Psihološka obzorja / Horizons of Psychology, 13, 2, 105-114 (2004)

Znanstveni empirično-raziskovalni prispevek

The mode of response and the Stroop effect: A reaction time analysis

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Abstract: While the classical card versions of the Stroop colour-word tasks employ verbal mode of response (the participants have to read the stimuli or name their ink colour aloud), the single-item computerised versions of the task frequently rely on manual mode of response (the participants need to signal the meaning of the stimuli or its ink colour by pressing the appropriate key). An experiment was carried out to directly assess possible ERP and reaction times differences between a verbal and a manual response mode version of the task. The comparison of reaction time results obtained on 22 students of psychology performing both verbal and manual response mode version of the task show longer reaction times for the manual version as well as important differences between the patterns of reaction times of individual conditions obtained in each version of the task. The result demonstrated a qualitative difference between the two versions of the task, which can be attributed to a stronger influence of automatic word reading in the verbal response mode version. The differences shown warn against a direct comparison of results obtained with different response mode versions of the Stroop colour-word task.

Key words: Stroop color word test, attention, reaction time, verbal response, test forms

Način odgovarjanja in Stroopov učinek: analiza reakcijskih časov

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Povzetek: Pri klasični verziji Stroopovega testa, v katerem povezujemo barvo in besedo, ki to barvo označuje ali pa ne, se običajno poslužujemo verbalnega načina odgovarjanja, kar pomeni, da mora udeleženec glasno brati dražljaje ali povedati barvo, v kateri so ti natisnjeni. Računalniška verzija testa pa sloni na ročnem, torej gibalnem načinu odgovarjanja, pri čemer udeleženec pomen dražljaja ali barve, v kateri je napisan dražljaj, označiti s pritiskom na ustrezno tipko. Izvedli smo preizkus, v katerem smo ocenili morebitne razlike med verbalno in ročno verzijo Stroopove naloge v elektroencefalogramsko posnetih možganskih valovih ERP ter v reakcijskih časih odgovarjanja. Primerjava izsledkov analize reakcijskih časov, izmerjenih pri 22 udeležencih, študentih psihologije, ki sta jim bili prezentirani obe verziji testa, kaže daljše reakcijske čase na ročni verziji kakor tudi pomembne razlike med vzorci reakcijskih časov v posameznih merskih pogojih na obeh verzijah testa. Rezultati nakazujejo na pomembne

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kvalitativne razlike med obema verzijama, ki bi jih lahko pripisali močnejšemu vplivu avtomatskega branja besed pri verziji z verebalnim odgovarjanjem. Razlike tudi opozarjajo na nevarnost neposrednega primerjanja rezultatov, ki smo jih dobili z dvema različnima verzijama Stroopovega testa.

Ključne besede: Stroopova naloga, pozornost, reakcijski časi, verbalni odgovor, oblika testa

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Since the ingenious idea of John Ridley Stroop (1935) to combine two competing aspects of a stimulus in a single task, the Stroop interference effect, expressed as a difference between the time needed to name the colour of a neutral stimuli (a colour patch) and the time to name the ink colour of an incongruent colour word (e.g. word „RED“ printed in green ink), has proved to be a useful tool in exploring attentional processes as well as an exciting subject of study in and of itself. The original experiment (Stroop, 1935) was conducted using a list of stimuli printed on a paper card. The task of the participants was to either name the colours of the stimuli or read the words listed on the card aloud as fast as possible. The time needed for processing an individual item could then be calculated by dividing the time recorded by the number of the stimuli on the card. The card version of the test and its variations have been used in an impressive number of studies providing an important body of empirical results and findings related to the Stroop task and its cognitive underpinnings (for a comprehensive review see MacLoad, 1991). To be able to obtain more detailed information about the reaction times of processing involved in the Stroop task, and combine it with additional measurements, like EEG and fMRI, a single-item version of the task was developed. At first technically rather complicated designs were shortly made easier by employing personal computers for both the presentation of the stimuli and reaction time recording.

With the development of computerised versions of the task two response modes were used. A verbal response mode equivalent to the original version of the task was enabled using a voice key device, registering the onset of a verbal response and signalling the computer recording the reaction times. Along with verbal response mode, manual response mode has become frequently used as well. The task of participants in the manual version of the task is to respond by pressing a predefined key, signalling the colour of the stimuli or the meaning of the word.

The manual response mode version of the task depends on the appropriate colour-name - key and word - key mapping and so introduces an additional processing demand on the participant, possibly changing the nature of the Stroop task itself. Initial studies employing manual versions of the task consistently reported of a smaller but still robust Stroop interference (for a review see MacLoad, 1991). Recently the manual and verbal response mode versions of the task were directly compared in a study by Liotti, Woldorff, Perez III and Mayberg (2000). Using overt verbal, covert verbal and manual responses while recording scalp ERPs, the authors noted that both

response modalities yielded robust Stroop interference while provoking a significantly different scalp distribution of the incongruent vs. congruent ERP difference wave, suggesting two independent dipole generators in anterior cingulate cortex.

The Stroop task, both in the original card form as well as its single-item incarnations, is today a widely used research and diagnostic tool providing a view into the cognitive and neural anatomy of attention. Many studies rely on the Stroop task to assess differences in attentional processes between groups (e.g., Schooler, Neumann, Caplan and Roberts, 1997; Spieler, Balota and Faust, 1996) or individual experimental conditions (e.g., Edwards, Brice, Craig and Peri-Jones, 1996; Ilan and Polich, 1999). For the comparisons to be valid, the tasks used have to be comparable and measure the same aspects of the attentional processes.

With an ever-growing number of variations of single-trial computer versions of Stroop interference tasks, one has to take into account that even though robust, the magnitude of the Stroop interference effect depends importantly on the specific design of the task, as do the actual reaction times and the brain regions involved as well. The complexity of processes involved in the Stroop tasks and the variability of results due to small changes in the experimental design (for review see MacLoad, 1991), are of crucial importance when interpreting the results of an individual study, and even more so when comparing the results between two or a number of studies. Uncontrolled moderating variables could lead to either potentiation or masking of apparent differences in the measured Stroop effect.

The aim of the study was to test in what way does the difference in the response mode (verbal vs. manual) affect the reaction times and the event related potentials (ERP) related to individual stimuli type in the single-item computer version of the Stroop colour-word task. To be able to get a comprehensive insight into possible differences, five types of stimuli were employed. The usual triplet of neutral, incongruent and congruent stimuli, was expanded to include two types of neutral control stimuli, nonword ("XXXXX") and word stimuli matched in length and frequency to colour target words, and a word reading stimuli consisting of colour words printed in grey.

Due to the additional task of translating the colour names to appropriate key presses in the manual response mode version of the task, we expected the reaction times there to be somewhat longer than in the verbal response mode. Next to a general slowing of responses we also expected a qualitative difference in the pattern of the measured Stroop interference and facilitation effects. Since the verbal responses are much strongly related to reading, we expected relatively faster reaction times in this response mode in word reading trials, while at the same time expecting longer reaction times for the incongruent as well as word neutral stimuli due to a stronger influence of automatic reading, presenting bigger need for the inhibition of the inappropriate response, and therefore resulting in a larger Stroop interference effect. Even though ERPs were recorder, only the results of reaction time analysis are presented in this report.

Method

Participants

22 undergraduate students (M age = 20.1 years, SD = 1.4, range = 19-24) recruited at the Department of Psychology, University of Ljubljana, participated in the experiment. All the participants had normal or corrected-to-normal eyesight.

Materials

Each participant completed two tasks, one using verbal and another using manual response mode (keyboard), each task made of 11 blocks. The first was a training block of 18 randomly presented nonword neutral trials ("XXXXX" presented in red, blue or green). The second was also a training block of 15 randomly selected trials this time employing all the possible types of stimuli. The rest nine blocks consisted of 45 trials presented in a quasi-random order, taking care that no colour and no type of stimuli used was presented twice in a row. The stimuli used were nonword neutral stimuli ("XXXXX" printed in red, green and blue), word neutral stimuli matched in frequency and length to the target colour words ("BALET" - *the ballet*, "BURJA" - *a type of wind*, "NOVELA" - *a short story*, printed in red, green and blue), congruent stimuli ("RDEČA"- *red*, "ZELENA" - *green*, "MODRA" - *blue,* printed in the matching colour), incongruent stimuli ("RDEČA", "MODRA", "ZELENA", printed in incongruent colour), and word-reading stimuli ("RDEČA", "MODRA", "ZELENA", printed in grey). Each of the type of stimuli used was presented in an equal proportion - 9 per block.

ERP recording

EEG activity was recorded using Ag/AgCl electrodes attached using creme and tape on the Fz, Cz and Pz positions (employing the international 10-12 system), with the reference electrodes attached to the left and right earlobe and the ground in the right temporal area. Electrooculographic (EOG) activity was recorded bipolarly with electrodes attached 2 cm laterally and 2 cm above the right eye. To reduce the EOG activity the participants were asked not to avert their gaze from the screen centre during the experiment. The recordings were amplified by factor 60 000, 1-100 HZ filters were used, individual resistances did not exceed 5kOhm. For every trial 2048 samples were recorded with 1 kHz sampling frequency, starting at 83 ms interval before the presentation of the stimulus.

Procedure

Each participant was tested individually. Stimuli were presented on a 21" Sony computer monitor controlled by a personal computer running Windows 98 operating system. Participants were told that they would be presented by a series of stimuli printed in colours red, green or blue. Their task was to name the colour in which the stimuli were presented by speaking the names out loud (verbal response mode) or pressing the appropriate button on the keyboard (manual response mode). Some of the stimuli would be presented in grey, in which case they should read the presented word out loud (verbal response mode) or again press the appropriate button on the keyboard (manual response mode). Their responses are to be as quick and accurate as possible. Every stimulus remained on the screen until a response was recorded, but not longer than 12 seconds, a new stimulus then followed after the delay of 2200, 2400 or 2600 milliseconds. The accuracy of the responses were recognised automatically in the manual response mode and were recorded by the experimenter in the verbal response mode.

The time of stimulus onset and responses were co-registered with the EEG signal. In the case of manual responses the time of response was registered by a signal from the computer triggered by a keyboard key press. In the case of verbal response mode, response was co-registered using a microphone attached to the EEG preamplifier. The reaction times for each trial were then extracted using custom made software looking for a significant change in the co-registered signal.

To control for the possible effect of training, half of the participants were first tested using the verbal response mode and the other half using the manual response mode. After the successful completion of the first task, the first half then continued with the manual response mode and the other half with the verbal response mode.

Results

From all the measurements made, first all the trials with response not occurring within the 2-second window of ERP recording were rejected. Second, fastest 6 and slowest 12 reaction times of 81 measurements made with every type of trial for each of the versions of the task used, were eliminated from further analysis to remove the influence of possible outliers. All further analyses were made on the mean reaction times for every trial type at every version of the task for every participant.

To first get a general overview of the reaction times, mean averages were computed and are presented in Figure 1. To test for general differences in reaction times a two-way analysis of variance (ANOVA) was computed, with both Response Mode and Trial Type as within-subject factors. The ANOVA revealed both main effects to be statistically significant, with manual responses yielding slightly longer

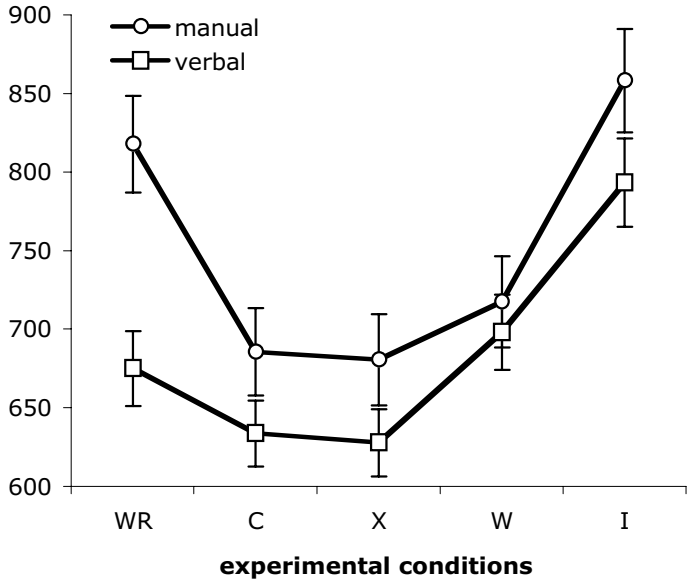

Figure 1: Mean reaction time for individual experimental conditions (WR - word reading, C - congruent, X - nonword neutral, W - word neutral, and I - incongruent) for manual and verbal response mode version of the Stroop task. Error bars represent the standard error of the mean.

reaction times ($F(1, 21) = 10.27$, p=0.0042) and different trial types giving different times to response ($F(4, 84) = 65.97$, p=0.0000). Analysis of variance also revealed a significant Response Mode X Trial Type interaction ($F(4, 84) = 20.40$, p=0.0000) leading to a conclusion that manual response mode did not only take additional processing time but also a qualitatively different pattern of differences among the processing times for individual trial types.

To further investigate the differences in the response times obtained in the verbal and manual response mode versions of the task, the reaction times were translated to individual estimates of Stroop interference and facilitation effects (Figure 2), the possible differences between them were then tested for using two-tailed t-test for dependent samples. The tests revealed no differences in the amount of either Stroop interference ($t(21) = 0.84$, $p = 0.4074$) or Stroop facilitation ($t(21) = 0.09$, $p = 0.9239$) when compared to nonword control stimuli. Compared to word control stimuli though, the interference was significantly higher in the manual response mode ($t(21) = 3.38$, $p = 0.0028$) while facilitation was commensurately smaller ($t(21) = 3.74$, $p = 0.0012$). To round up the comparison of the differences, both the interference due to verbal processing of a word control stimuli, as measured against nonword control stimuli, as well as switching to word reading, as compared to nonword control stimuli, showed a

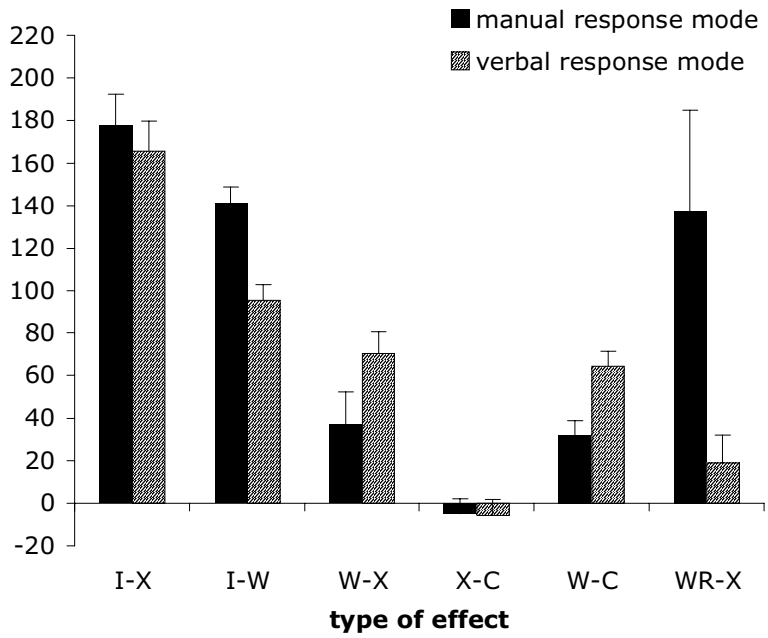

Figure 2: The differences in reaction times between individual trials for manual and verbal response mode version of the Stroop task (I-X - interference effect as measured against nonword control stimuli, I-W - interference effect as measured against word control stimuli, W-X the interference due to the verbal nature of word control stimuli as measured against nonword control stimuli, X-C - facilitation as measured against nonword control stimuli, W-C - facilitation as measured against word control stimuli, WR-X - the penalty of switching to word reading as measured against nonword control stimuli).

difference of effect due to the response mode used. While the verbal processing interference was smaller in the manual response mode version of the Stroop task ($t(21) = 3.16$, $p = 0.0047$) the reaction time penalty of switching to word reading was much higher ($t(21) = 4.96$, $p = 0.0000$).

Discussion

Consistent with expectation, the results of reaction times analysis of the single-item computer version of the Stroop colour-word task, demonstrated important qualitative differences in the performance on the manual and verbal response mode version of the task. The reaction times obtained showed not only slightly longer reaction times for the manual version of the task, but also important differences in the calculated Stroop interference and Stroop facilitation effects. The observed differences can be

traced to a single change in the pattern of reaction times, namely to the reaction times to the word control stimuli. While both interference and facilitation effects, as measured against the nonword control stimuli, remain comparable in both versions of the task, the relative change in the reaction times to the word control stimuli leads to significant differences in both interference and facilitation, as measured against word control stimuli. While there were significant differences between the reaction times to a word and nonword control stimuli already in the manual response mode version of the task, these became more pronounced in the verbal version of the task. With relatively longer reaction times to the word control stimuli, the interference becomes seemingly smaller and facilitation stronger.

When coupled with the significant differences in reaction times to a word-reading stimuli, which are much shorter in the verbal than in manual response mode version of the task, the observed differences in the reaction times to word control stimuli can be explained by a stronger tendency to a reading response to verbal stimuli in the verbal version of the task. Taking into account the demonstrated dependence of the Stroop interference on the relative automaticity of the tasks involved (MacLeod and Dunbar, 1988) that is strongly influenced by practice (MacLeod, 1998), the finding is easy to understand, as reading is more strongly related to vocal responses than to manual key-presses. A bit puzzling though is the lack of difference in the Stroop interference effect. If reading response is stronger in the case of the verbal version of the task, which prolongs the reaction times to word control stimuli, why does it not prolong the reaction times to incongruent stimuli as well?

A possible explanation of the lack of a stronger interference effect in the verbal response mode version of the task could be a sort of a ceiling effect. We can assume the existence of two milestones in the process of responding to a stimulus. The first marks the point in time when the information provided by the sensory system starts to build a preferential activation of a response. If there is no competing response intention a speeded response is possible right then, and this would be the time when responses to pure colour stimuli can be made. If there is a competing response intention, a response can only be made when there is enough difference in preferential activation between them. The smaller the relation of the competing intention to the response set, the faster can the difference be established and the response initiated. The second milestone would then mark the final time at which the individual characteristics of the stimulus are properly differentiated and the response perhaps even checked by internal monitoring. This would be the time at which even the response intentions competing within the same response set (as is the case with incongruent trials in a Stroop task) would be sufficiently separated to enable the initiation of a proper response. The second milestone would therefore present a relatively fixed point in time of final resolution not being influenced by mediating processes that might potentiate the strength of a competing stimulus intention during the intermediate phase. In this way we would have the response times for pure colour stimuli and pure incongruent stimuli fixed at each end of the response time continuum,

while the position of response times to the colour naming of non-colour related words, colour related words and colour words not in the response set could be positioned rather flexible in between the extremes and accessible to the influence of mediating factors such as the association between reading and response modality.

To conclude, we believe that the pattern of results obtained presents a strong case against mixing and matching different versions of the Stroop colour-word task, in this case a verbal and manual response mode version of the task, when comparing individuals or groups. Especially vulnerable seems to be the use of word control stimuli. As our results prove, the reaction times to non-colour word stimuli not only show a presence of Stroop interference effect, but the effect itself varies with the exact design and implementation of the task. We can only agree with the warning expressed by Barch, Carter, Hachten and Cohen (1999) that *"researchers* [need] *to carefully examine the assumptions underlying the interpretation of 'neutral' conditions in the Stroop, as well as others experimental paradigms.* [...] *'neutral' stimuli may not be truly neutral"* (p. 759). Our suggestion would be to base the estimation of Stroop interference and facilitation effects on the nonword neutral stimuli, but to also include word control stimuli as they might provide additional important information. Should we not include them in our design, it would not have shown important differences between the two tested versions of the task.

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Sprejeto/Accepted: 10.05.2004