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Contingent capture during search for alphanumerical characters: A case of feature-based capture or of conceptual category membership?

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ABSTRACT

To distinguish if search for alphanumerical characters is based on features or on conceptual category membership, we conducted two experiments where we presented upright and inverted characters as cues in a contingent-capture protocol. Here, only cues matching the top-down search template (e.g., a letter cue when searching for target letters) capture attention and lead to validity effects: shorter search times and fewer errors for validly than invalidly cued targets. Top-down nonmatching cues (e.g., a number cue when searching for target letters) do not capture attention. To tell a feature-based explanation from one based on conceptual category membership, we used both upright (canonical) and inverted characters as cues. These cues share the same features, but inverted cues cannot be conceptually categorized as easily as upright cues. Thus, we expected no difference between upright and inverted cues when search is feature-based, whereas inverted cues would elicit no or at least considerably weaker validity effects if search relies on conceptual category membership. Altogether, the results of both experiments (with overlapping and with separate sets of characters for cues and targets) provide evidence for search based on feature representations, as among other things, significant validity effects were found with upright and inverted characters as cues. However, an influence of category membership was also evident, as validity effects of inverted characters were diminished.

For visual search, humans create and use search templates consisting of (visual) characteristics of the searched-for targets (Desimone & Duncan, 1995). In everyday life, humans not only search for specific objects, but also for instances of whole object categories, without exact knowledge of the particular instance they will find (Schmidt & Zelinsky, 2009). For example, when looking for dresses during shopping, several differently shaped and coloured dresses would fit the purpose. It has been discussed but no conclusion has been reached yet if such searches for a whole category are based on some form of shared conceptual meaning and are thus independent from visual features of single instances or if different visual instances belonging to a particular category contribute to a pool of various visual features that humans search for. Many studies argue that categorical search can be carried out by search for visual features alone (cf. Alexander & Zelinksy, 2011) or at least that search templates and other attentional control settings in categorical search based on visual features are more effective than purely conceptually and, thus, visually somewhat vaguely defined attentional control settings (Wu & Fu, 2017). Supporting the assumption that search for category instances is feature-based, stimuli within specific categories typically share more common features with one another than stimuli belonging to different categories (Corcoran & Jackson, 1977; Krueger, 1984; Makovski, 2018). The corresponding search templates might either be derived from discriminative features of previously seen instances of a specific target category (Zhang, Yang, Samaras, & Zelinsky, 2006) or from prototypical features of instances of a specific category (e.g., Levin, Takarae, Miner, & Keil, 2001; Maxfield, Stalder, & Zelinsky, 2014; Robbins & Hout, 2015; Yang & Zelinsky, 2009). Recent studies argued for feature-based templates consisting of mostly enduring feature structures characteristic of a particular category rather than for very economical search templates based on only the necessary features to find instances of a specific category (Hout, Robbins, Godwin, Fitzsimmons, & Scarince, 2017; Yu, Maxfield, & Zelinsky, 2016). Apart from studies supporting the idea of categorical search being based on visual feature templates, there also exists research supporting the view that visual search for categories could be guided by more conceptual and less concrete knowledge and, thus, be independent from specific feature representations. For example, Jonides and Gleitman (1972) showed that character similarity within a category—or rather character dissimilarity between two categories—does not play a critical role in categorical search, by using the identical character *O* twice, which produced different effects depending on its categorization as the letter *O* or the number zero. Further studies using alphanumerical characters

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found effects in attentional capture based on conceptual distinctions rather than feature representations (Dixon & Shedden, 1987; Hamilton, Mirkin, & Polk, 2006; Leblanc, Prime, & Jolicoeur, 2008; Wu et al., 2013).

Recently, studies analysing the electrophysiological component N2pc (which reflects allocation of spatial attention) shed a light on the underlying mechanisms in categorical search and also found evidence for concept-based visual search for alphanumerical characters, although in these cases allocation of attention was seemingly weaker and slower compared to feature search (Jenkins, Grubert, & Eimer, 2017; Nako, Grubert, & Eimer, 2016; Nako, Wu, Smith, & Eimer, 2014; Wu et al., 2013).

All of the above mentioned research shows that category-related effects exist in visual search. However, no agreement concerning the influence of feature representations on categorical search has been reached. To contribute to a better understanding of categorical search, in the current study, we presented alphanumerical characters of three distinct categories: letters, numbers, and special characters. Alphanumerical characters have produced reliable search effects in the past, and attention can be guided as effectively by alphanumerical categories as by colour or shape (Jenkins et al., 2017). We presented the characters in a contingent-capture setup in which cues are presented at target position (in valid conditions) or away from the target (in invalid conditions) but in which cues are not predictive of the most likely target position (Folk & Remington, 1998; Wyble, Folk, & Potter, 2013). Here, only cues similar to the targets and, thus, matching the top-down search template capture attention and lead to validity effects (faster search and fewer errors for validly than invalidly cued targets; Posner, Snyder, & Davidson, 1980). In contrast, cues dissimilar to all targets and, thus, not matching the top-down search template fail to capture attention and show no significant validity effect. To discriminate between explanations based on conceptual search templates and explanations based on templates for shared typical or frequent features within one category, we did not only present top-down matching and nonmatching cues, but also presented the cues either upright (canonical) or inverted. An inversely presented cue still carries the same features as when presented upright. As different characters share more common features with one another within one category than across categories (proportion of linear and curvilinear features, prevalence of symmetries, and width; see for example Jonides & Gleitman, 1972; Krueger, 1984; McCarthy, 1972), both upright and inverted top-down matching cues (i.e., cues from the same category as the target) should lead to validity effects, if categorical search is based on feature representations. If, on the other hand, categorical search is conceptual and independent of feature representations, top-down matching cues should only capture attention and lead to validity effects when presented upright. In contrast, inversely presented top-down matching cues would not capture attention, as inverted presentation minimizes category saliency and attenuates the ability to categorize the stimulus (see, e.g., Elsner, Kunde, & Kiesel, 2008; Hamilton et al., 2006; Krueger, 1984; Rossion & Curran, 2010).

1. Experiments 1 and 2

To find out if contingent-capture effects in visual search for characters of different alphanumerical categories (letters vs. numbers) can be explained by templates consisting of feature representations, we presented both upright and inverted cues preceding a search display containing upright characters of different categories (letters, numbers, and special characters). In each trial, each participant had to search for an unknown character out of a set of stimuli all belonging to one specific alphanumerical category (e.g., letters) but without knowledge about which exact character was presented next. According to the contingent-capture theory, only cues matching the top-down search template—here cues out of the searched-for category—would capture attention (cf. Folk & Remington, 1998; Wyble et al., 2013). If feature search plays a role in categorical search, matching cues would capture attention and lead to validity effects independent of their orientation, as both upright and inverted cues share the same features. However, if search for a target character out of a specific alphanumerical category is not feature based but based on more abstract semantic concepts, recognition of cues as instances of the target category would seem to be necessary for their contingent-capture effects, and inverted cues would lead to substantially reduced or no validity effects (e.g., Elsner et al., 2008).

1.1. Method

1.1.1. Participants

Thirty-four students participated in the first experiment (M_{age} = 22.94 years, SD_{age} = 3.42 years) and 32 in the second (M_{age} = 23.44 years, SD_{age} = 3.04 years). One participant of Experiment 1 had to be excluded due to an error rate exceeding 20%. Participants received a small monetary gratification in return for their participation. We treated participants in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), and their wellbeing was closely monitored during the testing. Participants were instructed thoroughly, signed an informed consent prior to testing, were neither deceived nor harmed in any way, and knew that they could abort the experiment at all times without negative consequences. Data were fully anonymized.

Using R (R Core Team, 2017) and the package *pwr* (Champly, 2017), a power analysis ($\alpha = 0.05$, $f = 0.50$) showed that a minimum sample size of 52 participants is needed to obtain interaction effects of the within-participant variables Validity (valid/invalid), Cue Category (matching/nonmatching), Cue Orientation (upright/inverted), and the between-participants variable Character Set (overlapping/separate) with a statistical power of $(1 - \beta) = 0.80$. As a consequence, at least across experiments, the power of our test was sufficient to reveal a significant three-way interaction if it existed.

1.1.2. Stimuli and apparatus

The stimuli were the letters *R, F, G, N, L, J* (category letters), the numbers *1, 2, 4, 5, 7, 9* (category numbers), and the special characters *#, &, %, ?, £, §* (category special characters). As we also presented the stimuli inverted (vertically mirrored), it was important that the characters were not symmetrical. The height of the characters was approximately 1.2° visual angle. The average number of pixels per character was 423.17 (numbers: 358.00, letters: 456.50, special characters: 455.00). The characters were presented in black (CIE L*a*b*, 0.9/−0.1/−1.8). In the cueing display, four stimuli were presented simultaneously left above, right above, left below, and right below a centred fixation cross on a virtual circle with a radius of 3.5° visual angle. In the target display, there were additional disks in red (38.6/52.5/25.3) or green colour (39.2/−50.3/29.7) centred behind each stimulus (diameter 2° visual angle, distance between disks 3° visual angle). The colours red and green were approximately equiluminant and equidistant from black ($\Delta E_{red\text{-}black} = 70.0$; $\Delta E_{green\text{-}black} = 70.6$). The background remained grey throughout the whole experiment (80.0/−5.3/−18.7). We used 19″ LCD-Monitors (Acer B 193) with a resolution of 1280 × 1024 pixels at a vertical refresh rate of 75 Hz. The graphic card was an Nvidia GeForce (GT 220, colour 32 bit/96 DPI). The testing room was dimly and indirectly lit by small lamps behind the screens. Up to four participants were tested at a time. Their distance to the screen was kept constant at 57 cm by a chinrest. They responded by pressing key *F* or *J* on a standard keyboard with their index fingers, depending on the colour of the disk behind the target. E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) was used to program and conduct the experiment, all data was analysed using R (R Core Team, 2017) and the following packages: *apa* (Gromer, 2017), *ez* (Lawrence, 2016), and *ggplot2* (Wickham, 2009).

1.1.3. Task and design

Both experiments had three within-participant variables: Cue Orientation (upright/inverted), Cue Category (matching/nonmatching), and Validity (valid/invalid). Each participant was told to search for a character out of a specific category (letters or numbers, balanced across participants), and report the colour of the respective background disk at target position by keypress as fast as possible while avoiding errors. Colour-to-response key mapping was counterbalanced across participants. Which specific characters were used in the experiments was not communicated in the instruction. Besides one target character (e.g., a letter), a distractor character of the other category (a number) and two other distractors (special characters) were shown in each target display. Because of the use of characters from three different categories, the target character was never a category singleton and top-down (category-) singleton search was prevented (Bacon & Egeth, 1994). The positions of the characters as well as the colours of the disks were pseudo-randomly selected and uncorrelated across trials. Preceding the target display, a cueing display was shown. It consisted of one category-singleton cue and three category-nonsingleton distractors. The cue was valid in 25% and invalid in 75% of the trials. A matching cue was a character of the same category as the target (e.g., a letter), a nonmatching cue was a character of the other category (e.g., a number if the targets were letters). Trials with matching and nonmatching cues as well as trials with upright and inverted cues were equally likely and presented in a pseudo-random sequence. Category-nonsingleton distractors in the cueing displays were always special characters.

The only difference between Experiments 1 and 2 was whether each specific character was assigned to the cue and target displays (condition overlapping character set; Experiment 1) or whether there were separate sets of specific characters for the target versus cue displays (condition separate character sets; Experiment 2). In Experiment 1, specific characters of the three categories were assigned randomly to the cue and target displays in every trial, but without repetition of the same character within one trial. Thus, for example, an *L* could be a target in one trial and a matching cue in another trial. Likewise, a *2* could be a target-display distractor in one trial and a nonmatching cue in another trial. In Experiment 2, there were separate sets of three characters out of each category for the cueing and the target display, so that every character could either appear only in the cueing display or only in the target display throughout the whole experiment. Thus, for example, an *L* as a target was never used as a cue. Likewise, a *2* as target-display distractor was then never used as a non-matching cue. (The exact composition of the individual character sets was counterbalanced across participants.) We conducted this manipulation in Experiment 2 for two reasons. First, to avoid that suppression of the non-matching cues was due to the fact that the same characters could have been distractors in the target displays of other (e.g., preceding) trials, as it was the case in Experiment 1. Second, if participants searched for specific targets by their features once they had an idea of which targets to expect, the use of the same characters in target and cue display of Experiment 1 could have boosted the feature-based selection of the cues, and this was to be ruled out in Experiment 2.

1.1.4. Procedure

At the beginning of each trial, a fixation cross was shown for 1500 ms. Then the cueing display appeared for 100 ms. After an inter-stimulus-interval (ISI) of 50 ms, the target display was presented for 450 ms (see Fig. 1). Until response, but no longer than 1500 ms, a blank screen was shown. Prior to testing, participants got written and verbal instructions and repeatedly worked on 20 practice trials until they achieved an accuracy rate exceeding 80%. During practice, feedback on correct, incorrect, and too slow responses was given. The testing phase consisted of 512 trials, and together with preparations, practice phase, and debriefing, the whole experiment took about 60 min.

1.2. Results

We analysed both the correct reaction times (RTs) and error rates of Experiments 1 and 2 depending on the three within-participants variables Cue Orientation, Cue Category, and Validity. We also conducted a combined analysis of the data of both experiments, with the additional between-participants variable Character Set with the variations Overlapping (overlapping character sets for cue and target displays; Experiment 1) or Separate (separate character sets for cue and target displays; Experiment 2).

1.2.1. Experiment 1

1.2.1.1. Reaction time analysis. Only trials with correct responses and RTs within the range of 2 *SD*s plus/minus the mean per person and per condition were included in the analyses (in total 90.93% of the trials). A $2 \times 2 \times 2$ repeated-measures analysis of variance (ANOVA) of the mean correct RTs, with the variables Cue Orientation (upright/inverted), Cue Category (matching/nonmatching), and Validity (valid/invalid), was conducted (see Fig. 2 and Table A1). It yielded a significant three-way interaction of Cue Orientation × Cue Category × Validity, $F(1, 32) = 7.23$, $p = .011$, $\eta_p^2 = 0.18$. For significant lower order interactions and main effects see Table A2. The *p*-values of the post-hoc *t* tests examining contingent-capture and validity effects were adjusted using Holm's method (1979). For upright cues, we found a classic contingent-capture effect: A validity effect for matching cues, namely faster reactions for validly (759 ms) than invalidly cued targets (798 ms), $t(32) = -5.16$, $p < .001$, $d = -0.88$, and no significant difference between nonmatching valid and invalid cues, $t(32) = 1.91$, $p = .065$, $d = 0.33$. The same pattern arose for inverted cues: A contingent-capture effect with faster responses to validly (754 ms) than invalidly cued targets (771 ms) for matching cues, $t(32) = -2.28$, $p = .030$, $d = -0.39$, and no validity effect for nonmatching cues, $t(32) = 1.52$, $p = .138$, $d = 0.26$. The validity effect of matching cues was significantly attenuated for inverted relative to upright cues, $t(32) = 6.11$, $p < .001$, $d = 1.05$.

1.2.1.2. Accuracy analysis. The individual rate of accurate responses was arcsine-transformed per condition before conducting a repeated-measures ANOVA analogous to the one above (see Fig. 3 and Table A1). It showed a significant main effect of Validity, $F(1, 32) = 10.09$, $p = .003$, $\eta_p^2 = 0.24$. Participants responded with a higher accuracy to validly (96.8%) than invalidly cued targets (96.4%). No further effects were significant, all Fs$(1, 32) \leq 0.92$, all ps ≥ 0.344, all η_p^2s ≤ 0.03.

1.2.2. Experiment 2

1.2.2.1. Reaction time analysis. Consistent with the procedure in Experiment 1, trials with erroneous responses as well as RTs slower or faster than two *SD*s from the mean per person and condition were excluded (remaining trials: 91.34%). We conducted a $2 \times 2 \times 2$ repeated-measures ANOVA of the correct mean RTs, with the variables Cue Orientation (upright/inverted), Cue Category (matching/nonmatching), and Validity (valid/invalid). See Fig. 4 and Table A1 for the mean correct RTs of all conditions. Only the two-way interaction of Cue Category × Validity, $F(1, 31) = 14.31$, $p < .001$, $\eta_p^2 = 0.32$, was significant. No further effects were found, all Fs$(1, 31) \leq 3.10$, all ps ≥ 0.088, all η_p^2s ≤ 0.09. For the post-hoc *t* tests looking into contingent-capture and validity effects, the *p*-values were corrected for multiple comparisons following Holm (1979). For matching cues, the reaction to validly cued targets (765 ms) was significantly faster than to invalidly cued targets (789 ms), $t(31) = -3.09$, $p = .008$, $d = -0.54$. For nonmatching cues, the reaction to validly cued targets was slower (783 ms) than to invalidly cued targets (770 ms), $t(31) = 2.76$, $p = .010$, $d = 0.48$. Such reversed validity effects or same-location costs as they are sometimes called are a relatively common finding in the nonmatching conditions of the

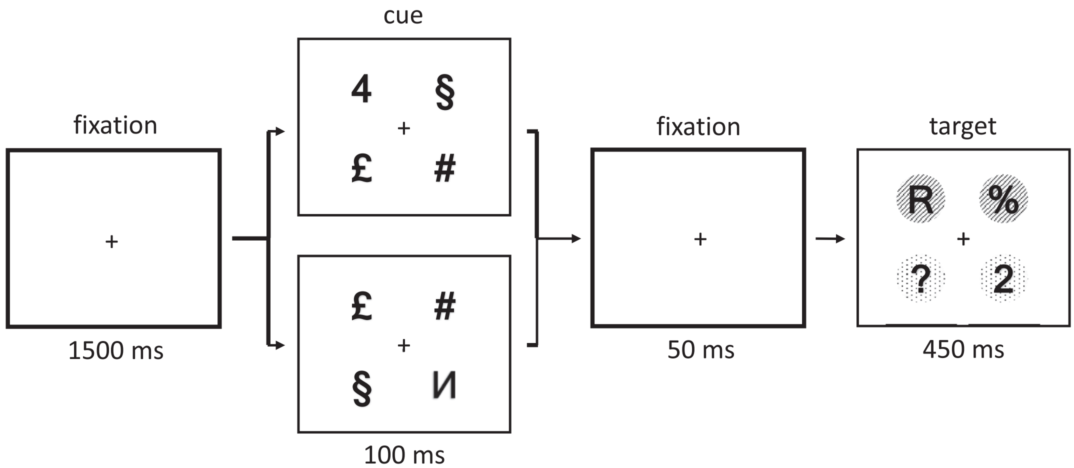

Fig. 1. Exemplary trial(s) where participants had to search for a letter as the target amongst other characters (here *R* in the upper left position of the rightmost panel) and report the colour of the disk at target position (*green* versus *red*; here illustrated as hatched versus dotted). Two different cueing displays are shown here: In the top box (2nd from left) an upright nonmatching valid cue (*4* in the upper left corner) and in the bottom box an inverted invalid matching cue (inverted *N* in the lower right corner). The arrows depict the flow of time. Stimuli are not drawn to scale.

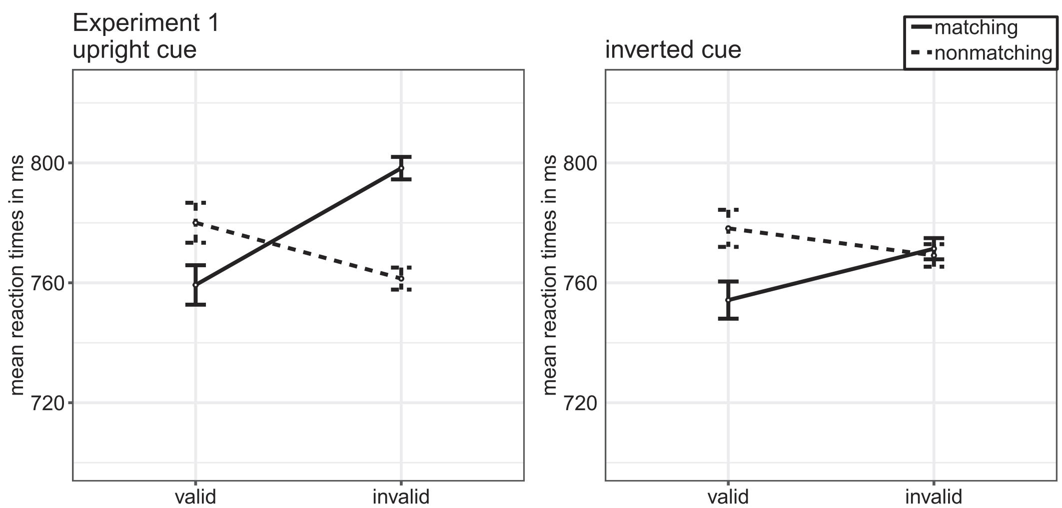

Fig. 2. Experiment 1 (overlapping character sets): Mean correct reaction times (in ms) for upright cues (left panel) and inverted cues (right panel) depending on Cue Category (matching: solid line, nonmatching: dashed line) and Validity (valid/invalid). Error bars represent average *SE*s.

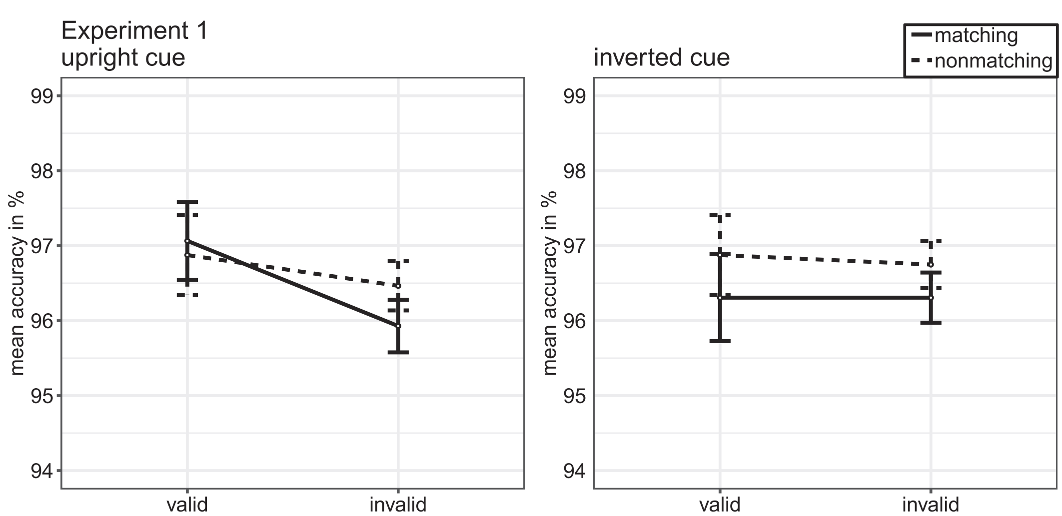

Fig. 3. Experiment 1 (overlapping character sets): Mean accuracy rates in percent for upright cues (left panel) and inverted cues (right panel) depending on Cue Category (solid line: matching, dashed line: nonmatching) and Validity (valid/invalid). Error bars represent average *SE*s.

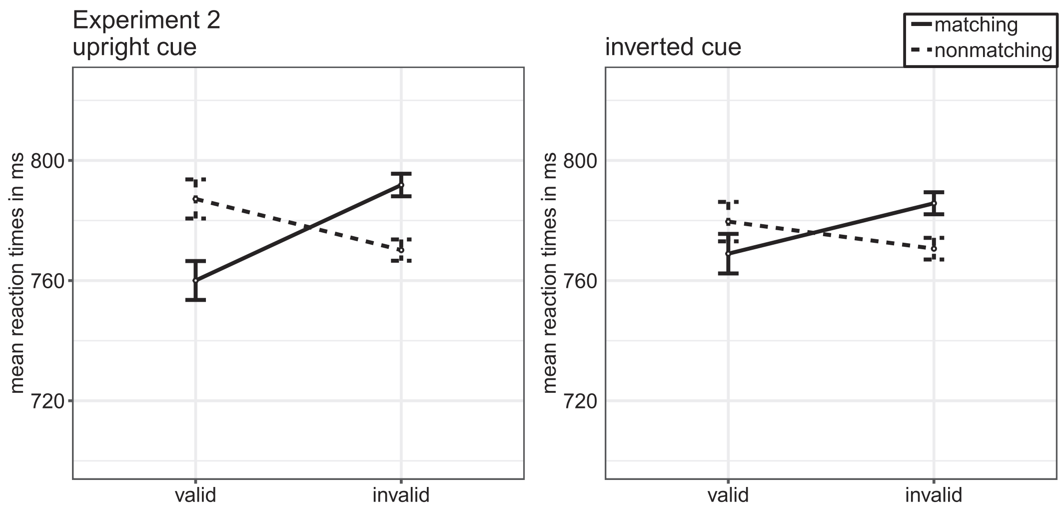

Fig. 4. Experiment 2 (separate character sets): The left panel shows mean correct reaction times for upright cues, the right panel for inverted cues, as a function of Cue Category (matching: solid line, nonmatching: dashed line) and Validity (valid/invalid). Error bars represent average *SE*s.

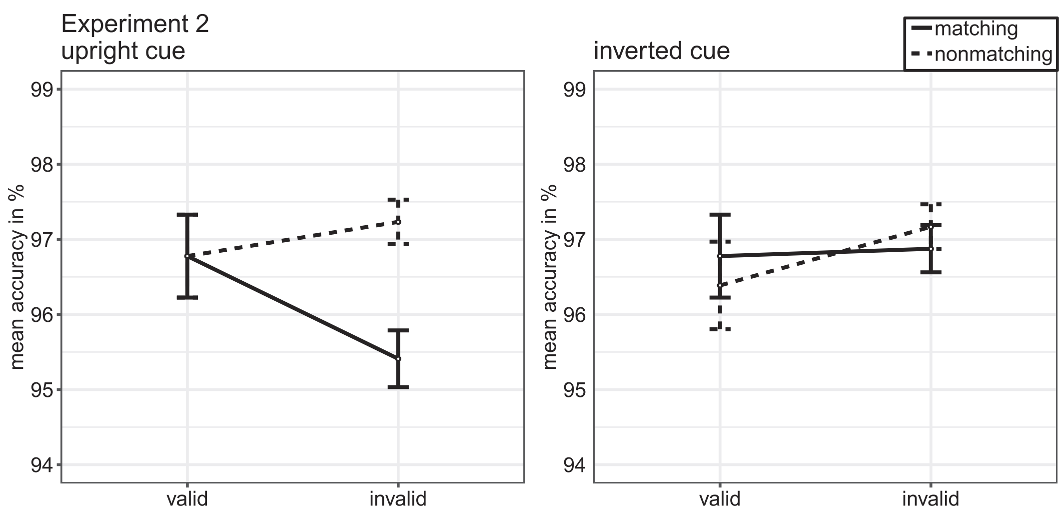

Fig. 5. Experiment 2 (separate character sets): Mean accuracy rates in percent for upright cues (left panel) and inverted cues (right panel) depending on Cue Category (solid line: matching, dashed line: nonmatching) and Validity (valid/invalid). Error bars represent average *SE*s.

contingent-capture protocol (cf. Lamy, Leber, & Egeth, 2004; Schöberl, Ditye, & Ansorge, 2017).

1.2.2.2. Accuracy analysis. The accuracy rates were pre-processed as in Experiment 1 (see above for details). See Fig. 5 and Table A1 for the mean accuracy rates per condition. The repeated-measures ANOVA revealed a significant main effect of Validity, $F(1, 31) = 4.49$, $p = .042$, $\eta_p^2 = 0.13$. Participants accuracy was higher for validly (96.68%) than invalidly cued targets (96.67%). No further effects reached significance, all $Fs(1, 31) \leq 3.06$, all $ps \geq 0.090$, all η_p^2s ≤ 0.09.

1.2.2.3. Combined analyses. We conducted an additional analysis combining the data from Experiments 1 and 2 in a repeated-measures ANOVA, with the same three within-participant variables as used before (Cue Orientation, Cue Category, and Validity), plus the additional between-participants variable Character Set, with the steps Overlapping (overlapping character sets for cue and target displays; data from Experiment 1) or Separate (separate character sets for cue and target displays; data from Experiment 2). We report only the significant highest-order interaction; all further significant main effects and lower-order interactions that were qualified by the highest-order interaction can be found in Table A3. The $2 \times 2 \times 2 \times 2$ mixed-measures ANOVA, with the mean correct RTs yielded a significant interaction of Cue Orientation, Cue Category, and Validity, $F(1, 63) = 9.43$, $p = .003$, $\eta_p^2 = 0.13$ (see Figs. 2 and 4). For the post-hoc *t* tests examining contingent-capture and validity effects of upright and inverted cues, the *p*-values were adjusted for four comparisons using Holm's method (1979). In trials with upright matching cues, reactions were significantly faster for validly (760 ms) than invalidly cued targets (795 ms), $t(64) = -5.63$, $p < .001$, $d = -0.69$. After upright nonmatching cues, RTs were significantly lower in invalid (766 ms) than valid trials (784 ms), $t(64) = 2.94$, $p = .005$, $d = 0.36$ (same-location costs). In trials with inverted cues, there was a validity effect for matching cues, $t(64) = -2.86$, $p = .006$, $d = -0.35$ (valid: 762 ms, invalid: 779 ms) but it was significantly smaller than in the upright condition, $t(64) = 4.31$, $p < .001$, $d = 0.53$, for the comparison between upright and inverted validity effects. There were no significant same-location costs by inverted nonmatching cues, $t(64) = 1.91$, $p = .061$, $d = 0.24$. There was also no significant difference between the same-location costs of nonmatching upright and inverted cues, $t(64) = -0.90$, $p = .373$, $d = -0.11$.

The same $2 \times 2 \times 2 \times 2$ mixed-measures ANOVA was conducted with the accuracy rates and revealed a significant main effect of Validity, $F(1, 63) = 14.33$, $p < .001$, $\eta_p^2 = 0.19$ (see Figs. 3 and 5). Participants made significantly fewer errors in trials with valid (3.27%) than invalid cues (3.49%). No further effects were significant, all *F*s(1,

63) ≤ 3.29, all $ps \geq 0.074$, all η_p^2s ≤ 0.05. For a complete listing of the results see Table A3.

2. General discussion

We investigated if contingent-capture effects during search for alphanumerical categories can be explained by search based on feature representations or on conceptual representations. For this purpose, we presented characters as top-down matching and nonmatching cues either upright or inverted in a contingent-capture protocol. As expected, selective validity effects for top-down matching cues were found in RTs of both Experiments 1 and 2, namely faster responses to validly than invalidly cued targets (cf. Wyble et al., 2013). Top-down non-matching cues led to same-location costs, faster reactions after invalidly than validly cued targets, which is also a common finding with the contingent-capture protocol (e.g., Lamy et al., 2004). If categorical search effects were based on conceptual meaning rather than feature representations, we would have expected differences between upright and inverted cues, as they both share the same features but the ability to categorize inverted cues is impaired (Elsner et al., 2008). Yet, a consistent main effect of validity was visible in the RTs of both orientations in separate analyses of Experiments 1 and 2, which is evidence for robust validity effects of matching cues, independent of cue orientation. These findings are in line with the literature. For example, Smilek, Dixon, and Merikle (2006) found that categorical search is feature-based in difficult tasks where participants search actively, serially, and analytically (like in our study), whereas conceptual search occurs in a passive, parallel, and automated way. Wu, Liu, and Fu (2016) also showed that a simultaneous presentation of target and distractors eliminated category-based attentional control settings. However, the validity effect in the RTs of matching cues was significantly weaker for inverted than upright cues, both in Experiment 1 (upright: $d = -0.88$, inverted: $d = -0.39$) and in the combined analysis (upright: $d = -0.69$, inverted: $d = -0.35$). This difference reflects an inversion effect (cf. Elsner et al., 2008), where inverting cues lead to attenuated category salience, diminished cue categorization and, therefore, less capture even by the matching cues. This demonstrates, that search does not rely on feature representations alone, but suggests at least partial influences of concept-based search templates. A combination of feature-based and conceptually based search templates has been demonstrated before. For example, Godwin, Hout, and Meneer (2014) found that attention was guided both by feature similarity and conceptual information in search for numbers among letters, although featural similarity had a greater influence than conceptual similarity, which again is in line with our findings of only partially concept-based search templates.

In addition to validity effects of matching cues, we found same-location costs for nonmatching cues in Experiment 2 and in the combined analysis. Concerning the exact origin of the same-location costs, different explanations have been put forward (cf. Schöberl et al., 2017). As all of these explanations are partly independent of what accounts for contingent capture, same-location costs are inconclusive for the question asked here–that is, if categorical search is based on feature or conceptual templates as we will review next.

2.1. Explanations for same-location costs

We do not think that the same-location costs can support either of the two explanations–feature-based or concept-based search–, as same-location costs are reflective of processes independent of initial capture. Mainly two different explanations have been put forward to explain same-location costs: attentional suppression effects (e.g., Eimer, Kiss, Press, & Sauter, 2009; Lamy et al., 2004; Theeuwes, Atchley, & Kramer, 2000) and object-file updating costs (e.g., Carmel & Lamy, 2014; Schöberl et al., 2017). According to attention-based theories, attention capture to the nonmatching cue shows inhibited, as attention allocation is initially suppressed for features or characteristics that reflect the irrelevance of the non-matching cue (Eimer et al., 2009) or because of more rapid deallocation of attention from nonmatching than matching cues in the cue-target interval following attention's initial capture by both of these cues (Theeuwes et al., 2000). Importantly, such suppression or deallocation does not have to be based on the same type of template as the initial capture. Representations used for suppression or for deallocation both likely draw on different stimulus characteristics (i.e., distractor characteristics) than are used for the target-directed top-down search templates.

This is also true of object-file updating. The object-file updating account ascribes same-location costs to the time-consuming mechanism of updating an object file in visual working memory. These object files are initiated by the cue features and have to be updated according to whether or not the target features at the cue's position correspond to the features of the cue. If a valid cue is nonmatching, per definition, its features differ strongly from the target features at the same location, so object-file updating is required and processing time passes before target recognition. In contrast, a matching cue shares the same or similar features with the target, so that object files have not to be updated at all or can at least be updated faster (Carmel & Lamy, 2014). Across studies, the object-file updating account is a more plausible explanation than the rapid deallocation principle, which latter was not confirmed in several studies (e.g., Chen & Mordkoff, 2007).

Importantly, in the present experiments, participants did not search for a specific target but for a whole target category, for example, letters. It has not been shown yet that different objects from the same category can be integrated into one joint object file, but it is conceivable that participants were nonetheless faster in updating a matching cue to a target (e.g., a letter to another letter) than updating a nonmatching cue to a target (e.g., a number to a letter), as letters share more features with other letters and numbers share more features with other numbers (within their categories) than numbers and letters with one another (across categories; cf. Krueger, 1984). Whatever exact mechanism would underlie object-file updating, we want to point out that, as with suppression and deallocation of attention capture, file updating and contingent capture are independent effects that need not necessarily be based on the same stimulus characteristics or search templates.

2.2. Further evidence for feature-based categorical search for alphanumerical categories

One could argue that the design with overlapping character sets for cues and targets in the present Experiment 1 might have fostered the influence of feature templates in categorical search, as each matching cue in a current trial was the exact same stimulus as a target in 16.7% of all trials, and thus expectations for specific targets could have built up over the course of the experiment and may have encouraged search for their particular features, so as to boost evidence for feature-based templates. Yet, in Experiment 2, with separate character sets, again an explanation in terms of feature-based templates was supported, as top-down matching but inverted cues led to a significant validity effect. Additionally, responses were overall faster in Experiment 2 (773 ms) than in Experiment 1 (778 ms) (see Table A1). This difference reflects the different degrees of difficulty caused by separate versus overlapping character sets for cue and target displays, again providing evidence for feature-based search, as concept-based search times should not be influenced by separate or overlapping character sets.

3. Conclusion

Altogether, our results point to the use of a feature-based template during search for categories rather than only a conceptual search template: Matching inverted cues led to significant validity effects, and separate (as compared to overlapping) character sets for cues and targets facilitated search (in Experiment 2 relative to Experiment 1). These findings can be well explained by feature-based search but not by conceptual search. However, a significantly lower validity effect of the inverted than the upright matching cues revealed that conceptual templates might at least be used to some extent during search for stimulus instances of alphanumeric categories.

Declaration of Competing Interest

None.

Appendix

Detailed listing of the ANOVA results and all mean reaction times and accuracy rates of both experiments.

Table A1
Complete Listing of All Mean Reaction Times (RTs; in ms) and Accuracy Rates (ACCs; in %) as a Function of the Factors Character Set, Cue Orientation, Cue Category, and Validity.

Character Set	Cue Orientation	Cue Category	Validity	RT	ACC
overlapping (Experiment 1)	upright	matching	valid	759	97.0
			invalid	798	95.9
		nonmatching	valid	780	96.9
			invalid	761	96.5
	inverted	matching	valid	754	96.3
			invalid	771	96.3
		nonmatching	valid	778	96.9
			invalid	769	96.7
separate (Experiment 2)	upright	matching	valid	760	96.8
			invalid	792	95.4
		nonmatching	valid	787	96.8
			invalid	770	97.2
	inverted	matching	valid	769	96.8
			invalid	786	96.8
		nonmatching	valid	780	96.4
			invalid	770	97.2

Table A2
All Significant Effects of the ANOVA With the Reaction Times of Experiment 1.

Main effects and interactions	*df*	*F*	*p*	η_p^2
Cue Orientation	32	5.24	.029	0.14
Cue Orientation × Cue Category	32	5.88	.021	0.16
Cue Category × Validity	32	34.10	< .001	0.52
Cue Orientation × Cue Category × Validity	32	7.23	.011	0.18

Table A3
Complete Results of the Combined ANOVAs With the Reaction Times and Accuracy Rates of Both Experiments.

Main effects and interactions	*df*	*F*	*p*	η_p^2
Reaction times				
Character Set	63	0.01	.942	< 0.01
Cue Orientation	63	2.60	.112	0.04
Cue Category	63	0.05	.818	< 0.01
Validity	63	4.12	.047	0.06
Character Set × Cue Orientation	63	0.99	.323	0.02
Character Set × Cue Category	63	0.04	.851	< 0.01
Character Set × Validity	63	0.03	.860	< 0.01
Cue Orientation × Cue Category	63	1.99	.163	0.03
Cue Orientation × Validity	63	0.88	.351	0.01
Cue Category × Validity	63	42.75	< .001	0.40
Character Set × Cue Orientation × Cue Category	63	5.03	.028	0.07
Character Set × Cue Orientation × Validity	63	0.21	.649	< 0.01
Character Set × Cue Category × Validity	63	0.12	.728	< 0.01
Cue Orientation × Cue Category × Validity	63	9.43	.003	0.13
Character Set × Cue Orientation × Cue Category × Validity	63	0.09	.759	< 0.01

(*continued on next page*)

Table A3 (*continued*)

Main effects and interactions	*df*	*F*	*p*	η_p^2
Accuracy rates				
Character Set	63	0.03	.855	< 0.01
Cue Orientation	63	0.17	.679	< 0.01
Cue Category	63	1.32	.255	0.02
Validity	63	14.33	< .001	0.19
Character Set × Cue Orientation	63	0.19	.666	< 0.01
Character Set × Cue Category	63	0.01	.941	< 0.01
Character Set × Validity	63	0.88	.352	0.01
Cue Orientation × Cue Category	63	0.41	.524	< 0.01
Cue Orientation × Validity	63	2.24	.125	0.04
Cue Category × Validity	63	3.29	.074	0.05
Character Set × Cue Orientation × Cue Category	63	2.26	.138	0.03
Character Set × Cue Orientation × Validity	63	0.24	.623	< 0.01
Character Set × Cue Category × Validity	63	1.14	.290	0.02
Cue Orientation × Cue Category × Validity	63	0.01	.903	< 0.01
Character Set × Cue Orientation × Cue Category × Validity	63	0.00	.963	< 0.01

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