Differentiation of holistic processing in the time course of letter recognition

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ABSTRACT

Pairs of letters, pseudo-letters, and basic geometrical shapes were presented in a sequential same–different task, in which the time between the first and second items was varied. The second item was either presented in isolation or surrounded by an irrelevant geometrical shape that could be congruent or incongruent to the target. Congruence effects were obtained for shapes and pseudo-letters, but not for letters if the interval between the first and second items was short. Absence of congruence effects was interpreted, in accordance with earlier findings, as categorical influence on early visual integration processes; letters are processed less holistically than non-letter shapes. The present result indicates that categorical influence of letters depends on the time course of stimulus processing. As a highly automatized process, it is effective for stimuli appearing at a relatively fast rate, whereas, a slower rate of stimulus presentation eliminates task-irrelevant categorical influences.

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1. Introduction

The process by which initial representations of visual sensory features give rise to integral texture and tentative object structure is called visual feature integration (Pomerantz & Lockhead, 1994). Over time, the feature integration process could be modified by perceptual learning (Goldstone, 1998). In these modifications, categorical information can play an effective role (Notman, Sowden, & Özgen, 2005). We may even expect, contrary to what has often been assumed (Massaro, 1998; McClelland, 1976; Posner & Mitchell, 1967), an influence of higher-order semantic categories on the early perceptual integration process (Ahissar & Hochstein, 1997; Pylyshyn, 1999; Schyns & Oliva, 1999; Stins & van Leeuwen, 1993).

This study addresses the role of semantic knowledge in visual feature integration, using the congruence effect (Bavelier, Deruelle, & Proksch, 2000; Lachmann & van Leeuwen, 2004; Lockhead & Pomerantz, 1994; Pomerantz & Pristach, 1989; van Leeuwen & Lachmann, 2004). This effect implies that it is easier to recognize a visual object when it is surrounded by a similar shape than when it is surrounded by a dissimilar one (see Fig. 1, bottom row), because early feature integration has combined features of an object with those of its surrounding. If the congruence effect fails to occur, this indicates that target and non-target features have not been integrated to the same degree. They can be separated without effort. Congruence effects may therefore be used to measure the degree of perceptual feature integration.

We will investigate whether higher-order semantic knowledge influences the degree of perceptual feature integration. An important semantically informed categorical distinction in visual information is “letters” vs. “non-letters”. Such a distinction is not easily translated into visual features. For instance, the capital “A” and the non-letter in Fig. 1 are similar in shape, and yet they belong to distinct semantic categories. For this reason, it is unlikely that dissociation in early processing is driven solely by pre-categorical visual features.

If these distinctions, nevertheless, play a role at the level of visual feature integration processes, these will lead to differences in congruence effects. We tested this prediction, comparing congruence effects for letters and non-letters (Lachmann & van Leeuwen, 2004; van Leeuwen & Lachmann, 2004). Lachmann and van Leeuwen (2004) used a same–different task (e.g., Nickerson, 1969) in which two items were presented subsequently for comparison. First and second items could be letters, pseudo-letters, or geometrical shapes. First items were always presented either in isolation or surrounded by a congruent or incongruent geometrical shape. For pseudo-letters and...
shapes, a congruence effect was obtained; comparison was faster when an item appeared in congruent surrounding, compared to incongruent surrounding. For letters, however, no such congruence effect occurred.

The contrasting results for letters and non-letters were obtained for a small, restricted set of stimuli. There is only a small subset of letters, all capitals, that fits nicely within surrounding frames, the shape of simple, geometrical figures such as circles, triangles, and rectangles. This will necessarily restrict our conclusions, as these stimuli might be special. However, more recently, the effects were replicated with Japanese participants using kana and kanji, which allowed more variation (Jincho, Lachmann, & Van Leeuwen, 2008).

The dissociation of effects for letters and non-letters was attributed to differences in visual feature integration strategies between these categories. These could be understood as follows: practice has endowed experienced readers with a special visual feature integration mode for letters (Burgund, Schlaggar, & Petersen, 2006; Lachmann, 2002). Whereas single non-letter shapes are preferably grouped with their immediate surroundings, single letters are not. In this specific sense, referring to objects and their neighboring context, shapes are processed more holistically (e.g., Kimchi, 1992); letters less holistically.

Note that this differentiation has no implications for how strongly the features are bound together at the within-object level. For this, one could argue that it depends on the Goodness of the object (van der Helm & Leeuwenberg, 1996; Wagemans, 1999), e.g., the symmetry of the triangle or the letter “A”. On the other hand, observers tend to ignore symmetry in letters (Lachmann & van Leeuwen, 2007), suggesting that letters are also processed less holistically at this level. Neither does the differentiation in holistic processing at any of these levels have any implications for the next higher level, which for letters would be that of morphemes or words. Our claim that letters are processed less holistically than non-letters, therefore, is not in conflict with the well-known word-superiority effect (Reicher, 1969). This effect applies at the level of groupings between letters. It could be argued that, in fact, recognition at this level might benefit from non-holistic processing at our current level (Freeman, Driver, Sagi, & Zhaoping, 2003); word-level processes, for instance, will have difficulty matching individual letters whose features have mistakenly been bound, based on pre-semantic information, to their surroundings. In sum, therefore, our claim of a distinction in holistic processing between letters and non-letters belongs exclusively to the level of visual integration between these objects and their immediate surroundings.

A further issue of interest is that perceptual feature integration depends on set or task (e.g., Schyns & Oliva, 1999; Stins & van Leeuwen, 1993). This applies specifically to processing of letters; in a choice-response task, van Leeuwen and Lachmann (2004) observed that non-letters were processed more holistically than letters when letters and non-letters similar in shape were assigned to opposite response alternatives (Experiment 4). However, the dissociation disappeared when letters and non-letters similar in shape were assigned to the same response alternative (Experiment 5). In this case the overall shape could be used as a response criterion. This resulted in identical congruence effects for letters and non-letters. It was concluded that in this case, both letters and non-letters were processed holistically.

The task dependency of the dissociation between letters and shapes rules out some alternative explanations for the effect. It could be argued, for instance, that the effect is due to a difference, not in the type, but in the rate of processing for more or less practiced stimuli. Differences in processing rate would then exist, however, in both tasks.

A further alternative explanation would invoke levels of processing. The task in which the dissociation disappears involves categories, in which global similarity is sufficient for making the distinction. This, presumably, is easier, and so one would expect the task is performed faster than the other task, in which distinctions between similar shapes are to be made. However, this is not the case. Especially for letters, an increase rather than a decrease in RT was observed from Experiment 4 to Experiment 5. In our understanding, this shows that holistic processing is less than optimal for letters. This is because letter-specific processing in experienced readers is highly automatized, and, therefore, considerably faster than the more holistic mode adopted for non-letters.

It is intriguing that skilled readers, who have learned to process letters less holistically than non-letter shapes, suddenly seem to process letters equally holistically, once their categorical identity becomes irrelevant. This would suggest that in this case the letter-specific processing mode, although preferable for letters, is actually less preferred. It is possible, however, that what is really un-preferred is having to switch between the letter and the non-letter mode on a case-by-case basis, so that perceivers prefer to have a uniform mode for letters and non-letters as soon as the task allows this, even if this implies a considerable reaction time cost. Indeed, between Experiment 5 and 6 in van Leeuwen and Lachmann (2004), a huge decrease in RT was observed, when letter and non-letter stimuli were blocked, rather than randomly intermixed.

2. Experiments

Let us consider an explanation for the above-mentioned results, based on the opposite assumption, viz. that early visual processing is independent of semantic category. One might then argue that non-letter processing is finished when this information is available, whereas for letters, further processing is automatized, and, therefore, mandatory. It then takes a while for the system to trace back to the visual information. This would explain why RTs are longer in conditions where a congruence effects is observed for letters. Such an explanation would predict as most likely that congruence effects in letters are the largest in cases where retracing the information is maximally difficult, i.e., in conditions where stimuli are presented at a relatively fast rate.

From our perspective, a contrasting predicting could be made. Several studies suggested that more holistic processing is characteristic of deferred stimuli, whereas, early on, processing is less holistic (Goldstone & Medin, 1994; van Leeuwen, Buffart, & van der Vegt, 1988). Comparing this for letters and non-letter shapes, we predict for the latter a steady preference for holistic processing, whereas, for letters we expect that holistic processing will appear later if the task enables this.
We adopted Lachmann and van Leeuwen's (2004) sequential same–different task but with an important difference. In the previous study, the two items of a same–different pair could both be letters and non-letters, as well as mixed. These occurred in balanced proportions. That means observers could not predict the categorical identity of the second item from the first. To bring back Fig. 1, an A presented first, for instance, could be followed by an A ("same") as well as by a pseudo-A ("different"). This means, as in the choice-response task in van Leeuwen and Lachmann (2004), Experiment 4, that categorical identity is relevant. In both experiments, as a result, a robust distinction in holistic processing between letters and non-letters was observed.

In contrast, in the current study, the first and the second items of a pair always have the same categorical identity. This contingency is not revealed in the instruction but could nevertheless be detected in the practice session. Therefore, when a first item of a pair is presented observers can, in principle, predict whether the second one is a letter or a non-letter. Hence in this task, the overall shape of the second item is sufficient to recognize it as same or different from the first. In analogy to van Leeuwen and Lachmann (2004), Experiment 5, this means that the distinction of, say, “A” and “pseudo-A” no longer is relevant after presentation of the first item; when it is a letter the second will never be a pseudo-letter, and vice versa. If this categorical irrelevance is effective we may expect that a holistic processing mode will be adopted for both letters and non-letters, so that the previously observed dissociation in congruence effects between letters and non-letters disappears.

However, the predictability of the category has to overcome the automaticity of the letter processing mode. This may take time, and, therefore, depend on stimulus presentation rate. To study this effect, we varied the interval between the first and second items. For non-letters we may expect to observe the predominance of a non-letters mode (i.e., holistic processing, congruence effects) independently of interval duration; for letters we may expect, given its automaticity, a preference for a letter mode for short interval durations (i.e., less holistic processing, no congruence effect). Only for longer processing durations do we expect that letters will preferably be processed according to the non-letter mode (i.e., more holistic, congruence effect).

A final issue is whether these developments depend on processing time alone, or whether in addition the visual presence of the stimulus is required. This is because one might assume that the physical availability of various form/category features of stimuli might vary in importance during processing. For this reason we varied two factors relevant to processing duration: the presentation duration of the first stimulus and the inter-stimulus interval (ISI) between the first and second stimuli.

2.1. Experiment 1

2.1.1. Method
2.1.1.1. Participants. There were 23 student volunteers (18 female) between 18 and 31 years old who were either paid or received course credit for participation. All participants had normal or corrected to normal vision and hearing.

2.1.1.2. Stimuli. A subset of the targets from van Leeuwen and Lachmann (2004) was used: the three capital letters: A, L, and C three corresponding pseudo-letters: pseudo-A, pseudo-L, and pseudo-C and three basic geometrical shapes similar to these items, respectively: a triangle, a rectangle, and a circle. The targets are shown in Fig. 2. They were presented either in isolation or surrounded by a geometrical shape, a slightly enlarged version of one of the shape targets (see Fig. 2). Shape targets are therefore identical, except in scale, with their congruent surroundings; target letters and pseudo-letters are only similar to them. Efforts were made to balance the sets of letters and pseudo-letters for degree of similarity with their congruence surrounding. Items surrounded by a different shape were labelled incongruent. In total, there were nine sets of stimuli: Isolated letters, letters within congruent surrounding shapes, letters within incongruent surrounding shapes, isolated pseudo-letters, pseudo-letters within congruent surrounding shapes, pseudo-letters within incongruent surrounding shapes, isolated shapes, and shapes within congruent surrounding shapes.

<table>
<thead>
<tr>
<th>Individual stimuli (targets)</th>
<th>Surrounding shapes (non-targets)</th>
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<tbody>
<tr>
<td>Letters Shapes Pseudo-letters</td>
<td>Congruent Incongruent</td>
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Fig. 2. Individual stimuli (targets: letters, shapes and pseudo-letters) and surrounding shapes (non-targets) used in Experiment 1.
shapes within incongruent surrounding shapes. Each set contained three stimuli, resulting in a total of 27 unique displays.

All stimuli were presented in white (28 cd/m²) on a CRT computer monitor screen set to black (0.46 cd/m²). Target stimuli were 30 mm and surrounding shapes 70 mm in height. They were presented at about 50 cm length distance, resulting in a visual angle of about 3.5° without and 8° with surrounding. Participants were seated in a chair, without head fixation. The experiment took place in a dimly lit room without windows.

2.1.1.3. Procedure. In the same–different task one item is compared to a single probe in order to decide whether it is the same or different. Both are either presented simultaneously (e.g., Keren, O’Hara, & Skelton, 1977) or successively (e.g., Sanders & Lamers, 2002).

In this study, successive presentation was used. Four blocks, each with a different time variation, were performed in counterbalanced order across participants. These blocks resulted from the factors ISI and exposure of the first stimulus. The ISI between the stimuli was varied on two levels, half of the cases ISI = 320, the other half ISI = 2920 ms. (Note that the accuracy of presentation times and ISI are limited by screen refresh rate, which was 16.6 ms). In all conditions, the first stimulus was presented sufficiently long to complete the feature integration process, but masked in order to eliminate visual persistence. The exposure time of the first item (S1 presentation time) was varied on two levels; half of the cases S1 presentation time = 80 ms, the other half S1 presentation time = 300 ms.

Prior to the experiment, participants conducted a 30 trials practice session. Here, and in the experiment, first, a fixation cross (10 x 10 mm) occurred for 50 ms at the left half of the screen, at the position that marked where the target stimulus would follow. After that the screen remained clear for 200 ms. Then the first target stimulus was presented for 80 ms (short S1 presentation time condition) or 300 ms (long S1 presentation time condition) and were masked for 16.6 ms (refresh rate). The mask consisted of all stimuli superimposed on their original locations, combined with features of the stimuli distributed over random locations across the whole screen and remained for the duration of the frame rate of the monitor. After an ISI of 320 ms (short ISI) or 2920 ms (long ISI) the second item was presented at the right side of the screen until response. Within the ISI a fixation cross occurred for 50 ms at the right side of the screen, marking the position where 250 ms later the second item will be presented. After the response the second stimulus was masked for 16.6 ms (refresh rate) and subsequently the screen remained empty. The masking of the second item was given for two reasons, firstly, as feedback that the response was received, and secondly, to reduce the possibility of some kind of an Einstellung–effect (Luchins & Luchins, 1995) for the next trial. After 2000 ms, the next trial started. Whereas during the practice trials for both speed and accuracy feedback was given, no feedback was given during the experimental trial.

In each trial, the first stimulus was always presented in isolation; the second stimulus was presented either in isolation or surrounded by a congruent or incongruent geometrical shape, all three conditions in the same proportion. As in Lachmann and van Leeuwen (2004), first and second stimuli were drawn from the categories of letters, pseudo-letters, or shapes. In contrast with the previous study, however, first and second stimuli were always of the same category. Thus, the first stimulus, e.g. the letter A, could be followed by three stimuli that require a same response: A without surrounding, A within a triangle or A within a rectangle. The A could also be followed by a stimulus that require a different response: C or L without a surrounding, C within a circle or L within a rectangle or C within a rectangle or L within a triangle. Given that there are three different material classes (letters, pseudo-letters, shapes), in each of which six different pairs can be formed in each of which the second one can appear isolated, congruent or incongruent, there are (3 x 6 x 3 ) = 54 unique different stimulus pairs. Likewise there are (3 x 3 x 3 ) = 27 unique same pairs, which were repeated twice in order to balance same and different. This resulted in 108 trials per block, which were presented in fully random order. Presented within the four blocks (short S1 presentation time/short ISI, short S1 presentation time/long ISI, long S1 presentation time/short ISI, and long S1 presentation time/long ISI) this resulted in 432 pairs to be compared by each participant. There was a break of 5–8 min between the blocks. Together with the instruction and the practice trials, one session lasted about 60–80 min.

Note that, as a result of this procedure, the surrounding shape was predictive for the response. For example, with the target letter A, a circular surround shape always requires a different response. Participants attend to irrelevant flankers if they are predictive for the response (Dishon-Berkovits & Algom, 2000). Thus the impact of surrounding shapes cannot be interpreted in terms of automatic processing as it is usually done in the flanker tasks. This, however, does not affect the relevance of the experiment, which is testing a hypothesis based on strategic influences on processing.

The experimenter read the instruction out loud to the participant. Participants were to respond as quickly and stimuli accurately as possible whether two successively presented items were either same or different and to ignore the surrounding shape, whenever one occurred, as irrelevant. They were not told explicitly that the first and second stimuli were always of the same category. A response consisted of pressing one of two response keys on the response unit. Response time measurement onset was synchronized with the start of the refreshment of the screen. Response–key allocation was counterbalanced across participants (here, and elsewhere, counterbalancing should be understood as by approximation whenever there is an uneven number of participants).

2.1.2. Results and discussion

A total of 9936 responses were collected. Responses were removed as outliers from the data set if the reaction time (RT) was shorter than 140 ms or longer than 3000 ms. Of the remaining RTS, those that exceeded the individual criterion RT > M + 3.5SD were removed as well (M = mean; SD = standard deviation). According to this procedure, 3% of the RTs were excluded from further analyses. These 28 cases were about equally distributed over the experimental conditions and individuals. Only correct responses were used for the analyses. The overall mean RT was 461 ms (SD = 137 ms) and the mean error rate was 6%. Twelve participants had zero errors in one cell or several cells. No (rank) correlation between RTs and error rate was observed and, therefore, analyses were performed on RT only. Mean RTs for all conditions are presented in Table 1.

The RT data were analyzed in terms of the two analyses of variance (ANOVA). For the calculation of the F-values the Greenhouse–Geisser correction was used, whereas the degrees of freedom reported are the uncorrected ones. The first ANOVA was aimed at the difference between second stimuli presented in isolation and ones surrounded by a congruent or incongruent shape. In this design, congruent and incongruent surrounding items were pooled into a “surrounded” category. This analysis used as factors Material (3 x Response type (2) x Surrounding (2), ISI (2320 ms or 2920 ms) and S1 presentation time (2, presentation times of the first stimulus, 80 ms or 300 ms)). Main effects were found for Material, Response type, Surrounding, and ISI. For Material, F(2,44) = 9.31, p < .01, letters (453 ms) were different from pseudo-letters (468 ms), F(1,22) = 20.27, p < .01 and shapes (462 ms), F(1,22) = 6.82, p < .05, (pseudo-letters and shapes did not differ, F. = 3.9). For Response Type, F(1,22) = 34.48, p < .01, same (445 ms) were faster than different (477 ms) responses, indicating the classi-
cal fast-same effect. For Surrounding, \( F(1,22) = 131.50, p < .01 \), isolated stimuli (445 ms) were faster than surrounded targets (469 ms). For ISI, with short ISI responses were faster (448 ms) than with long ISI (473 ms), \( F(1,22) = 6.01, p < .05 \).

An interaction between Response type and Surrounding. \( F(1,22) = 9.07, p = .01 \), indicated a larger fast-same effect for isolated (423–466 ms), \( F(1,22) = 29.54, p < .01 \), than for surrounded stimuli (456–482 ms), \( F(1,22) = 30.6, p < .01 \); both, however, reached similar levels of significance \( (p < .01) \).

An interaction between S1 presentation time and Surrounding. \( F(1,22) = 9.81, p = .01 \), indicated that an effect of presentation time of the first item (S1 presentation time) was found for surrounding conditions (459–479 ms), \( F(1,22) = 4.49, p < .05 \), whereas the S1 presentation time effect was not significant for isolated conditions (439–450 ms, \( F = 1.5 \)). When the second stimulus is isolated, matching a holistic template may be easier and, therefore, presentation time will be less critical.

The second ANOVA was aimed on testing the effect of Congruence by using the factors Material (3) \( \times \) Response type (2) \( \times \) Congruence (2), ISI (2) and S1 presentation time (2). Main effects were obtained for all factors. For Material, \( F(2,44) = 11.05, p < .01 \), again letters (459 ms) were faster than pseudo-letters (478 ms), \( F(1,22) = 26.57, p < .01 \), and shapes (470 ms), \( F(1,22) = 5.5, p < .05 \), which did not differ \( (F = 3.8) \). For Response type, \( F(1,22) = 32.69, p < .01 \), isolated (456 ms) were faster than different \( (482 \) ms) responses, demonstrating again the classical fast-same effect. For S1 presentation time, \( F(1,22) = 4.63, p < .05 \), short were responded to faster than longer presentation times (459–479 ms). For ISI, \( F(1,22) = 5.26, p < .05 \), short ISI resulted in faster responses \( (457 \) ms than long ISI (482 ms). For Congruence, \( F(1,22) = 5.37, p < .01 \), congruent \( (456 \) ms) are preferred over incongruent surroundings \( (483 \) ms).

An interaction between Material and Congruence, \( F(2,44) = 4.76, p < .05 \), was found (letters, pseudo-letters and shapes are 451, 464 and 453 ms in the congruent, and 468, 492, and 489 ms in the incongruent condition). As post-hoc pair-wise analyses showed, the congruence effect is strong in pseudo-letter and shape conditions, \( F(2,44) = 27.4, p < .01 \) and \( F(2,44) = 45.02, p < .01 \), respectively, but small for letters, \( F(2,44) = 9.55, p < .05 \). Alternatively this interaction reveals that in congruent conditions pseudo-letters showed longer RT \( (464 \) ms) than letters \( (451 \) ms), \( F(2,44) = 8.54, p < .01 \) and shapes \( (453 \) ms), \( F(2,44) = 4.73, p < .05 \), while letters and shapes did not differ, whereas, in incongruent conditions letters \( (468 \) ms) were faster than pseudo-letters \( (492 \) ms), \( F(2,44) = 33.3, p < .01 \) and shapes \( (489 \) ms), \( F(2,44) = 18.32, p < .01 \), while the latter two did not differ. Considered either way, the interaction shows that letters did not benefit from congruent surroundings.

An interaction between ISI and Congruence, \( F(1,22) = 5.98, p < .05 \), indicates that for congruent conditions, the effect of ISI is not significant, \( F = 2.5 \) (447 ms for short and 466 ms for long ISI), whereas it reaches significance for incongruent conditions, \( F(1,22) = 7.14, p < .05 \) (467 ms for the short, and 498 ms for the long ISI condition). With congruent conditions, long intervals between the stimuli seem to be less critical.

A triple interaction was found between Material, Congruence, and S1 presentation time, \( F(2,44) = 9.57, p = 0.049 \) (see Table 2). This interaction was the result of congruence effects occurring for all Material by S1 presentation time conditions, \( F(2,44) = 6.1–18.19, p < .01 \), except for letters in the short S1 presentation time condition, \( F = 1 \). In Fig. 3a–d the congruence effects are displayed for all S1 presentation times and ISI conditions. Under the short S1 presentation time/short ISI condition the congruence effect for letters (see Table 1) is completely absent. This result is in accordance with our prediction; in this condition the presentation rate is the fastest; predictability of the second stimulus category is not yet effective; it fails to determine the visual feature integration mode. As a result, the default mode is applied in this condition; more holistic for non-letters than for letters. In the other conditions, there is a congruence effect both for letters and for pseudo-letters as well as non-letter shapes. For stimuli presented at these slower rates, i.e., longer the exposure duration of the first stimulus and/or a longer ISI between the first and second stimuli, predictability is effective. The task irrelevance of the categorical identity leads to a uniformly holistic feature integration mode for all categories of targets.

We may raise the issue whether congruency is an all-or-none issue or a matter of degree of similarity between a target and surrounding. To investigate this issue, we performed an ANOVA including the factors Material (3), Congruence (2), and Surround (3): Triangle vs. Circle vs. Rectangle. Besides the earlier-observed effects of Material, \( F(2,44) = 10.23, p < .001 \), Congruence, \( F(1,22) = 63.34, p < .001 \), Surround, \( F(2,44) = 71.50, p < .001 \), as well as an interaction of Material and Congruence, \( F(2,44) = 5.03, p < .05 \), we obtained an interaction involving Congruence and Surround, \( F(2,44) = 27.22, p < .001 \), and a triple interaction of Material, Congruence, and Surround, \( F(4,88) = 3.67, p < .05 \). This result suggests that the effects of congruence are not all-or-none but vary continuously as a function of similarity between target and surrounding: maximal for shape (identical), strong for some letters and pseudo-letters (e.g., strong for triangular pseudo-letter and for circular letter), somewhat less strong for others (e.g., L and rectangle) and even weak for still others (e.g., A and triangle, pseudo-letter and rectangle, pseudo-letter and circle), depending on some topological features that are clearly different.\(^1\)

The observation that congruence effects are based on graded similarity presents a possible source of confounding in the present experiment: whereas, letters and pseudo-letters have various degrees of similarity to their congruent surroundings, shapes and congruent surroundings are identical. The mere addition of such stimuli could have had unpredictable side-effects. To test for this possibility, a control experiment was performed in which only letters and pseudo-letters were included.

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\(^1\) We would like to thank an anonymous reviewer for raising this issue.
2.2. Experiment 2

2.2.1. Method

2.2.1.1. Participants. There were 15 student volunteers (13 female) between 19 and 29 years old, who were either paid or received course credit for their participation. None of them took part in any other experiment reported here. All participants had normal or corrected to normal vision and hearing.

2.2.1.2. Material and procedure. A subset of the stimuli of Experiment 1 was used, consisting of the letters and the pseudo-letters only. In total, there were six sets of stimuli: Isolated letters, letters within congruent surrounding shapes, and letters within incongruent surrounding shapes, and isolated pseudo-letters, pseudo-letters within congruent surrounding shapes, pseudo-letters within incongruent surrounding shapes. Each set contained three stimuli, resulting in a total of 18 unique displays. Given that there are two different classes of material (letters and pseudo-letters), in each of which six different pairs can be formed, and in each of which the second one can appear either isolated, congruent or incongruent, there are $(2 \times 6 \times 3) = 36$ unique different stimulus pairs. Likewise there are $(2 \times 3 \times 3) = 18$ unique same pairs. The latter were repeated twice in order to balance same and different trials. This resulted in 72 trials per block. These were presented in fully random order. Within a session, there were three blocks with a short break in-between, resulting in a total of 216 responses for each participant. In contrast to Experiment 1 there were no variations of exposure time and ISI. The exposure time for the first stimulus was fixed to 800 ms and the ISI between the first and the second stimulus was fixed to 1200 ms. The whole experimental session lasted about 35 min.

2.2.2. Results and discussion

A total of 3240 responses were collected. The same outlier criterion as for Experiment 1 led to the exclusion of .5% of the cases. These were equally distributed over the experimental conditions and individuals. Only correct responses were used for RT analyses. The overall mean RT was 451 ms (SD = 129 ms) and the mean Error rate was 6.9%. Mean RT and Error rates were not correlated.

The mean RTs for all conditions are shown in Table 3. As in the previous experiment, the results were analyzed in terms of two ANOVAs, the first aimed at the difference between targets presented in isolation and those in which they were surrounded by a non-target shape. For this analysis, congruent and incongruent surrounding shapes were pooled into a “surrounded” category. Using the factors Material $(2) \times$ Response type $(2) \times$ Surrounding $(2)$, main effects were obtained for Response type, $F(1,14) = 10.35; p < .01$, and Surrounding, $F(1,14) = 90.56; p < .01$. Same (434 ms) were faster than different (468 ms) responses, replicating the classical fast-same effect, and isolated (432 ms) were faster than surrounded (460 ms) targets.

As in the previous experiment, the interaction of Response type and Surrounding reached significance, $F(1,14) = 15.54, p < .01$. Pair-
wise comparisons showed that the fast-same effect is present when the second stimulus is isolated (50 ms, $F(1,14) = 19.12, p < .01$, i.e., when the pair is maximally same, but not significant when the second stimulus is surrounded (26 ms, $F = 3.5$). There was a triple-interaction of Material, Response type, and Surrounding, $F(1,14) = 8.68, p < .05$. This interaction is based on the absence of a fast-same effect for surrounded letters (9 ms, $F < 1$), whereas this effect is present for isolated letters (53 ms), $F(1,14) = 20, p < .01$, surrounded (42 ms), $F(1,14) = 7.58, p < .05$, and isolated pseudo-letters (47 ms) $F(1,14) = 13.4, p < .01$.

The second ANOVA was performed to test the effect of Congruence of the surrounding shape. As in the previous experiment, isolated targets were omitted from this analysis. Using the factors Material (2) × Response type (2) × Congruence (2), the only main effect was found for Congruence, $F(1,14) = 9.87, p < .01$. Congruent surroundings (452 ms) were preferred over incongruent ones (470 ms). An interaction between Material × Response type, $F(1,14) = 7.02, p < .05$, indicated that a fast-same effect was obtained for pseudo-letters (438–480 ms), $F(1,14) = 7.58, p < .05$, but not for letters (457–466 ms, $F < 1$). The interaction of Material × Congruence, $F(1,14) = 7.76, p < .05$, is displayed in Fig. 4. This interaction resulted from the presence of a Congruence effect for pseudo-letters (445–476 ms), $F(1,14) = 50.79, p < .01$, in combination with its absence for letters (459–464 ms, $F < 1$). The effects replicate those of the previous experiment: with pseudo-letters in the role of non-letters, dissociation in congruence effects is obtained between non-letters and letters.

Pseudo-letters dissociate themselves more clearly from letters than in the previous experiment. Comparing RTs for pseudo-letters in Experiment 1 (Fig. 4) to those in Experiment 2 (Fig. 4), it appears that in Experiment 1 the pseudo-letters were, relatively speaking, assimilated to the letters, whereas, in the present experiment they are contrasted with the letters and take a role similar to the shapes in Experiment 1. This may have been a side-effect of including stimuli which are identical to their congruent surrounding. The effect is interesting in its own right, as it demonstrates the context-specificity of the categorical distinctions made. This result is in accordance with our general approach and not in conflict with the specific predictions made about the context-specificity of the dissociation in holistic processing between letters and non-letters.

### Table 3

Mean RT (ms) for all conditions of Experiment 2

<table>
<thead>
<tr>
<th>Response type</th>
<th>Material</th>
<th>Isolated</th>
<th>Congruent</th>
<th>Incongruent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>Letter</td>
<td>404</td>
<td>454</td>
<td>460</td>
</tr>
<tr>
<td></td>
<td>Pseudo-letters</td>
<td>412</td>
<td>419</td>
<td>459</td>
</tr>
<tr>
<td>Different</td>
<td>Letters</td>
<td>456</td>
<td>464</td>
<td>468</td>
</tr>
<tr>
<td></td>
<td>Pseudo-letters</td>
<td>459</td>
<td>470</td>
<td>492</td>
</tr>
</tbody>
</table>

![Fig. 4. Mean reaction times from Experiment 2 for pairs of letters and pseudo-letters for conditions in which the second item was presented surrounded by a congruent or incongruent shape. Error bars indicated 5% confidence intervals.](image)

3. General discussion

We used the congruence effect as a yardstick to measure to which extent stimuli were processed holistically, i.e., integrated with their surrounding context, and investigated the time course of categorical effects on holistic processing in letters and non-letters. Based on the previous results (Lachmann & van Leeuwen, 2004; van Leeuwen & Lachmann, 2004), we predicted that letters are habitually processed less holistically than non-letters. However, when both letters and non-letters occur in each other’s context, having to switch between a letter and a non-letter processing mode on a case-by-case basis is less preferred than uniformly adopting a non-letter processing mode, even if this takes more time.

Thus, if a task mixes letters and non-letters, both are processed differently if needed (van Leeuwen & Lachmann, 2004, Experiment 4), but both will be processed holistically, as non-letters of the task allows this (van Leeuwen & Lachmann, 2004, Experiment 5).

Given that the less holistic mode is default, automatized, and, therefore, fast for letters, we predicted that it is not abandoned even if it is irrelevant, if the task involves a relatively fast rate of visual processing. Using the sequential same–different task of Lachmann and van Leeuwen (2004), we presented same–different pairs with the same categorical identity only (i.e., a letter was always followed by a letter, a non-letter always by a non-letter). We made the categorical identity of the second target predictable from the first, so that the task could be performed by using the holistic processing mode for letters as well as non-letters. In Experiment 1, we varied the latency of the second stimulus and observed that with short delays, letters were still processed less holistically than non-letters: whereas robust congruence effects were observed for non-letters, in this condition no congruence effects were obtained for letters. In accordance with our hypothesis, this means that for an interval below 400 ms, the letter-specific mode is still active, even if the task does not require it. In Experiment 2, this was still the case even for an interval of 1200 ms.

Congruence effects became increasingly strong for longer letters, when the period between the onset of first and second stimuli was increased. This result appeared to be independent of whether the first stimulus was visually present for a long period during the interval. This suggests that these effects are mediated by phonological encodings and/or letter name codes (Posner, 1969). They may become effective gradually and slowly by activating top–down pattern recognition routines for letters. This top–down activity, according to our hypothesis, has the effect of rendering the letter-specific visual representation of the second stimulus task irrelevant, so that the letter-specific processing mode can be abandoned and a holistic feature integration mode uniformly adopted for letters as well as for non-letter shapes.

The dependency on the time interval between the first and second stimuli illustrates the context-sensitivity of letter-specific...
feature integration (Freeman et al., 2003; Lachmann & van Leeuwen, 2004; van Leeuwen & Lachmann, 2004). Sequential dependency of feature integration effects on congruence has previously been demonstrated in the Simon effect (Hommel, Proctor, & Vu, 2004).

The result evokes the well-known studies of Posner and colleagues (Posner, 1969; Posner & Mitchell, 1967). These authors introduced same–different responses based on other than visual aspects of the stimuli. They proposed a theory of serial processing stages. According to this theory, at the lowest level, patterns are initially encoded in terms of their elementary physical characteristics (“...the visual pattern “A” is coded as a set of lines forming a unified but unfamiliar figure which is not different from an infinite number of line combinations of similar complexity that are not letters”; Posner, 1969). The idea that distinct codes (physical and a name code) act in serial stages of information processing was later rejected by Posner himself (1978); the serial stage approach “…is simply too restrictive to use as a complete description of the processes involved”, and “The temporal hierarchy … does not imply that the processes involved at the different levels represent a strict series”, p. 35). As a possible alternative, Posner considered, e.g., an isolated systems theory, in which physical and categorical information proceeds through pathways that are to a certain extent independent from each other. The present results do not fully support this view. Relatively short-lived perceptual representations (which in Posner’s terms would qualify as a ‘physical code’) can be influenced by information about the categorical nature of the stimulation (Posner’s phonological code). The possibility of interaction between both types of representation was envisaged by Posner (1978).

In Experiment 1, three distinct categories were used: letters, pseudo-letters, and geometrical shapes. The status of the pseudo-letters was somewhat ambivalent and tended to behave as letters. One could argue that pseudo-letters dissociate, albeit weakly, from the shapes just because the latter are identical to their congruent surroundings, whereas letters and pseudo-letters are, at best, only similar to different degrees. This, in turn, would call into question the validity of the dissociation between the letters and the shapes. For these reasons, in Experiment 2 we tested pseudo-letters vs. letters only. Here, pseudo-letters more clearly played the role of non-letter shapes; their congruence effect contrasted much more strongly with the letters. This result illustrates once more the context-specificity of the role of categorical information. This may have triggered the non-letter-specific processing mode more persistent in Experiment 2 than in Experiment 1.

The “in-between effect” for pseudo-letters in the first experiment may be considered as an induced effect of categorization at the scale of the experiment. Thus considered, it bears significance for studies of feature integration using orthographical symbols (e.g., Pomerantz, Sager, & Stoever, 1977). Many of these studies have yielded inconclusive results: sometimes parentheses are preferably integrated into a holistic representation and sometimes they are not. Perhaps ambivalence whether parentheses should be treated as “letters” or as “shapes” may be responsible for this. To understand the nature of congruence effects it is important to take both into account, the task and the categorical identity of the stimuli. The present study shows that, in addition, also the temporal context matters.

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