was significant $F(3,47) = 6.00$, $p < 0.001$, $MSE = .00$, ηp2 = .10 (block 1 = .11 vs. block 2 = .11 vs. block 3 = .11 vs. block 4 = .10). There was a significant main effect of congruency $F(1,47) = 5.14$, $p < 0.05$, $MSE = .03$, ηp2 = .09, congruent = .09, incongruent = .12. The main effect of colour-word failed to reach significance $F(1,47) = 0.15$, $p = .69$, $MSE = .01$, ηp2= .00. There was a significant interaction between block x congruency x colour-word $F(3,47) = 4.22$, $p < 0.01$, $MSE = .00$, ηp2 = .08. This interaction was decomposed by testing the effect of block on the congruent and incongruent conditions in separate repeated measure ANOVAs for each condition (constant and varied colour words). For the constant colour-word condition, there were main effects of block $F(3,47) = 4.44$, $p < 0.01$, $MSE = .00$, ηp2 = .08 and congruency $F(1,47) = 13.00$, $p < 0.001$, $MSE = .00$, ηp2 = .21 and a no significant interaction between block and congruency $F(3,47) = .46$, $p = .70$, $MSE = .00$, ηp2 = .01 (see Table 3). For the varied colour-word condition, there were main effects of block $F(3,47) = 3.35$, $p < 0.05$, $MSE = .00$, ηp2 = .06 and congruency $F(1,47) = 3.31$, $p = .07$, $MSE = .00$, ηp2 = .06 and a significant interaction between block and congruency

F(3,47) = 6.00, *p* < 0.001, *MSE* = .00, ηp2 = .10. The effect of block was reliable for both congruent *F*(1,47) = 4.00, *p* < 0.01, *MSE* = .00, ηp2 = .07, and incongruent trials *F*(1,47) = 5.00, *p* < 0.01, *MSE* = .00, ηp2 = .08 (see Table 3).

Table 3. Mean Errors on Colour identification in Constant and Varied colour-word conditions in Experiment 3

	Constant colour-word		Varied colour-word	
	Congruent	Incongruent	Congruent	Incongruent
	M (SE)	*M* (SE)	*M* (SE)	*M* (SE)
1	0.09 (.02)	0.11 (.03)	0.09 (.02)	0.09 (.03)
2	0.09 (.02)	0.11 (.02)	0.07 (.02)	0.13 (.03)
3	0.09 (.02)	0.11 (.03)	0.07 (.02)	0.13 (.03)
4	0.08 (.02)	0.09 (.02)	0.06 (.02)	0.09 (.03)

DISCUSSION

Experiment 3 was designed to assess the practice effects on word and colour identification when only a single letter in the words was coloured. Previous studies have found reduced Stroop interference when only single letters are coloured (Risko et al., 2005). In the constant color-word condition, the interference effects increased across the trial blocks. In the varied colour-word condition there was also an overall interaction between trial block and congruency, although individual pairwise comparisons failed to find systematic increases in interference across the conditions – with the only reliable change between blocks 1 and 2. The evidence suggests that having constant colour-word relations led to the color-word relations being gradually learned and to interference increasing as a consequence. This occurred even though only a single letter was coloured in the display. The increase in Stroop interference in the varied colour-word condition could have been for various reasons, such as the switch from the initial set of colour-letter assignments (in block 1) to a second set (in block 2), drawing attention to colour in the subsequent blocks. However the gradual increase in the constant colour-word condition is indicative of a more incremental learning process.

GENERAL DISCUSSION

Across three experiments, we have found that keeping colour-word relations constant on incongruent trials modulates interference under Stroop stimuli. Notably, the symmetric congruency effects, found under manual response conditions, increases across trials when a small but constant set of incongruent colour-words assignment is used. The general pattern of these results was that there were increasing benefits to colour and word identification on congruent trials, while RTs on incongruent trials either tended to increase or they remained constant. In contrast, with incongruent colour-word assignments changes across trial blocks, congruency effects either did not change or did not vary systematically. Clearly, keeping colour-word relations constant had a substantial impact on performance. These data occurred both when the complete words were colored (Experiments 1 and 2) and when only a single letter was coloured in each word (Experiment 3).

To account for these results we suggest that there were two effects of practice on performance with constant, incongruent colour words, and these traded-off against each other. First there are overall beneficial effects of practice, which speed RTs. Second there is increased interference as integrated colour-word representations develop, with these representations making it more difficult to assign attention to one dimension without also processing the other. Due to attention being allocated to dimensions, interference effects increase and this is manifested through reduced RTs on congruent trials and minimal or negative effects of practice on incongruent trials (pitched against the overall benefits of practice). It is striking that the increased congruency effects occurred here even though the effects of practice are generally to reduce Stroop interference (Ellis et al., 1989; Stroop, 1935). The effect of contingency in word and colour was observed in speeded performance. Schmidt and Besner (2008) argued that the benefit was same for congruent and incongruent trials, though Schmidt (2013) retracted this claim. Our data showed a benefit for congruent trials only, which could possibly be due to the methodological difference between these studies. In the present study, congruent and incongruent stimuli were presented equal number of times, whereas this was not the case in the previous studies. Schmidt (2013) claimed that when the incongruent word was predictive of a single colour response, attention toward incongruent word did not interfere with performance. In the present study, there were two equiprobable outcomes for each word, and attention to the distracter might then increase interference. We also note that the interference effects here were roughly equated for word and color identification, fitting with previous studies using manual responses (McClain, 1983 a,b). Generally the increase in the congruency effects with practice was most apparent on colour identification trials, consistent with it being more difficult to focus attention on colour and to ignore word identity when the colour and the word are strongly integrated. However the main effects of keeping the incongruent colour-word relations constant held across word identification too. We conclude that the effects of learning an integrated representation means that attention was allocated to both dimensions irrespective of the dimension required for the task (colour or word identification).

Our results fit with prior evidence that Stroop interference is stronger for stimuli that form integrated representations. Previously word-colour integration has been manipulated by varying the perceptual relations between the colour and the whole word (e.g., Besner, Stolz, & Boutilier, 1997). In addition, in studies of colour naming with objects, having a learned relationship between the shape and the colour has been shown to slow colour naming under particular conditions (Rappaport, Riddoch, & Humphreys, 2013) and these interference effects are stronger when the colour is shown in the shape rather than when the colour is presented in the background. A larger Stroop effect has also been observed for the words presented in congruent rather than incongruent colour by learning colour-shape contingencies in the Stroop paradigm (Schmidt & Besner, 2008). These data and those we report here suggest that learning a specific word colour relation is critical for generating interference from the other dimension on performance. Unlike prior work showing that practice generally reduces the size of the congruency effect, the present experiments show a situation where practice increases the size of congruency effect. For example Musen and Squire (1993) report a similar experiment where participants practiced responding to small set of consistently mapped incongruent items. There was a reduction in reaction time to these items with practice. This result is inconsistent with the present finding that RTs for incongruent items did not change across blocks (e.g., in experiment 1). There are clear methodological differences between experiments however. One is that Musen and Squire presented 100% contingent word-colour combinations. Second, they gave more practice to subjects. Perhaps, the present findings would be different if participants would be given extended practice. The present study had only 128 trials, so our findings are constrained in making broad generalizations about learning and practice. Third difference is that Musen and Squire did not have subjects alternate between word and colour identification tasks. Effects of colour-word learning may be particularly strong under conditions of increased cognitive load.

It is also of interest that we found effects of item-specific learning between colour and shape when only a single letter in the words was coloured, even though the interference effects themselves tended to be weaker on the first trial blocks in this case (Experiment 3), when compared with when all the letters were coloured (Experiments 1 and 2). We propose that, initially, having a single coloured letter facilitated attention to this item on colour identification tasks and also made the colour easier to ignore, on word identification trials (Risko et al., 2005). However, learning of a constant relation between the depicted colour and the full word takes place, perhaps because participants do attend to the whole word (on colour identification trials) and the colour (on word identification trials) perhaps once attention has been allocated to the primary dimension. With Stroop task, the binding of the color and letter takes place automatically on a perceptual rather than conceptual level (Kusnir & Thut, 2012). As the specific colour-word relationship is learned, it becomes more difficult to attend to the colour without processing the word, or vice versa. We conclude that specific learning of colour-word relations can produce a pervasive effect on attentional allocation to each dimension. An emerging question is whether these effects reliably emerge with consistent practice on word identification. Future research must examine learning contingencies for word identification.

REFERENCES

Allport, D.A., Styles, E.A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of task. In C. Umilta & M. Moscovitch (Eds.), *Attention and Performance XV: Conscious and nonconscious information processing* (pp.421-452). Cambridge, MA: MIT Press.

Besner, D., Stolz, J. A., & Boutlilier, C. (1997). The Stroop effect and the myth of automaticity. *Psychonomic Bulletin & Review*, *4 (2)*, 221-225. doi: 10.3758/BF03209396

Cepeda, J. N., Kramer, F. A., & Gonalez de Sather, M. C. J. (2001). Changes in Executive control across the Life span: Examination of Task-Switching Performance. *Developmental Psychology, 37 (5)*, 715-730. doi: 10.1037//0012-1649.37.5.715

Dunbar, K. N., & MacLeod, C. M. (1984). A horse race of a different color: Stroop interference patterns with transformed words. *Journal of Experimental Psychology:*

Human Perception and Performance, 10, 622-639. doi: 10.1037/0096-1523.10.5.622

Ellis, N. R., Woodley-Zanthos, P., Dunaley, C. L., & Palmer, R. L. (1989). Automatic effortful processing and cognitive inertia in persons with mental retardation. *American Journal on Mental Retardation, 93 (4)*, 412-423.

Hall, D., Humphreys, G.W. & Cooper, A.C.G. (2001). Neuropsychological evidence for case-specific reading: Multi-letter units in visual word recognition. *Quarterly Journal of Experimental Psychology, 54A,* 439-467.

Humphreys, G.W., Mayall, K.A. & Cooper, A.C.G. (2003). The PIG in sPrInG: Evidence on the formation of letter groups from the reading of buried words. *Psychonomic Bulletin and Review, 10*, 939-946.

Humphreys, G. W., Riddoch, M. J., & Fortt, H. (2006). Action relations, semantic relations, and familiarity of spatial position in Balint's syndrome: Crossover effects on perceptual report and on localization. *Cognitive, Affective, & Behavioral Neuroscience*, *6 (3)*, 236-245. doi: 10.3758/CABN.6.3.236

Kane, M. J., Bleckley, M. K., Conway, A. R., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology*: *General, 130*(2), 169-83.

Keele, S. (1972). Attention demands of memory retrieval. *Journal of Experimental Psychology*, *93*, 245-2458. doi: 10.1037/h0032460

Kramer, F. A., Hahn, S., & Gropher, D. (1991). Task coordination and aging: explorations of executive control processes in the task switching paradigm. *Acta Psychologica,* 101 (2-3), 339-378. doi:10.1016/S0001-6918 (99) 00011-6

Kumada, T. & Humphreys, G.W. (2001). Lexical recovery on extinction: Interactions between visual form and stored knowledge modulate visual selection. *Cognitive Neuropsychology, 18,* 465-478

Kusnir, F., & Thut, G. (2012). Formation of automatic letter-color associations in non-synaesthetes through likelihood manipulation of letter-color pairings, *Neuropsychologia*, *50 (14)*, 3641-52. doi: 10.1016/j.neuropsychologia.2012.09.032

Lemercier, C. (2009). Incidental learning of incongruent items in a manual version of the Stroop task. *Perceptual and Motor Skills*.108, 1-12.

MacLeod, M. (1998). Training on integrated versus separated Stroop tasks: The progression of interference and facilitation. *Memory and Cognition, 26 (2)*, 201-211. doi: 10.3758/BF03201133

MacLeod, M. C. (1991). Half a Century of Research on the Stroop effect: An Integrative Review. *Psychological Bulletin, 109 (2),* 163-203. doi: 10.1037//0033-2909.109.2.163

McClain, L. (1983a). Color priming effects Stroop interference. *Perceptual and Motor Skills, 56*, 643-651. doi: 10.2466/pms.1983.56.2.643

McClain, L. (1983b). Effects of response type and set size on Stroop color-word performance. *Perceptual and Motor Skills, 5*6, 735-743. doi: 10.2466/pms.1983.56.3.735

Melara, R.D., & Algom, D. (2003). Driven by Information: A Tectonic Theory of Stroop Effects. *Psychological Review*. 110 (3), 422–471. doi: 10.1037/0033-295X.110.3.422.

Musen, G., & Squire, L. R. (1993). Implicit learning of color–word associations using a Stroop paradigm. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 19, 789-798.

Pritchatt, D. (1968). An investigation into some of the underlying associative verbal processes of the Stroop color effect. *Quarterly Journal of Experimental Psychology*, *20*, 351-359. doi: 10.1080/14640746808400174.

Rappaport, S.R., Humphreys, G.W. & Riddoch, M.J. (2013) The attraction of yellow corn: Reduced attentional constraints on coding learned conjunctive relations. *Journal of Experimental Psychology: Human Perception and Performance, 39,* 1016-1031.

Rappaport, S.R., Riddoch M.J., & Humphreys, G., W, (2011). Disruptive effects of diagnostic colour at different levels of processing: Evidence for intertwined colour-shape object representations. *Perception, 40,* ECVP Abstract Supplement, page 78.

Regan, J. E. (1981). Automaticity and Learning: Effects of familiarity on naming letters. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 180-195. doi: 10.1037/0096-1523.7.1.180

Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of Experimental Psychology*, *81(2)*, 275-280. doi: 10.1037/h0027768

Risko, F. E., Stolz, A. J., & Besner, D. (2005). Basic processes in reading: Is visual word recognition obligatory? *Psychonomic Bulletin & Review*, *12(1)*, 119-124. doi: 10.3758/BF03196356

Schmidt, J. R. (2013). The parallel episodic processing (PEP) model: dissociating contingency and conflict adaptation in the item-specific proportion congruent paradigm. *Acta Psychologica*, *142*, 119–126. doi: 10.1016/j.actpsy.2012.11.004

Schmidt, J. R., & Besner, D. (2008). The Stroop effect: why proportion congruent has nothing to do with congruency and everything to do with contingency. *Journal of Experimental Psychology: Learning Memory cognition, 34(3)*, 54-23. doi: 10.1037/0278-7393.34.3.51

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *Prime user's guide*. Pittsburgh, PA: Psychology Software Tools, Inc.

Sichel, J. R. & Chandler, K. A. (1969). The color-word interference test: The effects of varied color-word combinations upon verbal response latency. *Journal of Psychology, 72*, 219-231.

Sohn, Myeong-Ho., & Anderson, R. J. (2001). Task Preparation and Task Repetition: Two components model of Task Switching. *Journal of Experimental Psychology: General, 130 (4)*, 764-778. doi: 10.1037//0096-3445.130.4.764

Strobach, T., Liepelt, R., Schubert, T., Kiesel, A. (2011). Task Switching: effects of Practice on Switch and Mixing costs. *Psychological Research*. doi: 10.1007/s00426-011-0323-x.

Stroop, J. R. (1935). Studies of Interference in Serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662. doi: 10.1037/h0054651

Unsworth, N., & Spillers, G. J. (2010). Working memory capacity: Attention control, secondary memory, or both? A direct test of the dual-component model. *Journal of Memory and Language*. 62, 392–406

Wheeler, D. D. (1970). Processes in word recognition. *Cognitive Psychology*, *1 (1)*, 59-85. http://dx.doi.org/10.1016/0010-0285(70)90005-8

White, B. W. (1969). Interference in Identifying attributes and attribute names. *Perception and Psychophysics, 6*, 166-168. doi: 10.3758/BF03210086

Wylie, G., & Allport, A. (2000). Task switching and the measurement of "Switch costs". *Psychological Research*, *63*, 212-233.

Yeung, N., & Monsell, S. (2003). The effects of Recent Practice on Task Switching. *Journal of Experimental Psychology: Human Perception and Performance, 29 (5)*, 919-936. doi: 10.1037/0096-1523.29.5.919

(Manuscript received: 3 February 2014; accepted: 26 September 2014)