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Are Arabic numerals processed as pictures in a Stroop interference task?

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Abstract In a picture-word interference task, picture naming is interfered by an incongruent word, but word naming is hardly hindered by the presence of an incongruent picture. In this study, we investigated whether Arabic digits are processed more like pictures or like words. We report two experiments in which Arabic digits and verbal numerals were confronted in a Stroop task. Arabic digit naming is interfered by the presence of an incongruent verbal numeral, while naming the verbal numeral is not influenced by the presence of an incongruent Arabic digit. In a second experiment, we excluded the hypothesis that the results are due to ignoring the Arabic digits: interferences from an incongruent distracter were similar for both notations in a semantic classification task. It seems that an asemantic conversion for Arabic digits is too slow to influence naming times, and that Arabic digit naming, like picture naming, is semantically mediated.

Introduction

Everyday experience with numbers does not give us the impression that they form a part of the human cognitive system which is more complex than words or pictures. Normal adults do not experience difficulties in understanding and producing numerals. In the last decade, a great deal of research has been devoted to the functioning of the numerical cognitive system.

Numerical information can be represented by two main symbolic formats: digits and words. So far, research has been directed mainly to one or the other modality, without experimental paradigms looking at the interactions between both formats (but see Koechlin, Naccache, Block, & Dehaene, 1999). Links between the verbal and the Arabic modality have remained mostly at a theoretical level. Nevertheless, directly comparing the processing of digits and words can be a very fruitful approach to understand the operational details of the numerical cognitive system, to find out in what aspects Arabic numeral processing differs from verbal numeral processing.

Inspiration for this kind of research may be found in the literature on the processing of pictures versus the processing of words. There are no reasons to believe that word numerals (one, two, three, ...) are processed differently from other words (Cohen, Dehaene, & Verstichel, 1994). The research can thus be focused on the question whether Arabic numerals (1, 2, 3, ...) are processed more like pictures or like words. If it could be shown that digits behave like pictures, then there is a rich variety of picture-word processing paradigms that can be used to further generate hypotheses and develop theories about Arabic numeral processing. Alternatively, if digits turn out to be processed more like words, then theory development must be guided by models of word recognition.

One of the major differences between word processing and picture processing is that words, but not pictures, can be named without semantic mediation. Virtually all models of word naming consist of at least one nonsemantic conversion between orthographic input and phonological output. In some models, this conversion depends on direct grapheme-phoneme translations (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Parry, Langdon, & Ziegler, 2001); in other models, it consists of a connectionist type of conversion between letters and sounds (Plaut, McClelland, Seidenberg, & Patterson, 1996); and in still other models, it additionally consists of a direct link between an orthographic input lexicon and the speech output system (e.g., Besner, 1999). In contrast, nearly all models of picture naming (e.g., Glaser, 1992; Snodgrass, 1984; Theios & Amrhein, 1989; Humphreys, Price, & Riddoch, 1999)

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assume that pictures cannot be named if their meaning is not understood. Neuropsychological evidence for this position was reported by Hodges and Greene (1998). Only a few researchers (e.g., Brennen, 1999) defend the idea that there is a direct, non-semantic route from pictorial input to speech output.

Part of the evidence for the difference between picture and word processing comes from the well-documented Stroop task (e.g., Glaser, 1992). In the Stroop task, the influence of an irrelevant aspect of the stimulus on the processing of a relevant aspect is measured. The original finding was that naming the ink color of a word was severely hindered when the word referred to another color (e.g., when participants had to name the ink color of the word *RED* printed in blue), whereas word reading was little influenced by the ink color (i.e., participants could name the word *RED* equally well when it was printed in red or in blue; Stroop, 1935; see MacLeod, 1991, for a review).

The variant of the Stroop task that has been used to investigate the differences between picture and word processing, is the picture-word interference task. In this task, a picture and a word are contrasted against one another, and the participants either have to name one of the stimuli or have to make a semantic decision on one of the stimuli. The general finding is that words interfere with picture naming, but that word naming is hardly hindered by the presence of incongruent pictures (Rosinsky, Golinkoff, & Kukish, 1975; Glaser & Düngelhoff, 1984; Smith & Magee, 1980; Theios & Amhrein, 1989; Glaser & Glaser, 1989), leading to the conclusion that words have a more privileged access to the speech output system than pictures (Glaser, 1992). Interestingly, in the same paradigm, the reverse pattern has been found for semantic decisions: The influence of pictures on words is larger than the influence of words on pictures (Smith & Magee, 1980; Glaser & Düngelhoff, 1984), leading researchers to the additional hypothesis that pictures have more privileged access to the semantic meaning system than words (Glaser, 1992). The extension of the picture-word interference paradigm to number processing is quite straightforward: On the same display an Arabic and a verbal numeral are presented and participants have to process one stimulus, while trying to ignore the other. On the basis of the pattern of results due to the Arabic numerals, we can find out to what extent Arabic numerals are processed like pictures or like words. This is an important issue because current models of number processing disagree about the necessity of semantic mediation in the naming of Arabic numerals.

Some models (e.g., Brysbaert, 1995; McCloskey, 1992) claim that Arabic numerals are processed like pictorial stimulus materials in the sense that they cannot be named without semantic mediation. Evidence for this position comes from research with brain-damaged persons. McCloskey, Sokol, and Goodman (1986), for instance, showed that lexical substitution errors in reading Arabic numerals, fell into three separate clusters of units, teens and ten-words, indicating that some kind of lexico-semantic representation had to be activated. Other evidence is based on experiments with normal participants. Brysbaert (1995), for example, showed that number naming times are faster when the target numbers are preceded by primes with a close magnitude than when they are preceded by primes with a more distant value (see also Reynvoet & Brysbaert, 1999).

The idea that Arabic numerals always require semantic mediation to be named is, however, not shared by all researchers. Other influential models like those of Dehaene (1992) and Cipolotti & Butterworth (1995) assume a double route from Arabic input to spoken verbal output: one semantic and one non-semantic. Evidence for this position comes from neuropsychological case studies in which a dissociation has been reported between number naming and number understanding. Dehaene and Cohen (1997), for instance, described a patient (MAR) who could perfectly name digits but made about 20% errors when asked to indicate which of two digits was the larger.

Using the picture-word interference paradigm, we can examine whether Arabic numerals indeed require semantic activation before being able to access the speech output system, as claimed by Brysbaert (1995; see also Fias, Brysbaert, Geypens, & d'Ydewalle, 1996) and McCloskey (1992). If this is the case, then we predict that Arabic numerals will yield the same pattern of results as object drawings. That is, we expect interference from verbal numerals on the naming of Arabic numerals but not the other way around. In addition, we may look at what happens in a semantic decision task. If digits have faster access to the semantic system, we predict interference from Arabic distractors on the semantic processing of verbal targets, but not vice versa. For this prediction, however, it must be noted that research so far has provided little evidence for faster semantic access with Arabic numerals than with verbal numerals (Dehaene, Bossini, & Giraux, 1993; Fias et al., 1996; Noël, 1991). The reason for this may be that digits have an arbitrary relation with the concepts they express, whereas pictures of objects contain some features which have direct semantic value (affordances) or have properties that make up the semantic categories (e.g., legs in case of animals). If digits do not have a more preferred access to the semantic number system than verbal numerals, then we may expect a similar Stroop effect from verbal distractors on Arabic targets as from Arabic distractors on verbal targets.

Stroop tasks have been used before in the number processing literature. For instance, in several studies the physical size of the stimulus has been manipulated as the irrelevant dimension in a number comparison task (for a review, see Noël, 1991). By evaluating the magnitude of the Stroop effect as a function of the notational system, it was hoped to get an idea of the speed of semantic access for different codes. In general, an interference effect has been obtained both with Arabic and verbal numerals, although the effect tended to be slightly larger for the Arabic than for the verbal code (Foltz, Poltrock, & Potts, 1984; Noël, 1991).

To our knowledge, the Stroop paradigm has not yet been used to directly confront Arabic and verbal numerals. In two experiments, an Arabic and a written verbal numeral were presented on the same display. They could either refer to the same quantity (congruent condition) or to different quantities (incongruent condition). Targets and distractors belonged to the same response set, so that interference should be maximal (La Heij, Van der Heijden, & Schreuder, 1985; Proctor, 1978). For half of the participants, the Arabic numeral was the target and the verbal numeral the distractor; for the other half of the participants, the roles were reversed. Using this paradigm, we hoped to reveal the mutual interactions between Arabic and verbal number processing as a function of task requirements. An asemantic task (reading aloud; Experiment 1) and a semantic task (parity judgment; Experiment 2) were used.

Experiment 1

In the first experiment, we investigated interference effects in a number naming task. To interpret possible differences between the congruent and the incongruent condition in terms of facilitation or inhibition, we added a neutral condition with a non-numerical, meaningless distractor. On the basis of our previous experiments (Brysbaert, 1995; Fias et al., 1996; Reynvoet & Brysbaert, 1999), we did not expect interference from an Arabic distractor on the naming of a verbal numeral. In contrast, previous studies lead us to predict that Arabic numerals may show interference effects from a verbal distracter.

Method

Participants

Thirty-two native Dutch-speaking students participated in the experiment (13 males, 19 females). On the average, they were 20 years old (SD = 4.0 years). The subjects also participated in Experiment 2. The order of the experiments and target modality was counterbalanced across participants.

Apparatus

Stimuli were presented on a VGA monitor connected to a computer running under the MS-DOS operating system (486 processor). Reaction times (RTs) were recorded with a voice key connected to the game port.

Instructions

Participants were told that two numbers, one in Arabic digit form and one in written verbal form, would be presented on the same display, one above the other. Half of the participants were asked to read aloud the Arabic numeral, the other half the verbal numeral. After the participant had pronounced the response, the experimenter typed it in on the keyboard (without echo to the screen) and noted whether time registration had been successful. The participants were asked not to pay attention to the irrelevant number. Both speed and accuracy were stressed.

Stimuli and procedure

Stimuli were presented in white on a black background using Borland C's triplex font. They consisted of an Arabic numeral (0–9) and a verbal numeral ("nul", "een", "twee", "drie", "vier", "vijf", "zes", "zeven", "acht", or "negen"), presented one above the other. Which of the two notations was presented on the top, was decided at random on each trial. For half of the participants, the Arabic numeral was the target; for the other half, it was the verbal numeral. The relation between target and distracter was manipulated and could be either congruent (the distracter referred to the same number as the target), incongruent (the distracter referred to a different number), or neutral (the distracter was either a row of five Xs when the distracter modality was verbal, or a single X when the distracter modality was Arabic). Depending on the number of letters in target or distracter, the stimulus size varied from 220 to 350 mm.

In the incongruent condition every target number was presented once with each other number as distracter. This resulted in 90 incongruent stimuli. To balance the number of stimuli over conditions, 90 stimuli were also used in the congruent and neutral conditions. In the congruent condition each target number was presented with the same number in the other modality nine times. In the neutral condition each number was presented with the meaningless distracter nine times. The total list of 270 stimuli was presented in a random order.

A trial started with a fixation mark (||) presented in the center of the screen for 500 ms and was then replaced by the actual stimulus which remained on the screen until a button was pressed. The interstimulus interval was 1,500 ms.

Results

Two participants were excluded from analysis because they were excessively slow (more than 3 SDs above the mean of the other participants). On average, 4.25% of the time registrations could not be used, either because of voice key failures or due to a wrong response. There was no evidence for a speed-accuracy trade-off, as evidenced by a correlation of 0.89 ($n = 6$, $P < 0.05$) between RT and percentage of errors computed over the six cells of the design (two for target modality and three for congruence level).

Median RTs (see Fig. 1) were analyzed with a 2 (target modality: Arabic or verbal) × 3 (congruence level: Congruent, neutral, or incongruent) design with target modality as a between-groups variable and congruence level as a repeated measure.

For the RTs, there was a main effect of Congruity [$F(2, 56) = 28.8$, $MSE = 121.2$, $P < 0.01$], together with an interaction between Congruity and Target Modality [$F(2, 56) = 14.07$, $MSE = 121.2$, $P < 0.01$]. The main effect of Modality was not significant [$F(1, 28) < 1$, $MSE = 7716.8$]. A posteriori comparisons showed that the interaction between Congruity and Target Modality was due to the fact that there was a significant difference between the congruent and the incongruent condition for Arabic targets [$F(1, 28) = 37.0$, $MSE = 382.6$, $P < 0.01$] but not for verbal targets [$F(1, 28) = 1.7$, $MSE = 382.6$]. The percentage of errors did not reveal any differences between congruent and incongruent trials.

In principle, this global analysis might have been biased by the fact that a heterogeneous group of participants was used. Indeed, all subjects participated in the

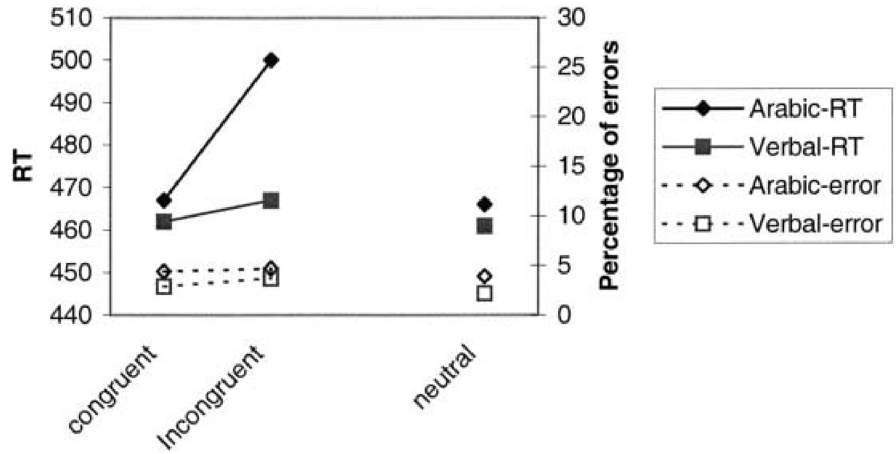

Fig. 1 RT and error data of the number naming Stroop experiment (Experiment 1) (*RT* reaction time)

two experiments with order and target modality counterbalanced across subjects. As a consequence, not all subjects had an equal level of experience in all conditions. To eliminate any interpretational problems attributable to unequal levels of experience, we ran an additional analysis restricted to the results of those subjects who started with the naming task and were thus not influenced by prior experience with the task.

The results showed a significant effect of congruency [$F(2, 26) = 15.68$, $MSE = 75.918$, $P < 0.001$]. A closer look at the data revealed that this congruency effect was completely due to the condition in which the Arabic digit was the target, leading to a significant interaction between congruency and modality [$F(2, 26) = 11.79$, $MSE = 75.918$, $P < 0.001$] (see also Table 1). Thus, the results perfectly mirror the global analysis.

To evaluate the extent to which number magnitude was involved, we separated the incongruent trials in two classes according to the numerical distance between target and distractor. This factor was evaluated at two levels. If the numerical distance between target and distractor was smaller or equal than three, the trial was categorized as close, whereas trials with a numerical distance between target and distractor larger than three were categorized as far. A value of three was chosen since this resulted in an almost equal number of items in both groups (close: 48 items, far : 42 items). The comparison did not reveal a significant effect ($F<1$; $MSE = 199.5$) of numerical distance between target and distractor.

Discussion

We found that reading times were higher when participants had to read an Arabic numeral in the presence of an incongruent verbal numeral than in the presence of a congruent distractor. However, when participants had to read a verbal numeral, it did not matter whether the Arabic distractor was congruent or not (Fig. 1). Thus, naming latencies of the word 'twee' (two) did not differ when the Arabic distractor was 2 or 3.

Table 1 Mean RTs obtained from those subjects who had no prior experience with the digit naming, word naming, digit parity judgment or word parity judgment task (*RT* reaction time)

	Congruent	Incongruent	Difference
Digit naming	434	464	30*
Word naming	447	448	1
Digit parity	604	633	29*
Word parity	596	637	41*

*Significant at $P < 0.01$

This asymmetry in our data is consistent with the literature of picture-word interference tasks, if we assume that Arabic numerals are processed like pictures and verbal numerals like words. It seems that verbal numerals have preferred access to phonological information, either through a non-semantic, non-lexical letter-sound conversion system (Coltheart et al., 1993; Plaut et al., 1996) or through a direct link between the orthographic input lexicon and the speech output system (Besner, 1999). Consistent with the picture-word interference paradigm, the inhibition originated from the output system because there was no effect of the numerical distance between target and distractor.

Although it may be tempting to conclude on the basis of our findings that such non-semantic routes (in particular the direct link between the pictorial input system and the speech output system) does not exist for Arabic digits, it must be kept in mind that our data are also compatible with a model in which a non-semantic route exists but is considerably slower than the semantically mediated pathway.

Experiment 2

The second experiment was designed to further investigate to what extent the comparison between verbal numerals and words on the one hand, and Arabic numerals and pictures on the other hand, is justified. For this purpose, we selected a numerical task that can be compared directly with the semantic classification tasks used in the picture-word interference paradigm. Parity judgment has been reported to be such a task because it requires access to the meaning of the numbers to be solved correctly (Dehaene et al., 1993; Fias et al., 1996; Reynvoet & Brysbaert, 1999).

On the basis of the existing Stroop literature (see above), one prediction can be made with a high degree of certainty: Arabic distractors must interfere with the processing of verbal targets. Absence of such a congruity effect would be evidence that participants could suppress the processing of the Arabic numerals, while attending to the verbal numerals (maybe because they were smaller), and would mean that the results of Experiment 1 must be interpreted with caution.

It is less clear whether in addition one can predict that verbal distractors will interfere with Arabic targets. If digits are as closely connected to the semantic system as pictured objects are, then one does not predict interference. However, if the connection between digits and the semantic number system is less tight, due to the arbitrary relation between the symbols and the concepts, then one may expect interference. As indicated above, the existing literature on number processing seems more in line with the latter prediction than with the former (e.g., Dehaene et al., 1993; Fias et al., 1996; Noël, 1991).

Method

Participants

The participants were the same as in Experiment 1. The order of the experiments and target modality had been counterbalanced across participants.

Apparatus

Apparatus was the same as in Experiment 1, except that the voice key was replaced by a manual response board connected to the game port.

Stimuli and procedure

Stimuli were the same as in Experiment 1. Half of the participants were asked to indicate by pressing one of the two response buttons whether the Arabic numeral was odd or even. The other half of the participants were asked to respond to the verbal numeral. The assignment of parity status to the response buttons was counterbalanced across participants and did not change in the course of the experiment.

Results

The two participants that had been excluded from Experiment 1 were also excluded from this experiment. Percentage of errors was 6.1% on the average (maximum 18.1%). There was a correlation of 0.76 between RT and percentage of errors, indicating the absence of a speed-accuracy trade-off, even though the correlation was only marginally significant ($n = 6$, $P < 0.08$).

Median RTs were analyzed in a 2 (target modality: Arabic or verbal) × 3 (congruence level: congruent, neutral, or incongruent) design with target modality as a between-groups variable and congruence level as a repeated measure. Number of errors were analyzed in the same way. The results of the error analysis followed the same pattern as the RT findings, although the greater noise level caused some non-significant effects that were significant in the RT analysis. The error data are depicted together with the RT data in Fig. 2, but are not always fully reported.

There was a main effect of Congruity [$F(2, 56) = 48.84$, $MSE = 216.3$, $P < 0.0001$], together with an interaction between Target Modality and Congruity [$F(2, 56) = 12.18$, $MSE = 216.3$, $P < 0.0001$]. The main effect of target Modality did not reach significance [$F(1, 28 < 1$, $MSE = 18922.9$]. The interaction between Modality and Congruity was due to the neutral condition. When the ANOVA was limited to the congruent and the incongruent condition alone, the main effect of congruency remained significant [$F(1, 28) = 46.32$, $MSE = 603.7$, $P < 0.0001$] and was not involved in an

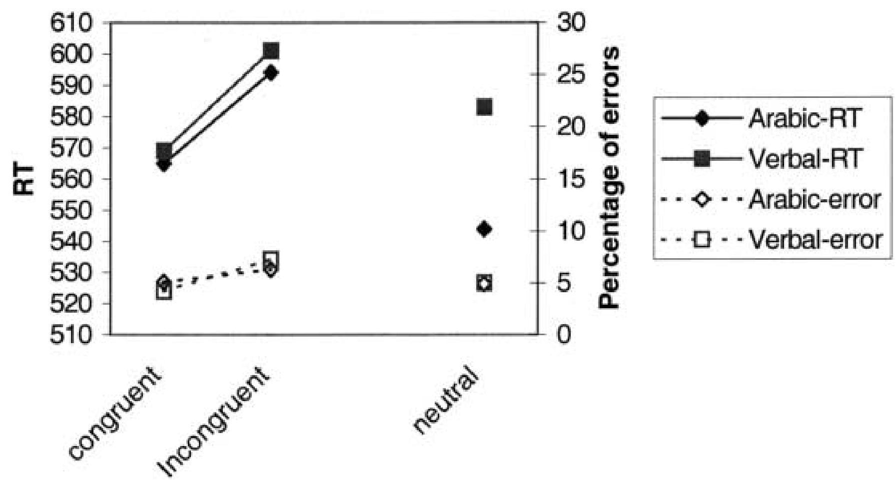

Fig. 2 RT and error data of the parity judgment Stroop experiment (Experiment 2)

interaction with Target Modality [$F(1, 28) < 1$, $MSE = 603.7$]. There was also a main effect of Congruity in the analysis of the percentage of errors [$F(2, 56) = 4.42$, $MSE = 9.7$, $P < 0.05$], which did not interact with Modality [$F(2, 56) < 1$, $MSE = 13.4$].

The above analysis did not take into account that an incongruent distracter could be congruent at the level of the response. This is the case, for instance, when an even target (e.g., 2) was accompanied by an even distracter (e.g., 4), which both required the same response. Therefore, in a second analysis we changed the design into a 2 (target modality) × 3 (congruence level: congruent, response congruent and response incongruent) design (see Fig. 3). In a response congruent trial, target and distracter had the same parity status, while for incongruent trials the parity status of target and distracter differed. In the analysis of RTs, there was a marginally significant difference between the response congruent and the response incongruent condition [$F(1, 28) = 2.91$, $MSE = 1334.0$, $P < 0.1$], and both the difference between the congruent condition and the response congruent condition [$F(1, 28) = 23.4$, $MSE = 967.6$, $P < 0.0001$] and between the congruent and the response incongruent condition [$F(1, 28) = 39.9$, $MSE = 1132.9$, $P < 0.0001$] were significant. There was no main effect of Target Modality [$F(1, 28) < 1$, $MSE = 20093.5$], nor an interaction between Congruity and Modality [$F(2, 56) < 1$, $MSE = 572.4$]. The results of the analysis of the percentage of errors were somewhat different. The difference between the congruent and the response congruent condition was not significant [$F(1, 28) = 2.1$, $MSE = 13.7$] and the difference between response congruent and response incongruent was fully significant [$F(1, 28) = 8.88$, $MSE = 128.5$, $P < 0.01$].

We also performed an additional analysis limited to the results of the subjects who started with the parity judgment task to be able to exclude possible bias effects of unequal experience. Again, the same pattern of results as in the complete data set was obtained (see Table 1): Congruent trials were faster reacted to than incongruent trials [$F(2, 26) = 23.58$; $MSE = 260.61$; $P < 0.001$]. The data of these subjects also revealed a significant interaction effect between congruency level and modality [$F(2, 26) = 5.17$; $MSE = 260.60$; $P < 0.05$], but this effect was completely due to neutral condition.

As in Experiment 1, we looked at the effect of target-distractor distance. This factor was again evaluated at two levels. If the distance was smaller or equal to three it was coded as close; if it was larger than three it was coded as far. Close trials were responded to faster than far trials [$F(1, 28) = 6.08$; $MSE = 2051.2$; $P < 0.05$].

Discussion

As expected, in Experiment 2, Arabic distractors had an effect on the processing of verbal targets (see Fig. 2). Because the parity judgment task requires access to semantic information and because there is no evidence that this information can be addressed better from the verbal code than from the Arabic code, we should to find a Stroop effect if the verbal and the Arabic stimulus were processed in parallel. Therefore, the presence of the effect in the present experiment is a guarantee that the null-effect of Arabic distractors on the naming of verbal targets in Experiment 1 was not due to the fact that participants could ignore the digits (remember that exactly the same stimulus displays and participants were used in both experiments).

Contrary to the picture-word interference literature, we found exactly the same congruency effect in the condition with Arabic targets and verbal distractors as in the condition with verbal targets and Arabic distractors. This is in line with previous evidence that access to the semantic number system is not significantly faster for Arabic numerals than for verbal numerals.

A remarkable finding of the present experiment were the fast responses in the neutral condition with Arabic targets and the sequence “XXXXX” as distractor. By itself, this deviating observation does not undermine the conclusions reached by the comparison of the congruent

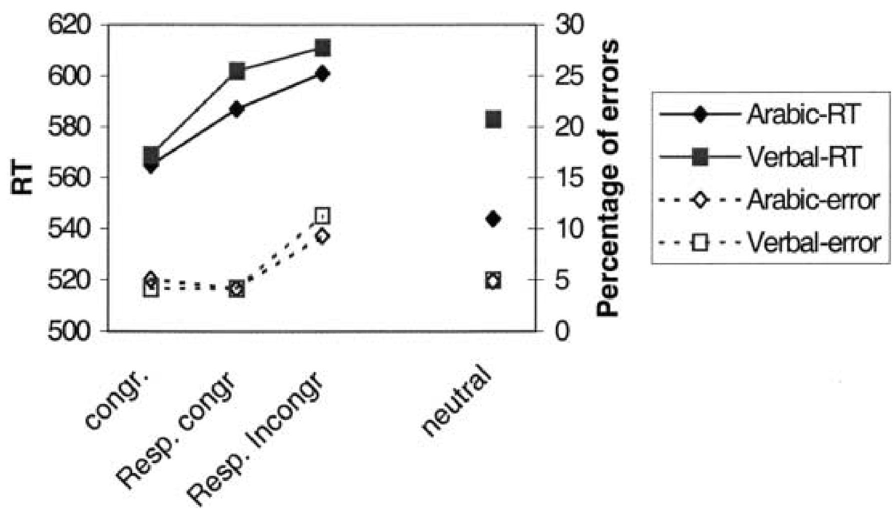

Fig. 3 Results of the parity judgment Stroop experiment with the incongruent level separated for response congruent and response incongruent distractors (Experiment 2)

and the incongruent conditions; it just makes it difficult to know whether the interference effect was due to inhibition in the incongruent condition or to facilitation in the congruent condition (Tzelgov, Henik, Sneg, & Baruch, 1996).

Maybe we should not have used a fixed sequence of five Xs, but should have used sequences of Xs that had a length matched with the verbal numerals (i.e., ranging from three to five letters). It is not unlikely that the big length difference between the distractor and Arabic digit may have been exploited by the attentional system to locate the target more rapidly and to execute the necessary eye movements. Alternatively, it could also be that some numerical attribute of the neutral distractor interfered with the results. For example, an Arabic target was always accompanied by a row of five Xs, perhaps indicating the response "odd" and leading to a conflict with an even target numeral. Another possible interfering characteristic of the neutral X is that it also refers to the roman numeral ten.

General discussion

In this study, we primarily investigated whether Arabic numerals can be named directly, like words, or whether they require semantic mediation to be named, like pictures. Some researchers have pointed to the fact that a very small number of rules suffice to transform Arabic numeral input into spoken verbal output (e.g., Deloche & Seron, 1987). Thus, there are no a priori reasons why numbers could not be pronounced correctly without the speaker knowing what they refer to. On the basis of this argument, models have been proposed in which there is a direct conversion from Arabic input to phonological output (e.g., Dehaene, 1992; Cipolotti & Butterworth, 1995). Other researchers have pointed to the fact that, although such a conversion is theoretically possible, there is little empirical evidence for its existence in normal number processing (Brysbaert, 1995; Fias et al., 1996; McCloskey, 1992; Noël & Seron, 1995).

To examine the existence of direct digit-sound translations, we made use of a robust Stroop effect, namely the asymmetry of the word-picture interference in the naming task. Simultaneously presented words interfere with the naming of pictures, whereas simultaneously presented pictures do not impede the naming of words (Glaser, 1992). We repeated this pattern of results with displays in which verbal and Arabic numerals were put in competition with each other.

To make sure that the results were not due to particular characteristics of the stimulus displays (in particular the fact that the Arabic numerals subtended a smaller visual angle than the verbal numerals), we in addition ran a semantic categorization experiment in which interference from Arabic distractors on the processing of verbal targets was expected. As Fig. 2 shows, such a congruity effect was indeed present in the parity judgment task. This task also showed that, unlike the classical results of the picture-word interference paradigm, verbal distractors interfered with the processing of Arabic targets. They even did so to the same extent. We believe this is because the relationship between digits and number magnitudes is arbitrary, making digits less directly coupled to the meaning system than pictures of entities that exist in the outside world and that contain important features of the semantic categories.

Although our results fail to show evidence for nonsemantic digit-sound transcoding in normal number naming, at this moment it may be more prudent not to say that such transcoding does not exist at all. For it could be that such conversion exists, but is too slow to influence normal voice onset times. Such an additional route could be helpful in explaining some findings with neuropsychological patients (Brennen, 1999; Cipolotti & Butterworth, 1995; Dehaene & Cohen, 1997). However, our findings do show that this pathway, if it exists, is not be very important in normal number processing and seems unlikely to have a strong contribution in number manipulation tasks, such as calculation.

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