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Chris Koch
George Fox University, ckoch@georgefox.edu

Joetta Gobell

Gale H. Roid

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EXPLORING INDIVIDUAL DIFFERENCES IN STROOP PROCESSING WITH CLUSTER ANALYSIS

Target Article on Stroop-Differences

Christopher Koch, Joetta Gobell, & Gale H. Roid
Department of Psychology
George Fox University
414 N. Meridian St.
Newberg OR 97132 USA
http://www.georgefox.edu/people/faculty/ckoch/

ckoch@georgefox.edu

Abstract

A relatively small number of studies of the Stroop task has examined individual differences in age, sex, hemispheric processing, and language. The amount of interference is the primary dependent measure in most studies, not the factors that contribute to the interference. In the present target article, cluster analysis is used to identify groups of participants who respond similarly on the Stroop task. Integrated color-word Stroop stimuli were presented for varying durations in the first study. Significant individual differences were found. A cluster analysis identified two groups of subjects. One group responded consistently across durations and conditions while the other responded more erratically. Potential sources of individual differences were examined in a second study. 120 subjects were given the Color and Word Test along with selected subtests of the Stanford Binet Intelligence Test, age appropriate Wechsler tests, and the Detroit Tests of Learning Aptitude. Again, cluster analysis found two groups of subjects. The group with higher scores on visual reasoning and short-term memory produced more interference.

Keywords

cluster analysis, individual differences, short-term memory, Stroop interference, visual reasoning

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    Koch/Gobell/Roid: INDIVIDUAL DIFFERENCES IN COLOR STROOP

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AUTHORS' RATIONALE FOR SOLICITING COMMENTARY: We have found a
pattern of individual differences on the Stroop color-word test
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that do not seem to be among those reported previously (MacLeod,
1991). Two separate attempts to identify the source of these
individual differences have failed, although we kept finding the
same patterns of responding. We hope the article will draw
attention to the need to examine individual differences in Stroop
processing and and that the Psycoloquy it elicits will help
identify their basis.
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I. INTRODUCTION.

1. The Stroop color-word task requires participants to name the color print of a color word. The color word is either congruent or incongruent with the color print (Stroop, 1935). When the color word (e.g., RED) is congruent with the color print (e.g., red), the RT for naming the color print decreases, compared to a control condition in which the color of a color patch is named. This is referred to as Stroop facilitation. However, when the color word (e.g., BLUE) is incongruent with the color print (e.g., red) the RT for color naming increases. This is referred to as Stroop interference. The vast majority of research regarding the Stroop task has focused on why facilitation and interference occur. Relatively little research has addressed individual differences on this task (cf. MacLeod, 1991). The research that has been conducted on individual differences with the Stroop task has primarily examined sex, age, hemispheric differences, and language.

2. Several researchers have found no sex differences on the Stroop task (Golden, 1974; Sladekova & Daniel, 1981). A clear trend has been found for age differences, however, with the amount of Stroop interference following an S-shaped function. Interference is minimal for children in the first grade and gradually increases through second and third grades (Schiller, 1966). Stroop interference then declines through adulthood until approximately 60 years of age, when interference increases again (Comalli, Wapner, & Werner, 1962). The initial increase in Stroop interference in children has caused several researchers to explore the relationship between reading ability and interference (e.g., West & Stanovich, 1978; Wilder, 1969). Although Warren and Marsh (1978) found no hemispheric differences, and Long and Lyman (1987) found greater interference in the right hemisphere, the literature suggests that more interference occurs in the left hemisphere than the right (Schmidt & Davis, 1974; Tsao, Feustal, & Soseos, 1979; Cohen & Martin, 1975; Toma & Tsao, 1985; Lupker & Sanders, 1982). Finally, Preston and Lambert (1969) and Dyer (1971a) found interference between the two languages of bilinguals, but not to the same magnitude of within language interference. Although these studies provide some information regarding individual differences on the Stroop task, the range of factors contributing to individual differences is fairly small. For instance, no research has examined differences due to personality or various cognitive abilities (e.g., working memory, spatial reasoning).

3. Repeated measures ANOVA is used when subjects receive all levels of the factors manipulated in a study. The benefit of the repeated measures design is that individual differences do not contribute to between treatment variability and are statistically eliminated as a source of within treatment variability. Individual differences within treatment conditions contribute to between subjects variability. Although individual differences are not analyzed as part of the repeated measures ANOVA, between subjects effects are analyzed separately in SPSS. Significant between subjects effects suggest that there are significant individual differences within treatment conditions (Norusis, 1993).

4. Perhaps one reason why relatively little individual difference research has been conducted on the Stroop task is because these studies have generally focused on the amount of interference, rather than the factors that contribute to it. Since interference is typically calculated by subtracting the RT for the control condition from the RT for the experimental conditions (i.e., congruent and incongruent), a within-subjects design is used in most Stroop research. The benefit of this is that individual differences do not contribute to between treatment variability and are statistically eliminated as a source of within treatment variability. However, individual differences within treatment conditions contribute to between subjects variability. Although individual differences are not analyzed as part of the repeated measures ANOVA, between subjects effects are analyzed separately in SPSS. Significant between subject effects suggests that there are significant individual differences within treatment conditions (Norusis, 1993).

5. Shih & Sperling (1994) note that problems arise with ANOVA when looking at more than one dependent variable or when there is variation from one session to another. They suggest that cluster analysis be used to identify homogeneous subgroups that can then be compared on the performance task. They also suggest that ANOVA be conducted to find statistical significance, and that cluster analysis be used as an analytical tool to find homogeneous subgroups based on

performance. Similarly, cluster analysis may be used to identify subgroups of individuals who perform differently on the same task.

6. This target article explores the use of cluster analysis as an analytical tool for detecting subjects who contribute to between-subjects effects or effects due to individual differences. In the first study, a color-word Stroop task using the duration approach developed by Koch and Brown (1992; Koch & Brown, submitted) was used to examine individual differences in RT. This version of the Stroop task presents integrated color-word stimuli for varying durations. Past research examining differences in Stroop processing over time, however, have separated the color and word dimensions by time (e.g., Dyer, 1971b). Although researchers have examined individual differences in Stroop processing (e.g., Naish, 1980; West & Stanovich, 1978), no one has examined individual differences in Stroop tasks which manipulate stimulus duration. In the second study, individual differences due to various cognitive abilities were examined on a standardized color-word Stroop task.

II. STUDY ONE.

II.i. METHOD

II.ii. SUBJECTS

7. Eleven undergraduates from the University of Georgia participated in the experiment for class credit. All subjects had normal or corrected to normal visual acuity and normal color vision.

II.iii. APPARATUS

8. Color-word Stroop stimuli were presented on a CRT monitor using Graves & Bradley's (1988) timing and screen control routines that allow the PC to be used as a tachistoscope and record response times with millisecond accuracy. Response times were measured from stimulus offset to a key press. Four keys were used corresponding to the four colors presented in the experiment. Red and green were coded with the middle and index fingers of the left hand using the "z" and "x" keys respectively. Similarly, yellow and blue were coded using the right hand and the "." and "/" keys. Stimuli were presented at a fixed viewing distance of 103 cm. The longest word (YELLOW) subtended 1 deg VA (w). All words subtended .17 deg VA (h). Color values were determined photometrically at .1 foot lamberts.

II.iv. DESIGN

9. In a 3 x 10 repeated measures design the word type and stimulus duration were varied. The three word types were: color congruent (CC), color incongruent (CI), and color neutral (N). Stimulus duration ranged from 40 to 1000 msec (40, 60, 80, 100, 120, 160, 200, 300, 500, 1000).

II.v. PROCEDURE

10. Subjects first learned the coding scheme by pressing the appropriate key when blocks of color were presented at fixation for 100 msec. A 90% accuracy rate was necessary to continue. All subjects met this criterion. Next, subjects were shown each word used in the experiment in white print at fixation for 20, 40, 60, and 80 msec. They were required to name the words. This was done to ensure that subjects could read the color-word stimuli when presented for short durations. Although less than 5% of the words were correctly identified when presented for only 20 msec, approximately 50 percent of the words were correctly identified at 40 msec, 80% at 60 msec, and 90% at 80 msec.

11. Subjects were then instructed that words were going to appear in different colors and that they were supposed to press the key corresponding to the color of the color-word stimulus as quickly and as accurately as possible. CC, CI, and N stimuli were randomly presented. Stimulus duration also varied randomly. There were 150 practice trials followed by 300 experimental trials.

II.vi. RESULTS & DISCUSSION

12. Consistent with previous research (Koch & Brown, 1992; Koch & Brown, submitted), a 3 x 10 repeated measures ANOVA yielded a significant main effect of word type ($F(2, 20)=6.29$, $p<.008$) and stimulus duration ($F(9, 90)=40.69$, $p<.001$) and a significant interaction between word type and stimulus duration ($F(18, 180)=3.2$, $p<.001$). Response times for CC and N stimuli were faster than response times for CI stimuli. Also, response times decreased as stimulus duration increased (Table 1).

TABLE 1. Median RTs across stimulus conditions and durations for all subjects, the seven consistent subjects, and the four inconsistent subjects.

Duration	Color Congruent	Color Incongruent	Color Neutral
	All Subjects		
40	870.00	1044.20	855.86
60	797.20	1006.89	843.50
80	773.00	818.83	791.00
100	802.00	654.60	900.25
120	743.40	784.70	830.80
160	752.80	799.60	711.70
200	676.22	819.80	774.22
300	675.60	687.90	620.40
500	638.90	666.30	755.00
1000	563.90	538.00	533.50
	Consistent Subjects		
40	868.50	1210.00	855.86
60	797.20	923.11	854.70
80	722.60	784.67	793.10
100	802.00	742.00	956.50
120	743.40	745.00	808.80
160	752.80	824.10	711.70
200	676.22	823.30	766.80
300	707.50	687.90	685.10
500	638.90	680.50	755.00
1000	593.80	638.90	580.80
	Inconsistent Subjects		
40	877.57	917.70	878.82
60	719.00	1053.80	734.32
80	799.84	853.02	750.50
100	816.13	627.67	708.72
120	738.78	945.05	903.00
160	746.45	741.50	714.71
200	632.76	603.17	832.45
300	641.45	726.73	583.00
500	594.64	631.35	690.75
1000	521.70	365.45	487.25

13. There was a significant between-subjects effect ($F(1, 10)=433.24$, $p<.001$), however. Since this effect suggests significant differences between subjects, it is important to identify which subjects are different from others. Identifying a subject or group of subjects that respond differently from the majority has sometimes been done by visually inspecting plots of response times for subject and "seeing" which subjects "looked" different. Plots for two subjects are presented in Figures 1 and 2. Subject 3 (Figure 1) appears different from subject 2 (Figure 2). Although this type of visual inspection can be informative, it is subjective. Therefore, a hierarchical cluster analysis using the squared-Euclidean distance and the nearest neighbor method was conducted using the response times from all word types across all durations for each subject (SPSS CLUSTER; Norusis, 1993). The cluster analysis identified four subjects (subjects 1, 3, 6, and 9) who seemed to respond differently than the rest (Figure 3). Examining the response time plots for each subject suggests that the four "different" subjects identified in the cluster analysis displayed greater variability in RTs across stimulus durations (Figure 1) while the seven subjects who formed the other cluster responded more consistently across stimulus durations (Figure 2).

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FIGURE 1 (Koch). INDIVIDUAL VARIATION IN RESPONSE TIME (Subject
3). Subjects of this kind (4 in all) displayed greater variability
in Reaction Times (RTs) across Stimulus Durations. (Reaction Time
vs. Stimulus Duration for Color-Congruent, -Incongruent, and
Neutral Conditions.)
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ftp://www.cogsci.soton.ac.uk/pub/psycoloquy/1999.volume.10/Pictures/koch2.html

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FIGURE 2 (Koch). INDIVIDUAL VARIATION IN RESPONSE TIME (Subject 2).
Subjects of this type (7 in all) responded more consistently across
Stimulus Durations.  (Reaction Time vs. Stimulus Duration for
Color-Congruent, -Incongruent, and Neutral Conditions.)

             Rescaled Distance Cluster Combine

  C A S E      0         5        10        15        20        25
Label     Num  +---------+---------+---------+---------+---------+

Case 2      2   -+-----+
Case 4      4   -+     |
Case 10    10   -------+---+
Case 5      5   ---+-+ |   |
Case 8      8   ---+ +-+   +-+
Case 7      7   ---+-+     | |
Case 11    11   ---+       | +---+
Case 6      6   -----------+ |   +--------------------------------+
Case 9      9   -------------+   |                                |
Case 3      3   -----------------+                                |
Case 1      1   --------------------------------------------------+

FIGURE 3. Denogram for the cluster analysis identifying the seven
consistent and four inconsistent subjects. Distances are rescaled
to numbers between 0 and 25. Vertical lines (+ and |) demarcate
clusters of individuals.
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14. We performed a second 3 x 10 repeated measures ANOVA using the seven subjects who clustered together and eliminating the four subjects who appeared to respond erratically across stimulus durations (Table 1). Results were similar to those with all 11 subjects. There was a significant main effect of word type ($F(2, 12)=10.68$, $p<.002$) and stimulus duration ($F(9,54)=32.76$, $p<.001$) and a significant interaction between word type and stimulus duration ($F(18, 108)=3.53$, $p<.001$). However, the effect size, measured by eta-squared (Hays, 1988, Kerlinger, 1986), increased for each effect (Table 2). Therefore, eliminating the four erratic subjects did not change the overall results of the experiment but did increase the size of each effect.

TABLE 2. Changes in effect size due to eliminating four erratically responding subjects.

Effect	All Subjects	Eliminating Four Erratic Subjects
Word Type	.386	.640
Stimulus Duration	.803	.845
Interaction	.242	.370

15. Unfortunately, eliminating the four erratic subjects did not eliminate the significant between-subjects effect ($F(1, 6)=731.78$, $p<.001$). A third repeated measures ANOVA was conducted covarying the response times for each word type presented for 40 msec (n=11). As in the two previous analyses, there was a significant main effect word type ($F(2, 20)=4.19$, $p<.03$) and stimulus duration ($F(8, 80)=29.91$, $p<.001$) and a significant interaction between word type and stimulus duration ($F(16, 160)=2.57$, $p<.001$). Between-subjects effects, however, were eliminated. This finding suggests processing speed is a potential individual difference for Stroop processing (c.f., Schooler, Neumann, Caplan, & Roberts, 1997).

16. In summary, this study shows that individual differences exist on the Stroop task using the duration approach and that cluster analysis is a useful tool for identifying these similarly responding subjects. However, the source of these individual differences is still unknown. The fact that between subjects effects were eliminated when the response times at the shortest stimulus durations were used as a covariate in an ANCOVA suggests that processing time may be one source of individual differences. Chaiken (1994) provides some support for this hypothesis by finding that inspection time is related to both intelligence and to speed related processing (e.g., visual search).

17. However, the findings from this study need to be interpreted cautiously due to the relatively small sample size for examining individual differences. In addition, the study was designed in such a way that explanations regarding individual differences were made post hoc without sufficient information regarding potential individual differences. This is typical of most experimental Stroop research because the interference effect is the focus of the research not the differences that exist between subjects. In order to account for these two problems a second study was conducted in which the sample size was increased and individual differences due to various cognitive factors were explored.

III. STUDY TWO.

III.i Method

III.ii. Subjects

18. 120 subjects were obtained from a stratified random sample of all census regions in the United States as part of a larger data collection project (Roid & Miller, 1997). Ages ranged from 32 months (2 years and 8 months) to 269 months (22 years and 5 months). The sample was approximately half male (56%) and half female (44%). Finally, the sample was ethnically diverse with 43% Caucasian, 23% African American, 24% Hispanic, 3% Asian, 5% Native American, and 1% other. All subjects had normal color vision.

III.iii. Instruments

19. Subtests from three measures of intelligence were administered. The measures of intelligence included the Stanford Binet: Fourth Edition (SB:FE), the Wechsler tests, and the Detroit Tests of Learning Aptitude-3 (DTLA-3). Subjects below the age of 6 were given the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-R). Subjects between the ages of 6 and 16 were given the Wechsler Intelligence Scale for Children-Third Edition (WISC-III). The Wechsler Adult Intelligence Scale Revised (WAIS-R) was given to subjects ages 16 and older. Subtests from the SB:FE included matrices, paper folding and cutting, bead memory, and memory for objects. Wechsler subtests used in the study included picture completion, coding, block design, and digit symbol. Finally, the picture fragment and design sequence subtests of the DTLA-3 were administered. Golden's (1978) Color and Word Test was used to assess Stroop interference.

III.iv. Procedure

20. 60 school psychologists who were experienced examiners with graduate-level training on administering the SB:FE, the Wechsler Intelligence tests (WPPSI, WISC-III, and WAIS-R), and the Stroop Color Word Test collected the data in this study. Examiners were given sampling instructions for their individual regions throughout the country during a four-day training workshop.

21. Demographic information was recorded. Subjects were given the SB:FE, the appropriate Wechsler test, and the DTLA-3. All subjects completed the instruments in this order. After the intelligence measures were completed, the three page Stroop and Color Word Test was administered with the Word Page first followed by the Color Page and the Word-Color Page. Each page consisted of a 5 x 20 matrix of words or colors. Figure Xs appeared in either red, green, or blue print on the Color Page. The words RED, GREEN, and BLUE were presented in black print on the Word Page. Finally, the words RED, GREEN, and BLUE were presented in incongruent red, green, or blue print on the Word-Color Page. Subjects were instructed to correctly name the color print of each item on the Color Page and Word-Color Page and to correctly name the color words on the Word Page. There was a 45 sec time limit for each page.

III.v. Results & Discussion

22. Interference scores were determined by subtracting the number of correctly identified items on the Word-Color Page ($M = 30.83$, $SD = 12.50$) from the number of correctly identified items on the Color Page ($M = 53.62$, $SD = 16.53$). A

mean difference score of 22.79 (SD = 11.01) was found between the two conditions suggesting Stroop interference.

23. Hierarchical cluster analysis was conducted using the Ward's method in order to identify subjects who had similar interference scores. The analysis resulted in two groups. 34 subjects clustered into Group 1 and 27 clustered into Group 2 (59 either did not cluster into these two groups or had missing data). The data was then coded for these two groups. Mean interference was 19.12 (SD = 6.31) for Group 1 and 29.11 (SD = 10.00) for Group 2. Thus, Group 1 showed significantly less interference than Group 2 ($t(59) = 4.76$, $p < .001$).

24. Several demographic variables were examined to determine the source of individual differences between these two groups. No differences were found for gender, ethnicity, educational level of the father, and rural versus urban homes. However, there was a significant age difference ($t(59) = 9.15$, $p < .001$). The median age for Group 1 was 108 months (SIR = 14.5) while the median age for the Group 2 was 196 months (SIR = 24). Interestingly, these results appear opposite of Comalli, Wapner, & Werner (1962) and Schiller (1966) who found that interference increases with age until 8 to 10 years at which point interference peaks and tends to decrease throughout adulthood until approximately 60 years of age when interference begins to increase once again. In addition, there is an overall correlation between age and interference scores ($r(59) = .40$, $p < .002$) in the present study again suggesting that interference increases with age. A closer examination of the relationship between age and interference in the two groups reveals two nonsignificant correlations in opposite directions. Group 1 ($r(32) = .12$, NS) shows a slight increase in interference while Group 2 ($r(25) = -.09$, NS) shows a slight decrease in interference. Therefore, the interference trend for Group 2 appears consistent with children 8 to 10 years of age through adulthood in previous research and Group 1 appears consistent with children below the age of 10.

25. These two groups also differed on several components of intelligence. Group 2 had higher scores than Group 1 on the matrices ($t(57) = 6.38$, $p < .001$), bead memory ($t(58) = 7.19$, $p < .001$), and memory for objects ($t(58) = 5.65$, $p < .001$) subtests of the SB:FE. Group 2 also scored higher than Group 1 on the picture completion ($t(47) = 4.48$, $p < .001$), coding ($t(40) = 5.95$, $p < .001$), and block design ($t(47) = 3.38$, $p < .001$) tasks within the Wechsler tests. Finally, Group 2 scored higher than Group 1 on the design sequence ($t(40.84) = 7.43$, $p < .001$) subtest of the DTLA-3. The results from the various subtests of the three intelligence measures suggest that subjects with greater perceptual reasoning and short-term memory show more interference. Thus, differences in Stroop processing related to age may be mediated by cognitive factors such as perceptual reasoning and short-term memory.

IV. GENERAL DISCUSSION.

26. Although some researchers have explored individual differences on the Stroop task, the majority of Stroop research disregards them. This may be because individual differences are not really the focus of these studies and because the within-subjects designs typtically used tend to minimize the statistical effect of individual differences. The present studies suggest that cluster analysis can be used to identify groups of subjects with similar patterns of Stroop interference. It appears to pick out two groups of subjects on the Stroop task regardless of task (computerized versus paper) or dependent variable (RT versus number of correct). RT differences (Study 1) may be due to processing speed, whereas accuracy (Study 2) may be depend on cognitive ability differences as measured by standard intelligence tests. Carroll (1980) found that speed and ability account for approximately 77% of the variance on speeded tasks.

27. Additional research is required to determine the source of individual differences in Stroop processing and when they appear. Previous research has almost exclusively focused on sex, age, and hemispheric differences (MacLeod, 1991). Examining processing time and cognitive ability as contributors to between-subjects effects will not only provide greater insight into Stroop processing but will also represent a major departure from past research exploring individual differences on the Stroop task.

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